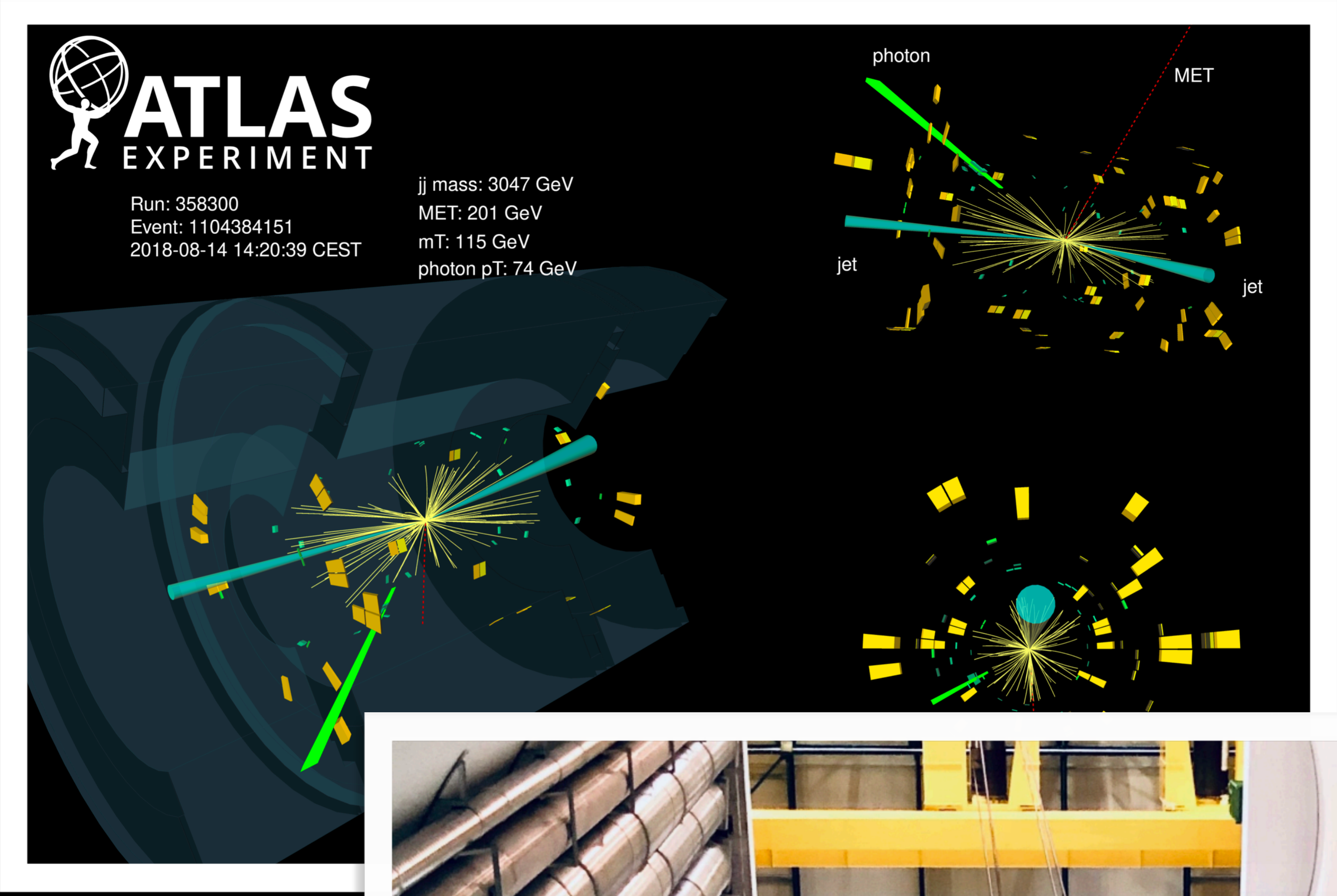
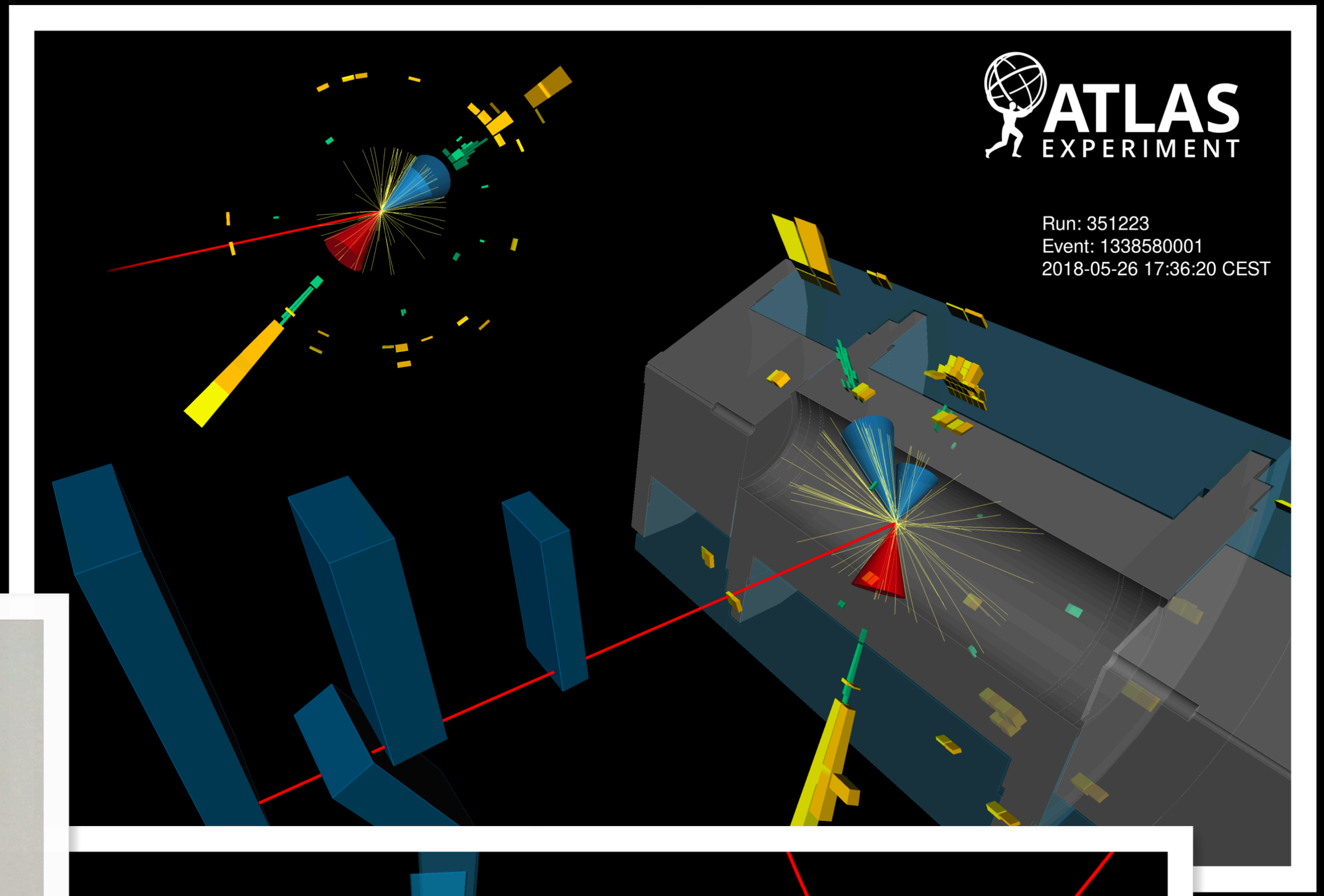
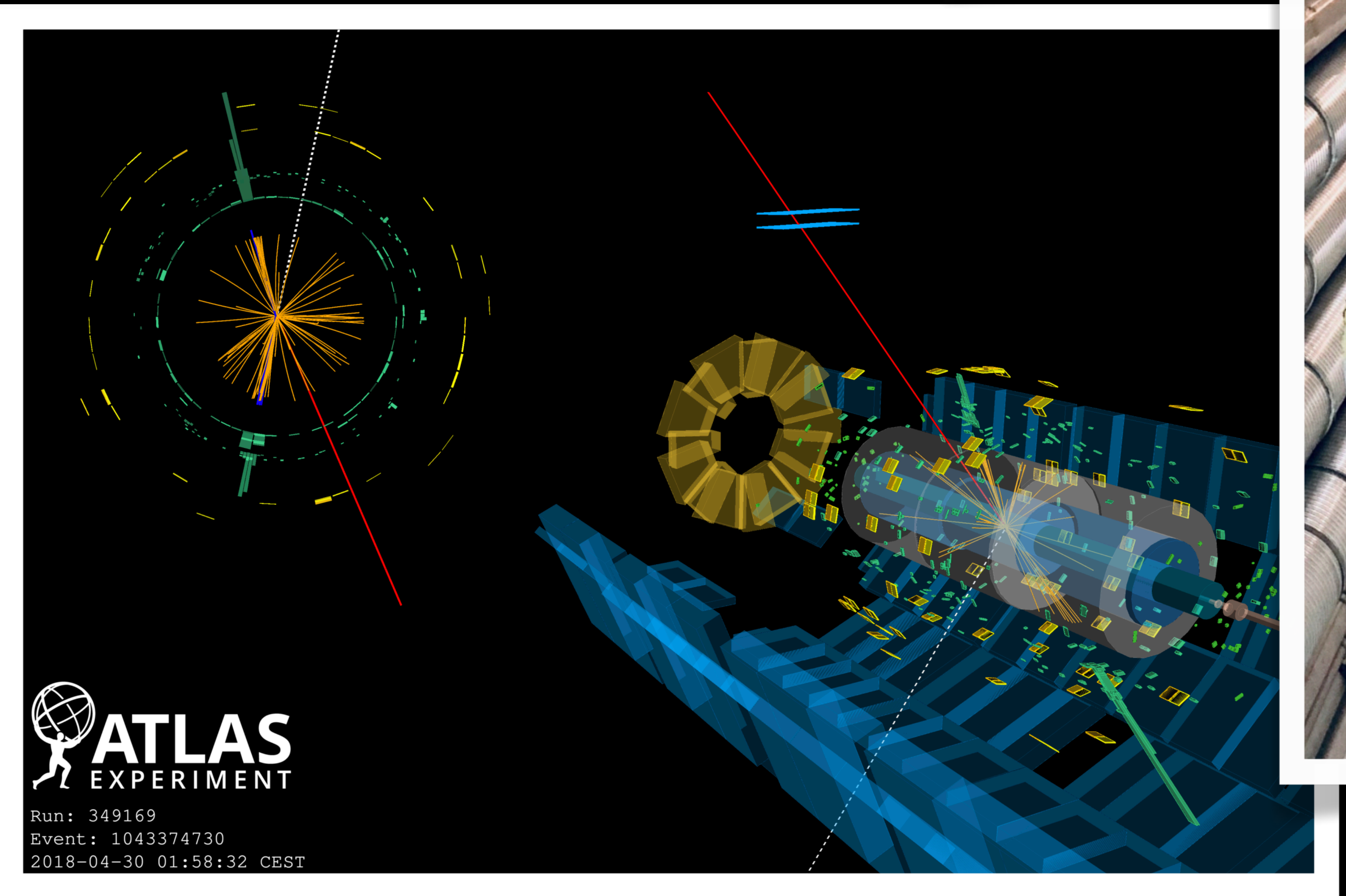
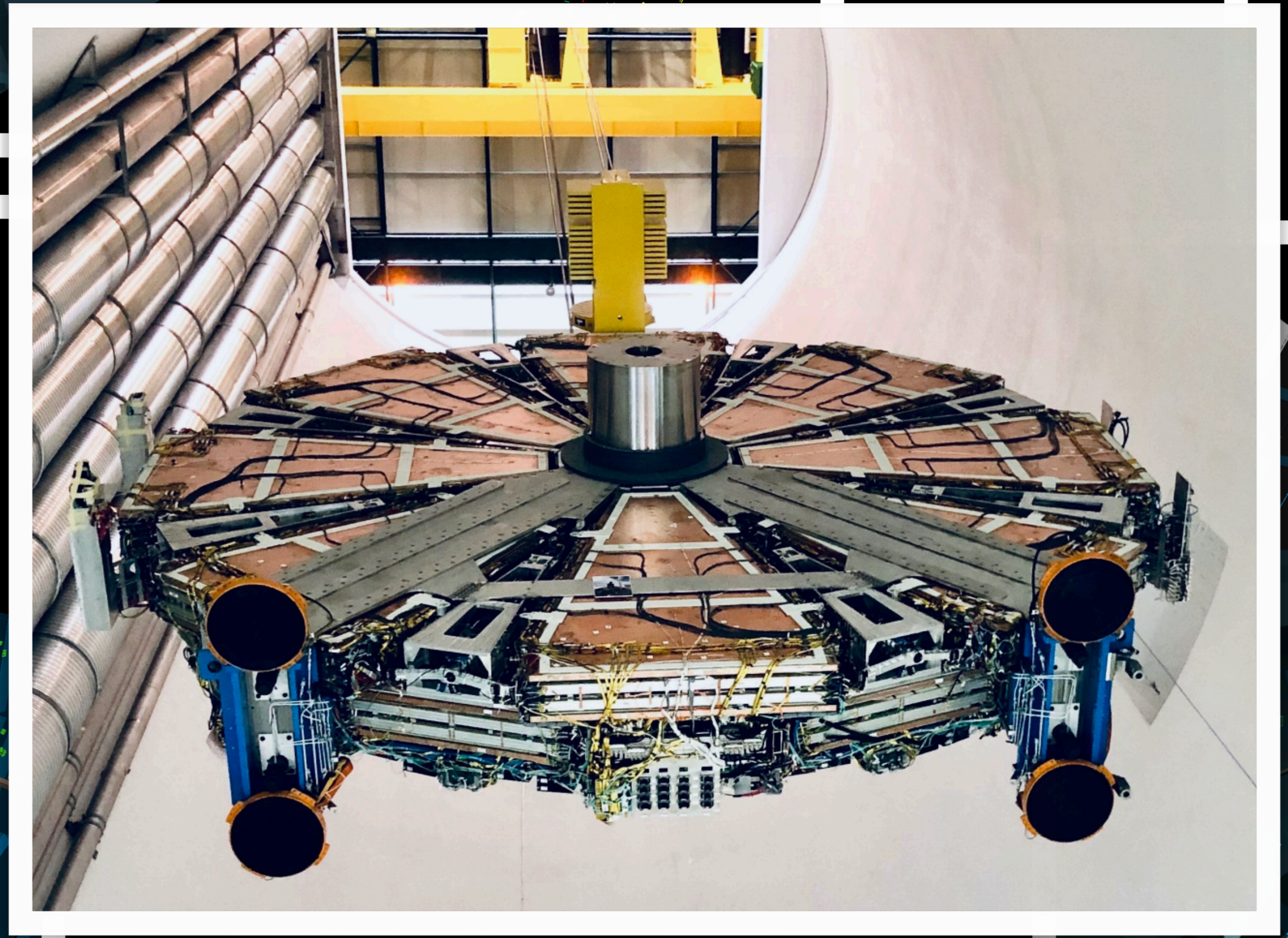
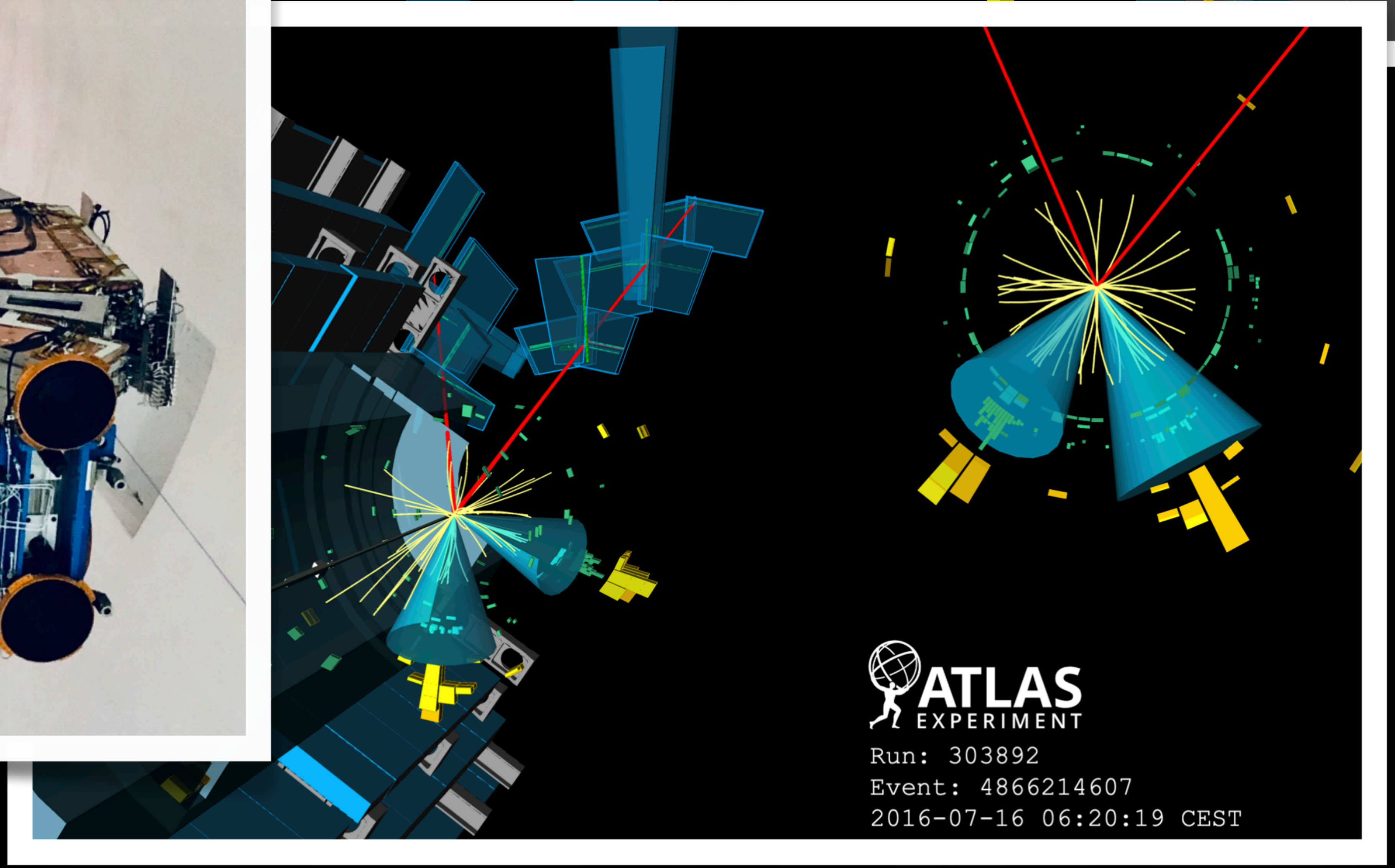
Highlights from ATLAS











Stéphane Willocq (Univ. of Massachusetts, Amherst)
on behalf of the ATLAS Collaboration

EPS-HEP on 27 July 2021

A vast physics program

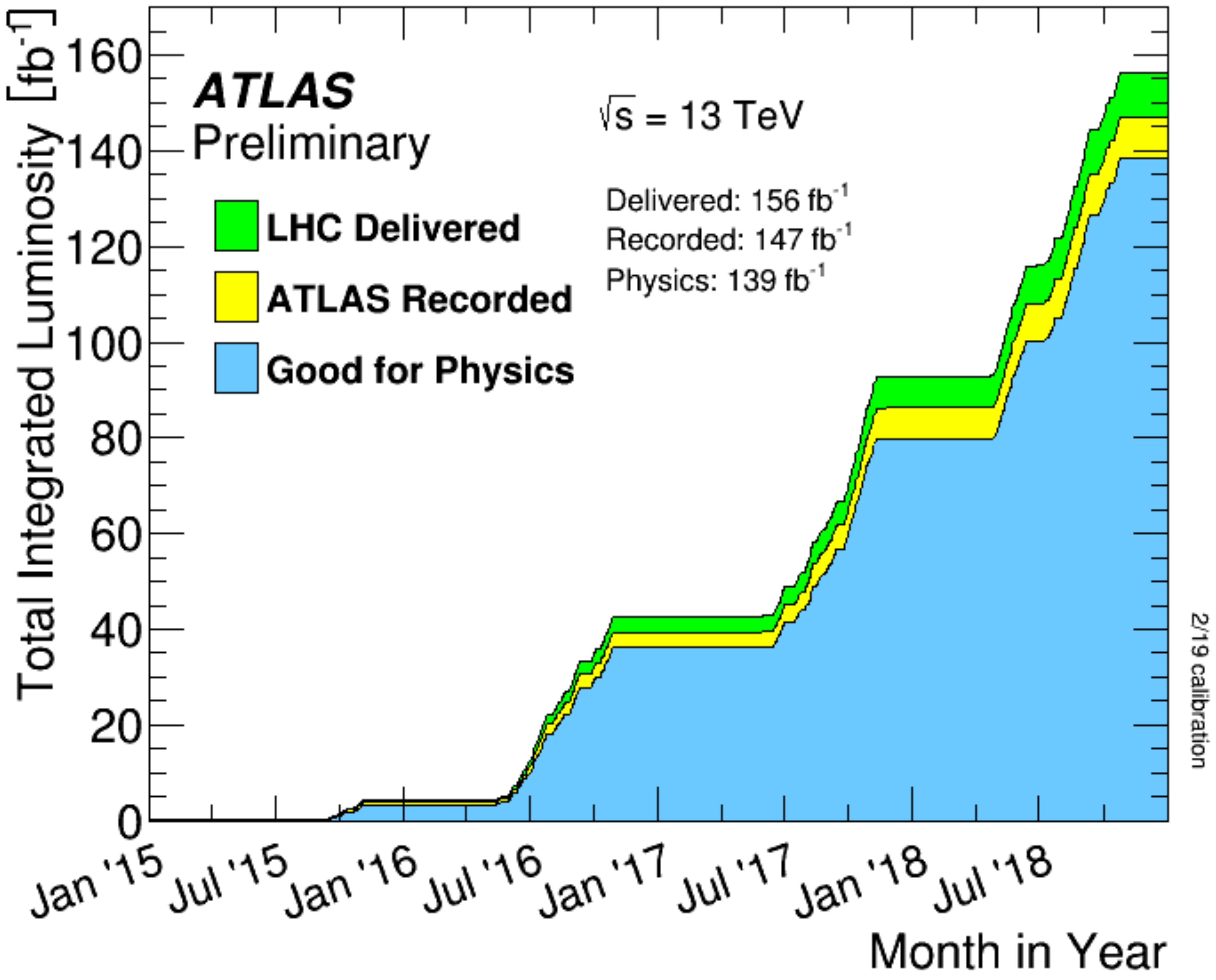
- Physics@LHC is most ambitious and farthest reaching HEP program ever
- **Huge dataset with well understood detector performance** allows
  - Precision measurements $$\mathscr{L}_{\mathrm{SM}} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\,\overline{\psi}\not{D}\psi + \psi_i y_{ij}\psi_j\phi + \mathrm{hc} + |D_\mu\phi|^2 - V(\phi)$$
    - Determine fundamental parameters, probe higher-order QCD and EW effects
  - Access to rare processes (e.g. production of WWW or $t\bar{t}t\bar{t}$)
    - Probe poorly or untested corners of SM
  - Broad search program at TeV scale and beyond (high energy frontier) & feeble interactions (low coupling frontier)
    - Directly address compelling issues: naturalness, dark matter, flavor puzzles, etc.
  - Study of new states of matter —> quark-gluon plasma

LHC data

- **Extremely successful Run 2**
  —> dataset is a goldmine for physics
- Recorded: 147 fb^{-1} (*pp*)
  - Data taking efficiency = 94%
- Good for Physics: 139 fb^{-1} (*pp*)
  - Data quality fraction = 95%
- Also heavy-ion collisions
  - Pb+Pb, p+Pb, Xe+Xe
- ATLAS already released 134 results on full Run 2 data (prior to this conference)
  - Complete set at this link
  - 26 new results just released for EPS-HEP

139 fb^{-1} @ $\sqrt{s}$ = 13 TeV

Run 2



- Here a subset of these new results is presented New (new since LHCP conference in June)
  + several other recent results (released within last 4 months)

Run 2 breakthroughs (abridged)

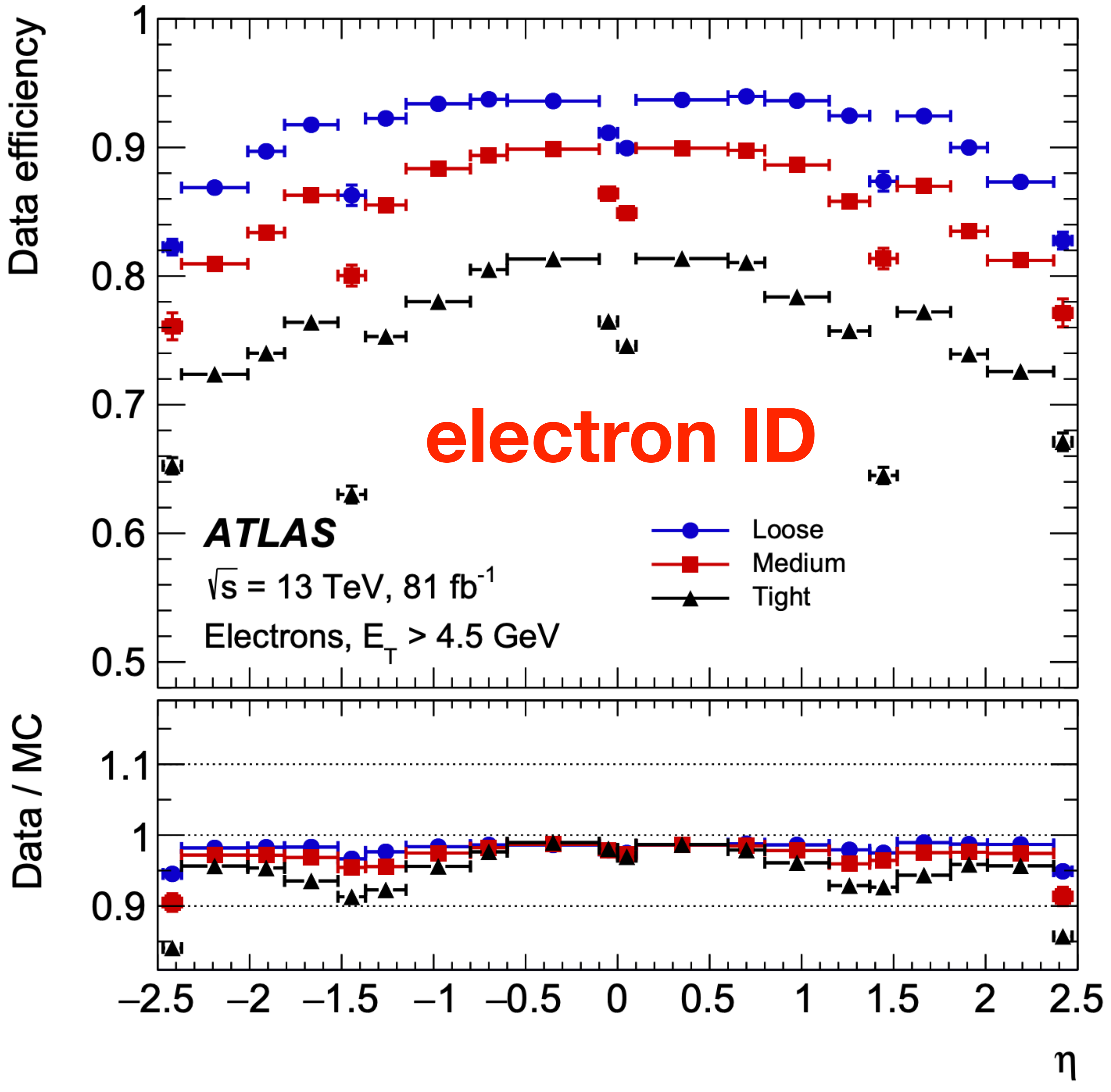
- **Higgs**
  - Observation of all main production mechanisms → ggF, VH, VBF, ttH
  - Observation of Yukawa interactions w/ 3rd generation fermions → $\binom{t}{b}, \binom{\nu}{\tau}$
  - Constraints on Higgs self-interaction via HH cross section
- **Rare processes**
  - Observation of all weak boson scattering modes (incl. $W^{\pm}W^{\pm}$) as well as $\gamma\gamma \to \gamma\gamma$ and $\gamma\gamma \to WW$
  - Observation of $t\bar{t}W$, $t\bar{t}Z$ and tZq + evidence for $t\bar{t}t\bar{t}$ production and $H \to \ell\ell\gamma$
- **Searches**
  - Excluded wide range of BSM parameter space w/ broad search program
    - SUSY & resonances: gluino, squark, stop, Z' exclusion* up to m = 2.3, 1.8, 1.2, 5.0 TeV, resp.
    - Dark matter, incl. $\mathscr{B}(H \to \text{invisible}) < 11\,\%$
    - Exptally challenging: Compressed spectra, unconventional signatures (e.g. long-lived particles)

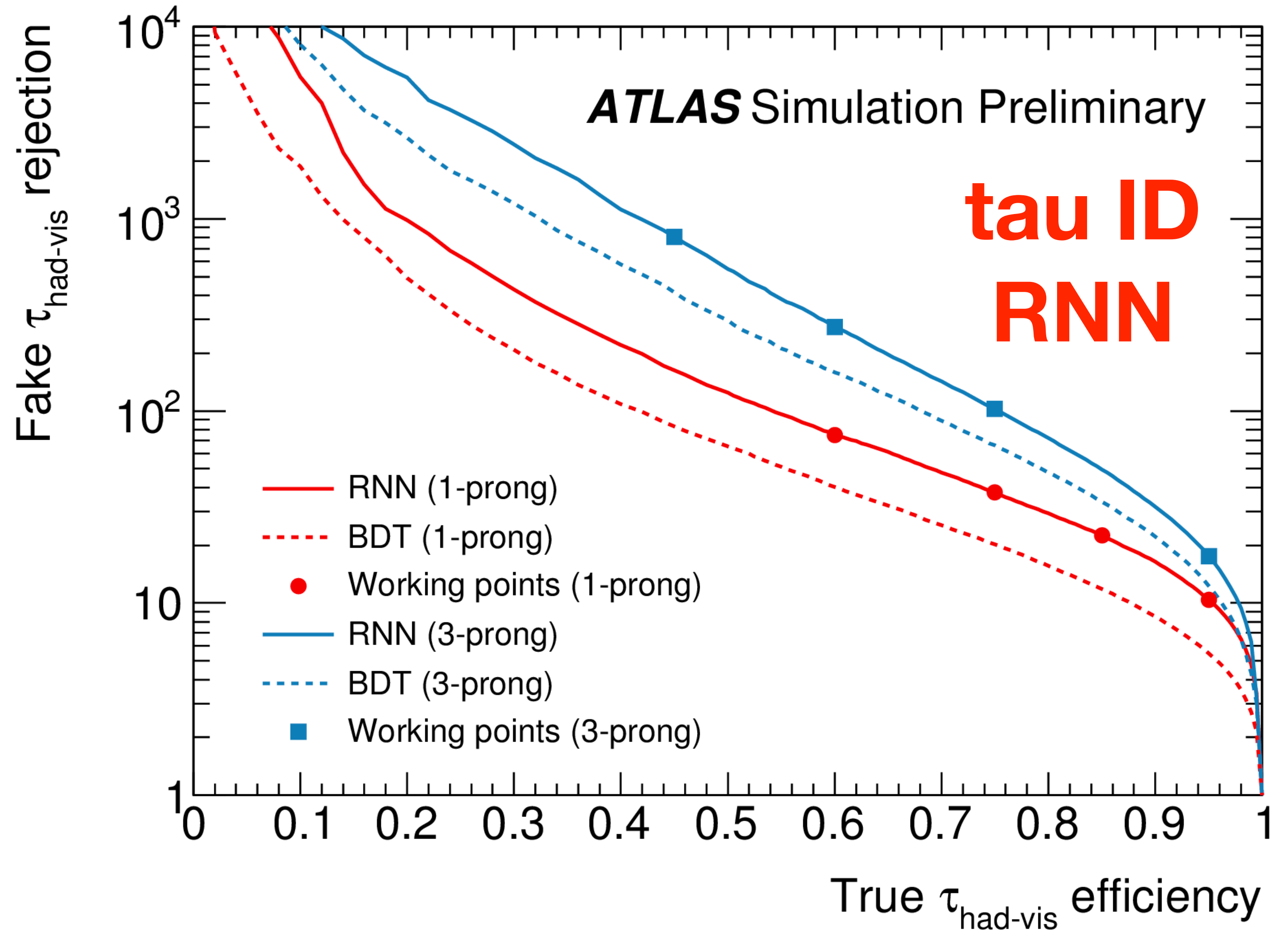
* all limits in this talk are at 95% CL

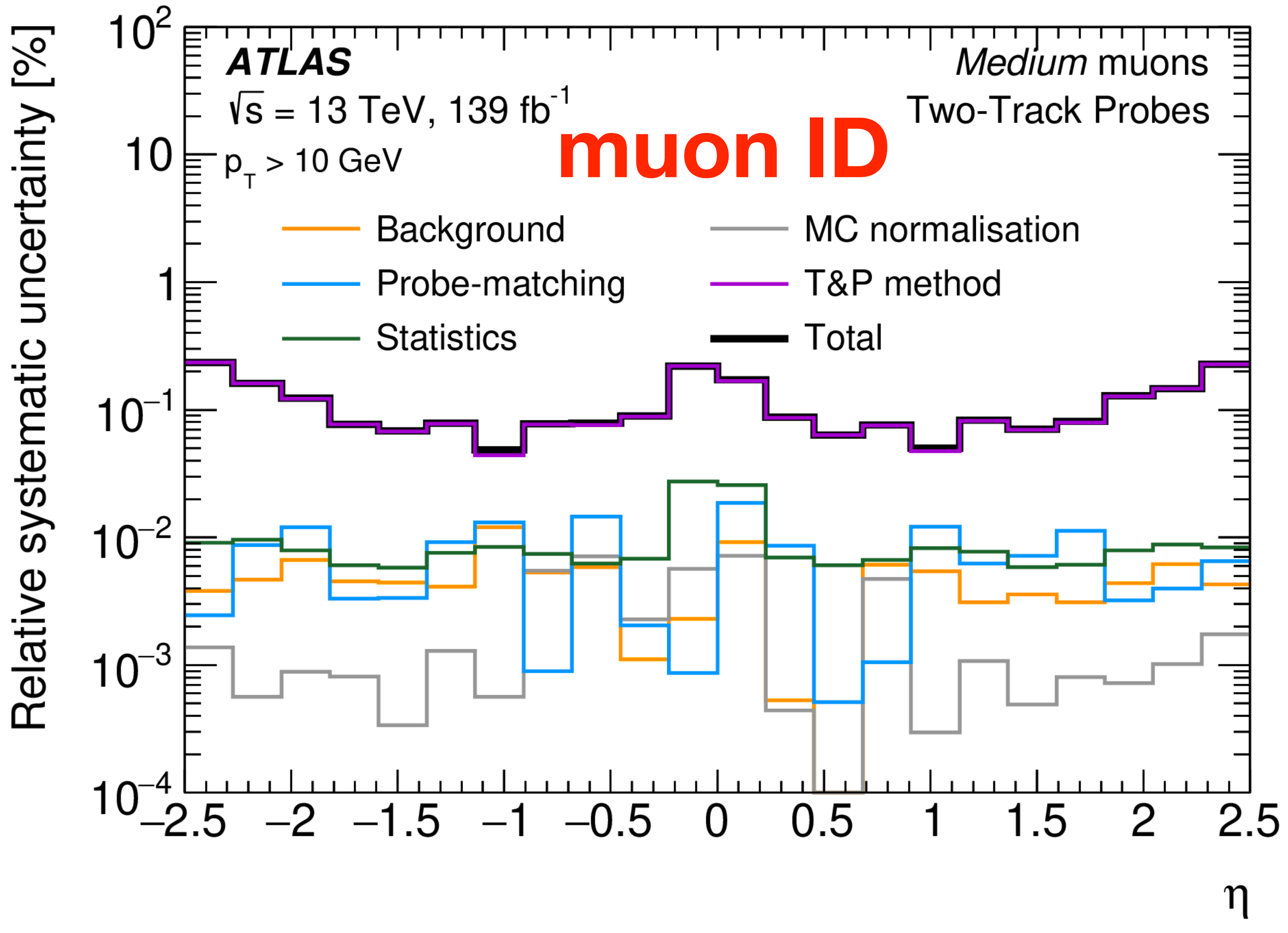
Detector performance

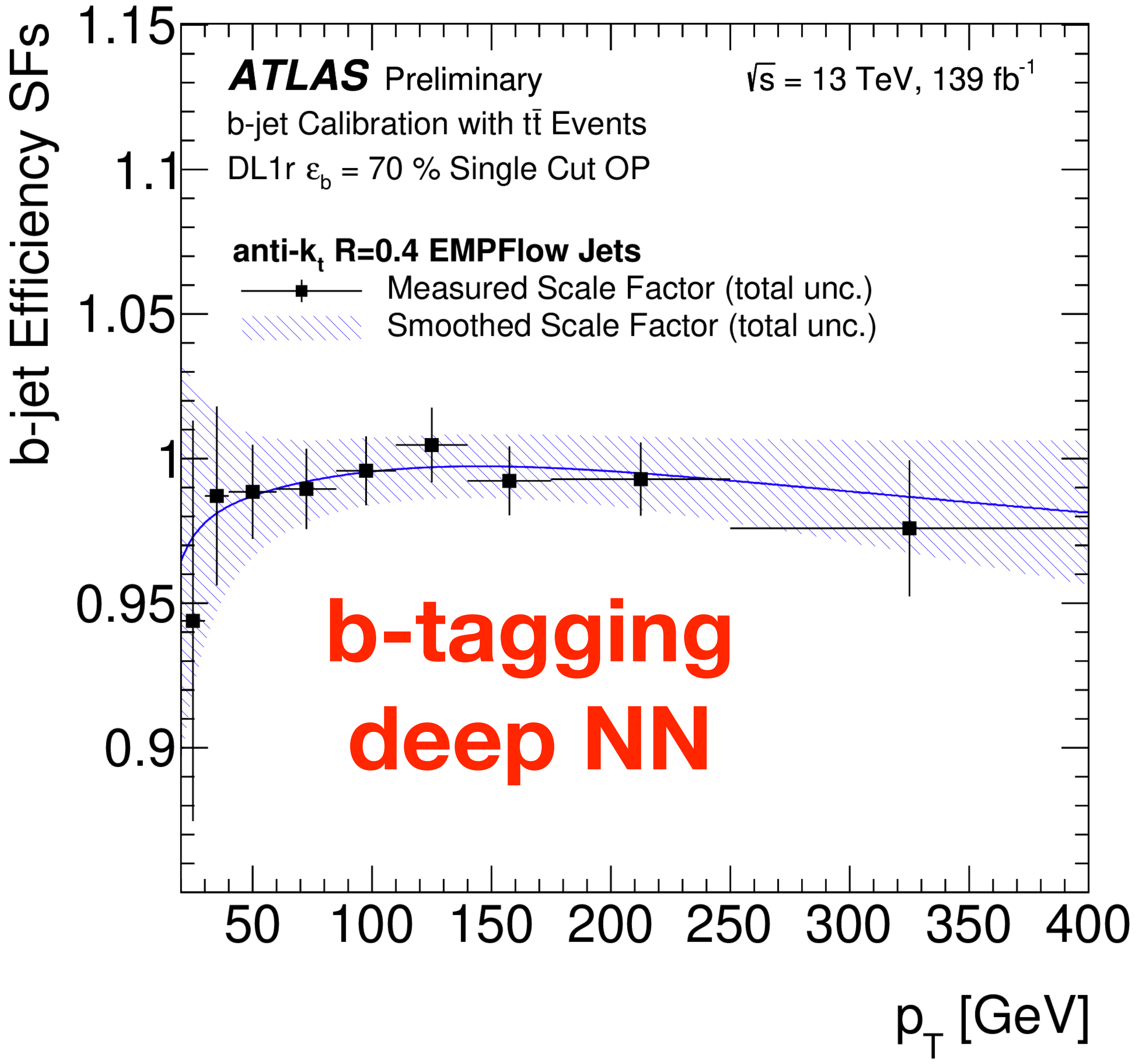
- Bumper crop of results from Run 2 only possible thanks to excellent understanding of detector performance, and development of reconstruction and identification algorithms

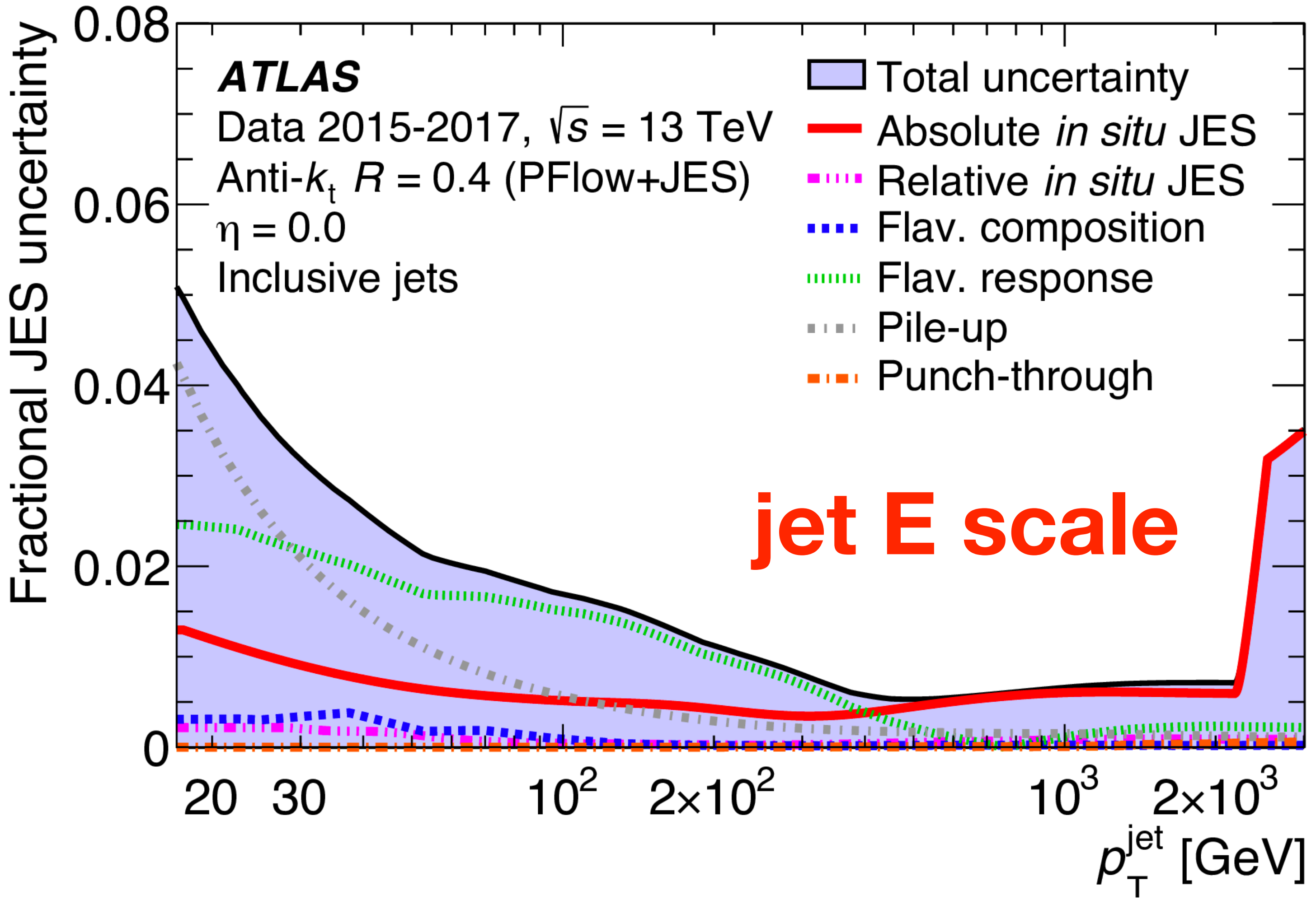
- High level of precision achieved & excellent modeling with simulation







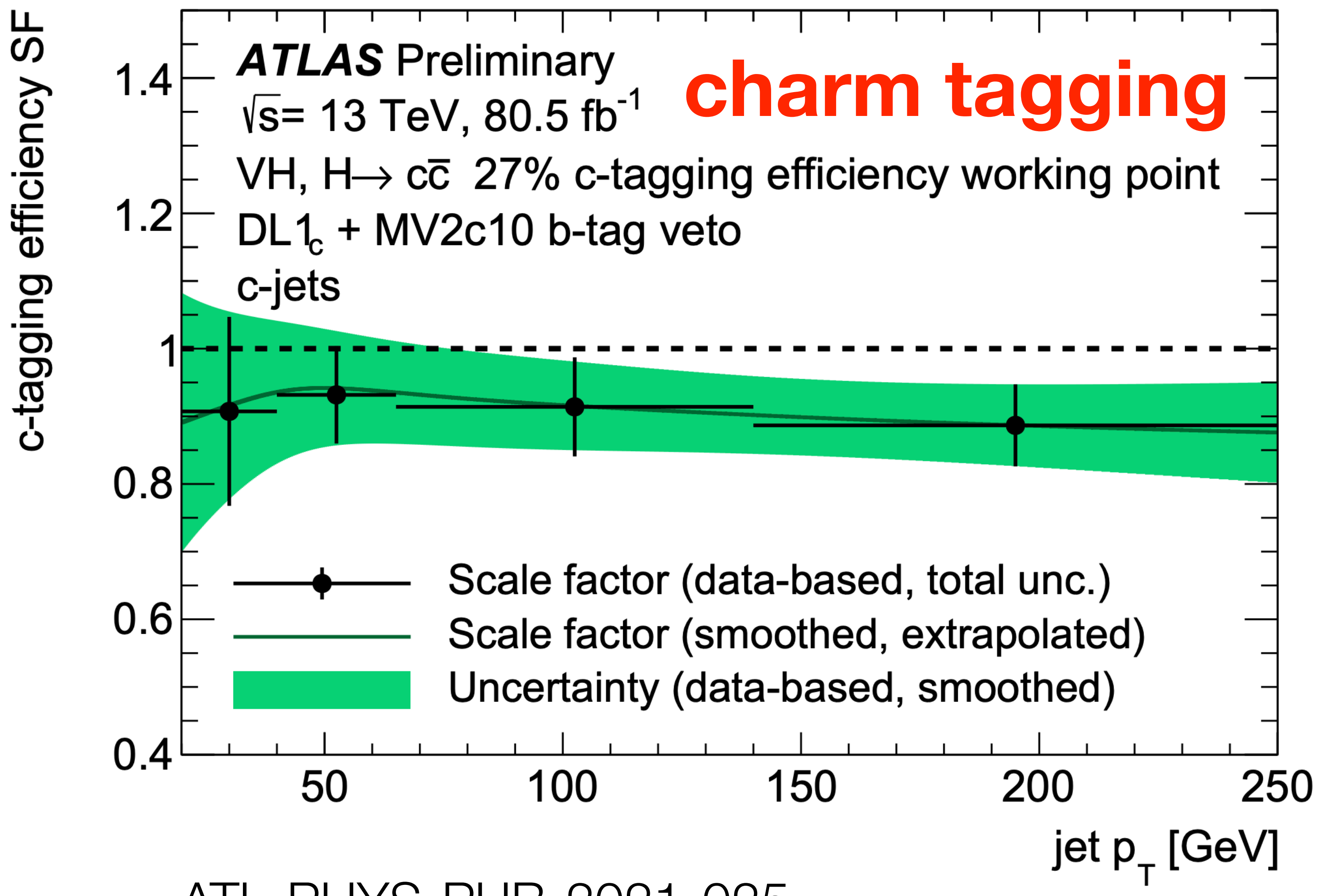




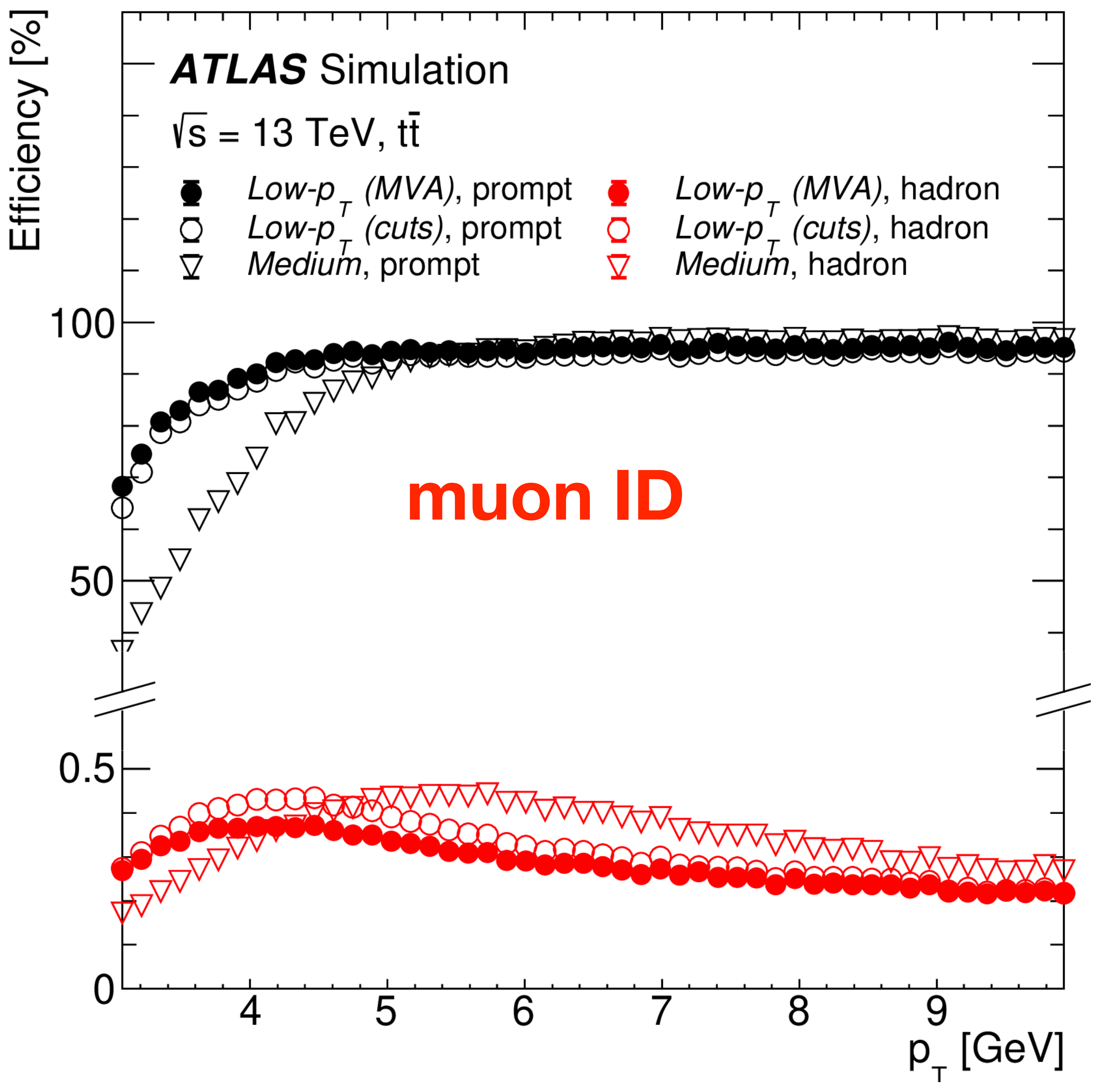
Detector performance — latest results

- Charm-hadron tagging
- Deep NN for $E_{\mathrm{T}}^{\mathrm{miss}}$ reconstruction
- Single-particle calorimeter response in $W^{\pm} \to \tau^{\pm}\nu \to \pi^{\pm}\nu\nu$
- Lepton identification at very low p_T (down to 3.0 GeV for μ)

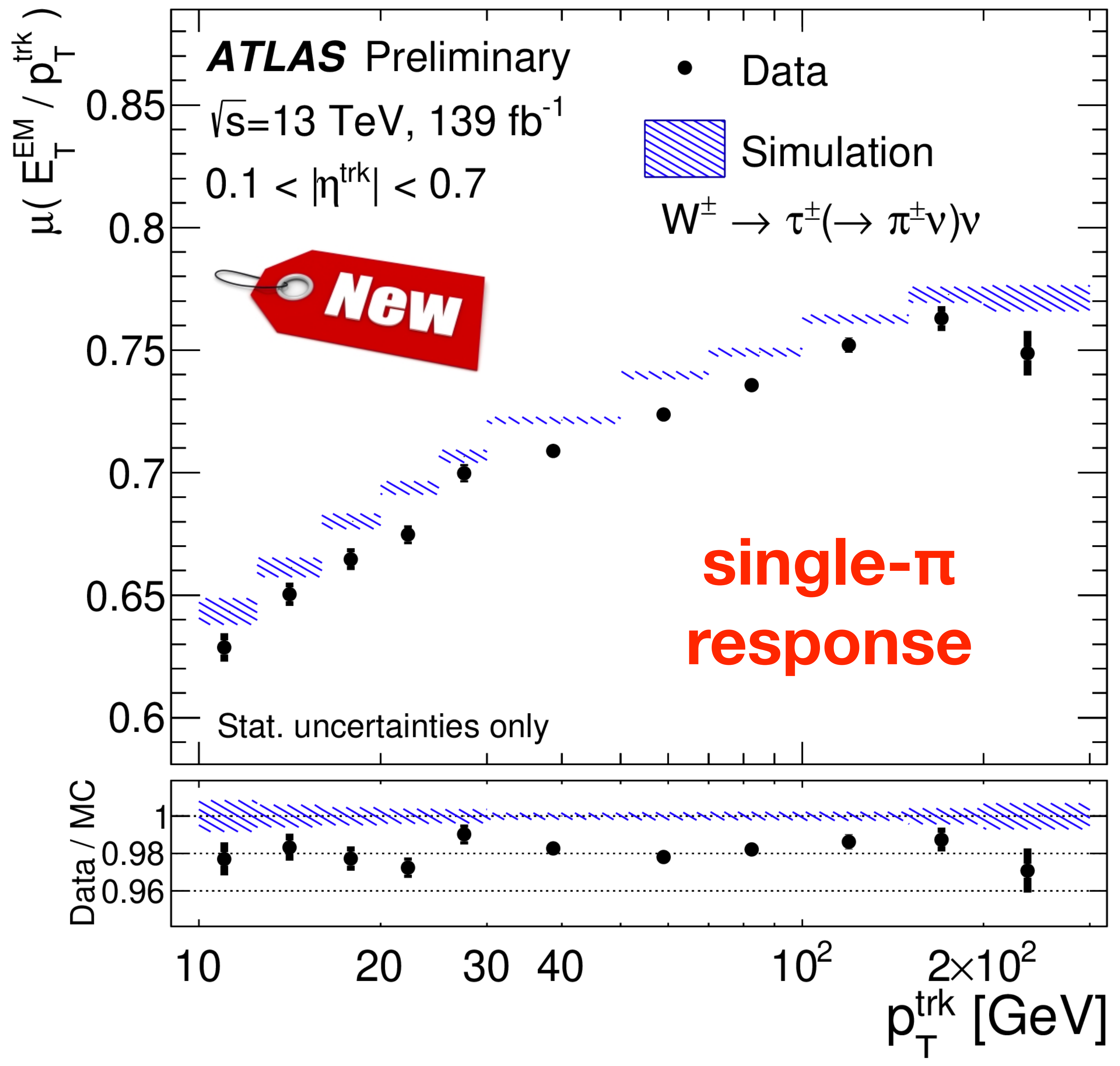
ATLAS-CONF-2021-021



arXiv:2012.00578



CERN-EP-2021-147



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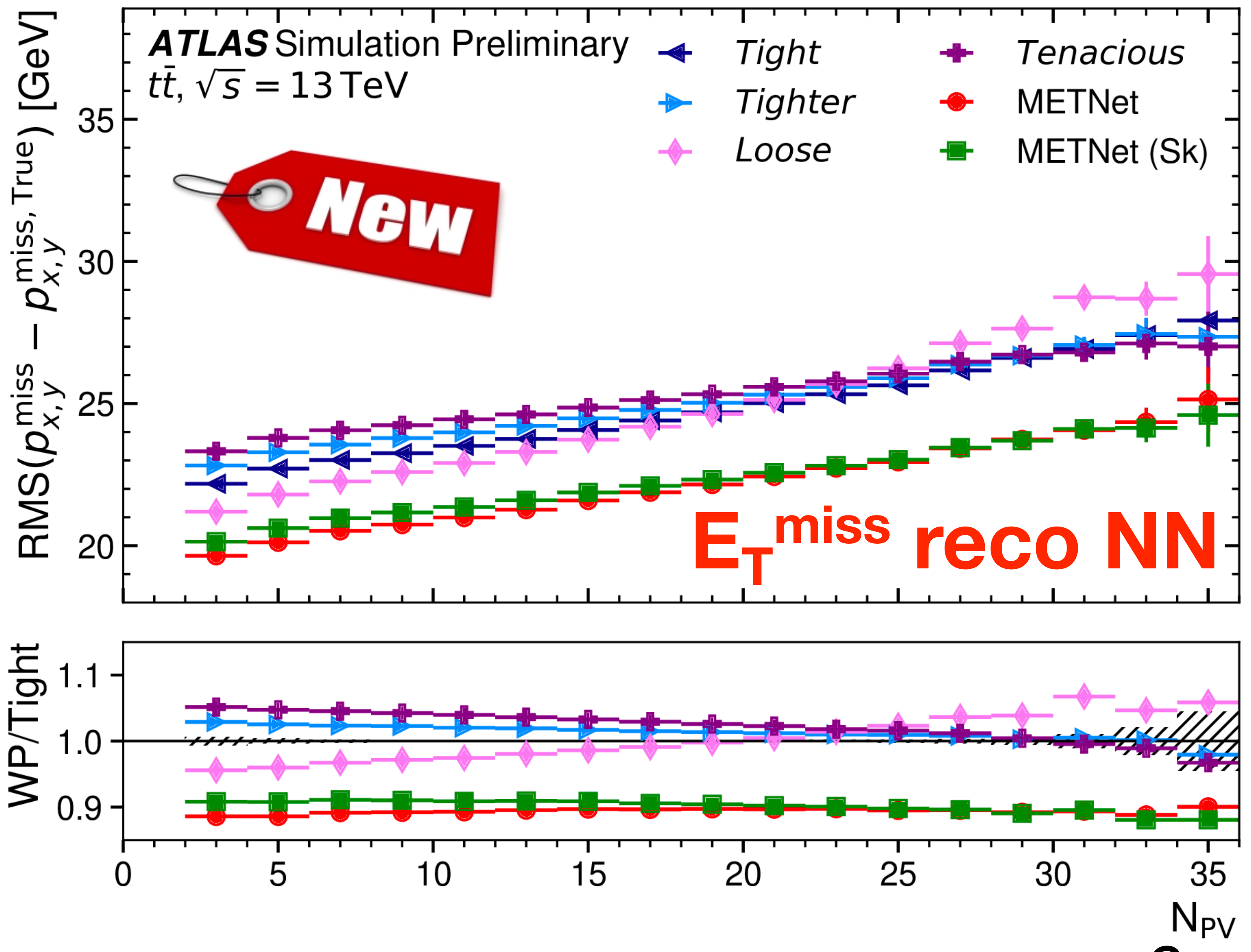
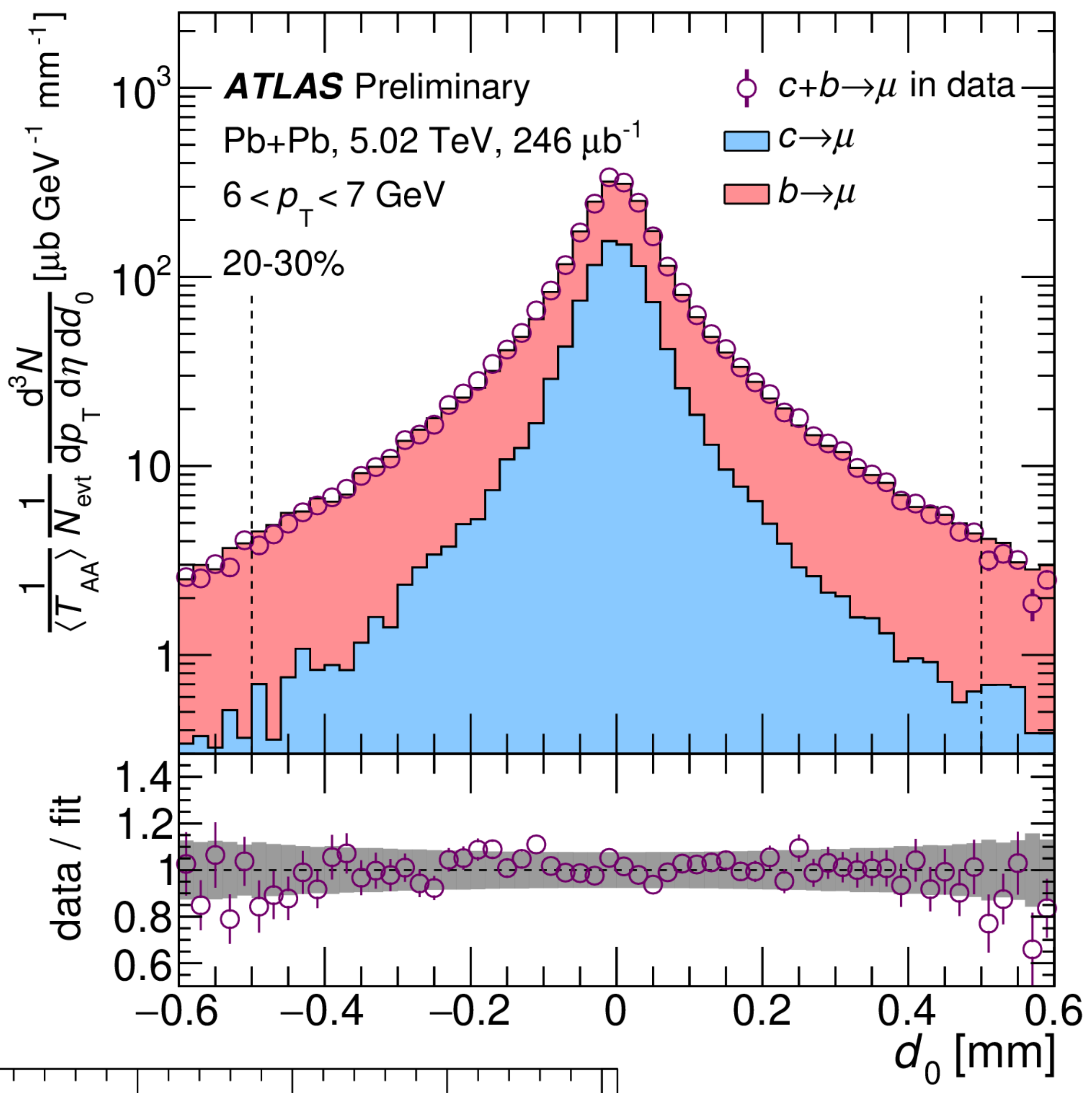


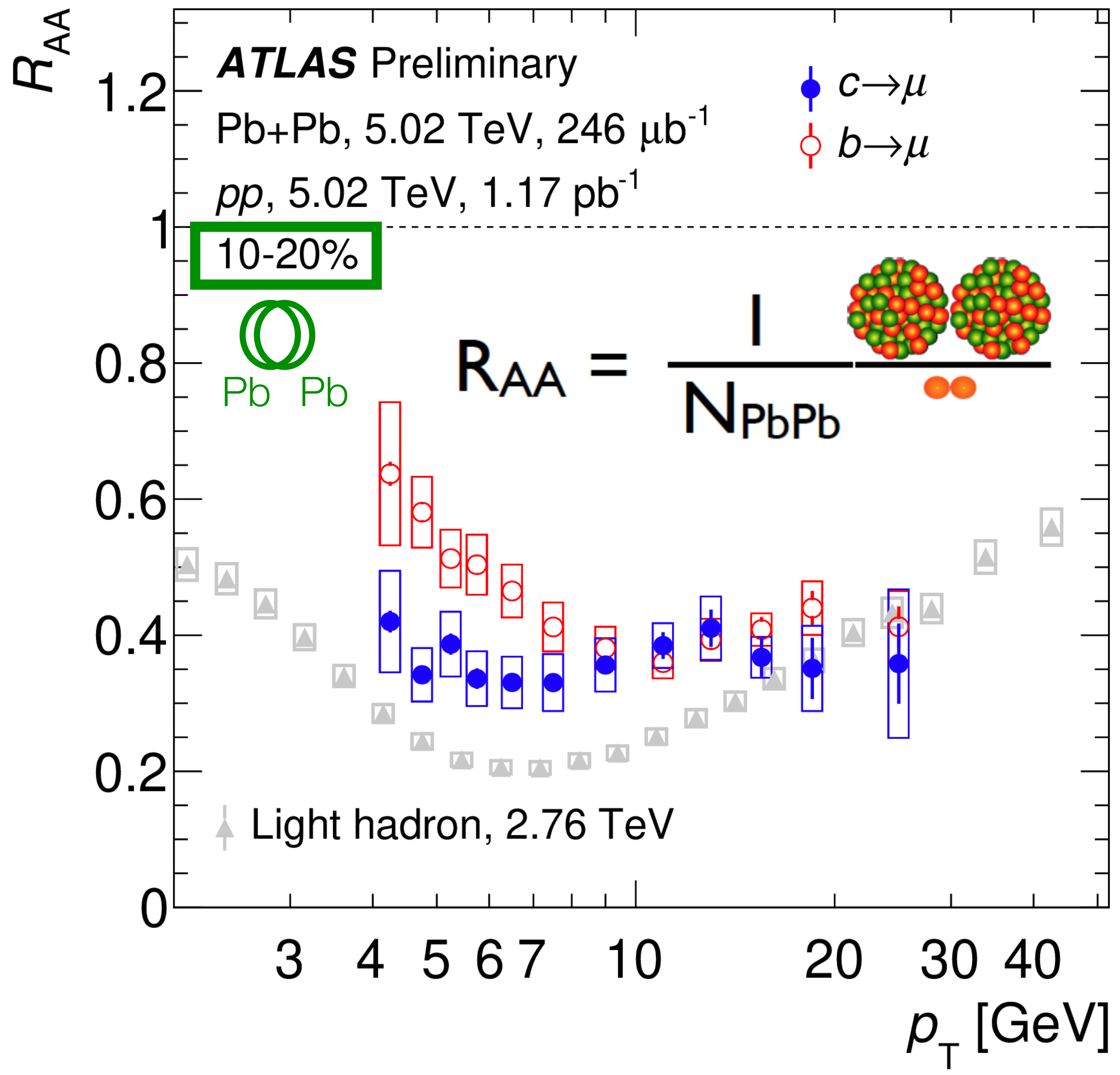
Bottom & charm energy loss in dense nuclear medium

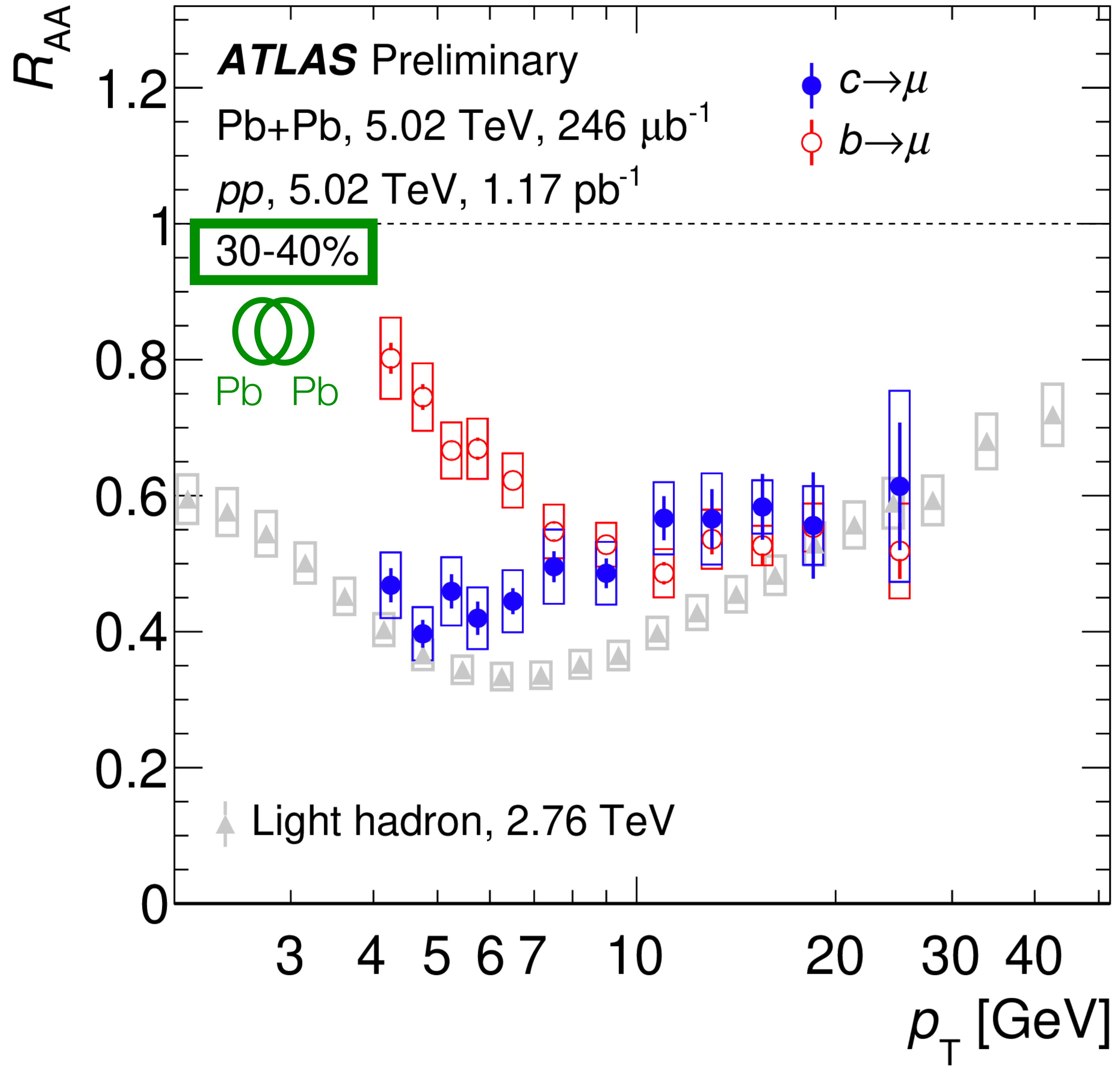
ATLAS EXPERIMENT

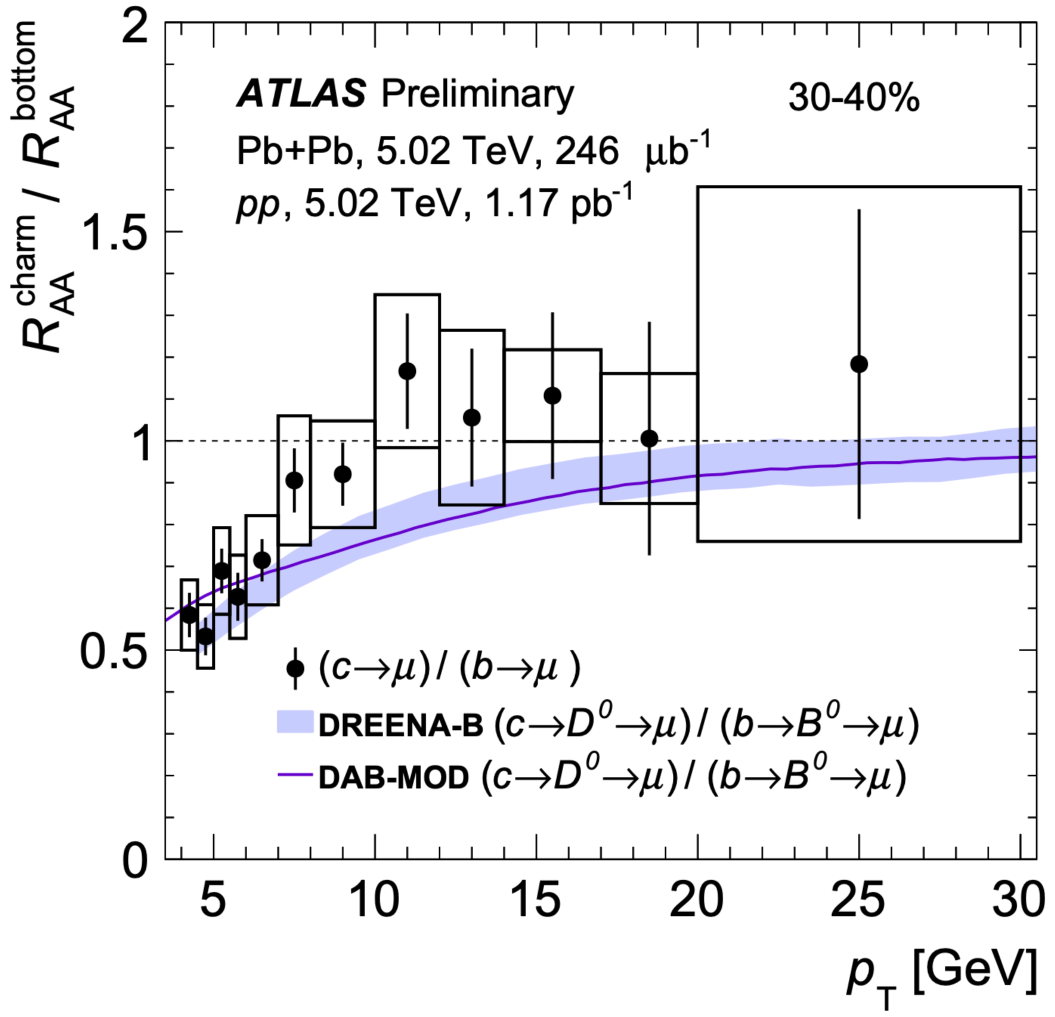
ATLAS-CONF-2021-020

- Study muons from decay of bottom and charm hadrons in pp and PbPb collisions
  —> learn about energy loss mechanisms for heavy flavors in quark-gluon plasma
- Light/heavy-flavor hadron separation w/ muon p_T imbalance inner tracker vs. muon spectrometer
- b/c-hadron separation using muon impact parameter
- Stronger nuclear suppression for charm vs. bottom as predicted
  - Suppression also depends on p_T and centrality of PbPb collision









Z-boson + jets production

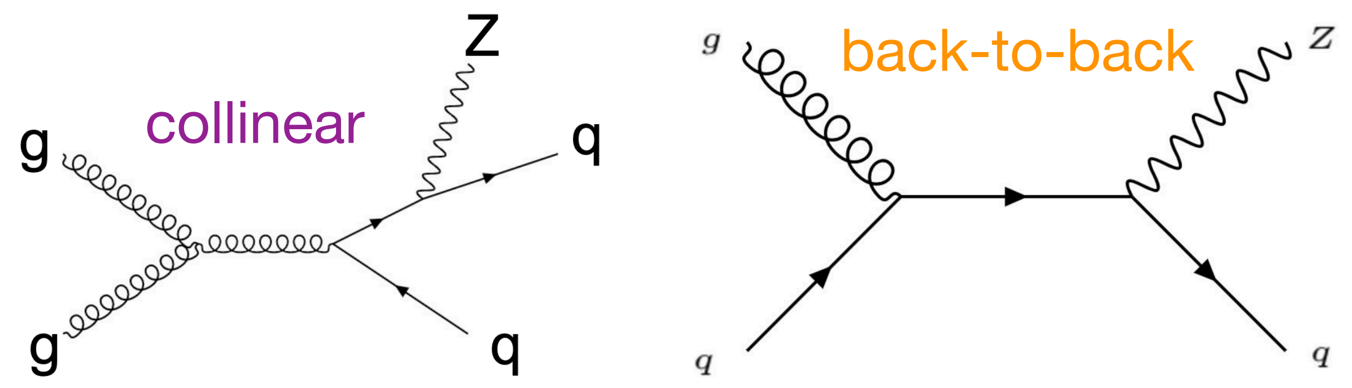
New

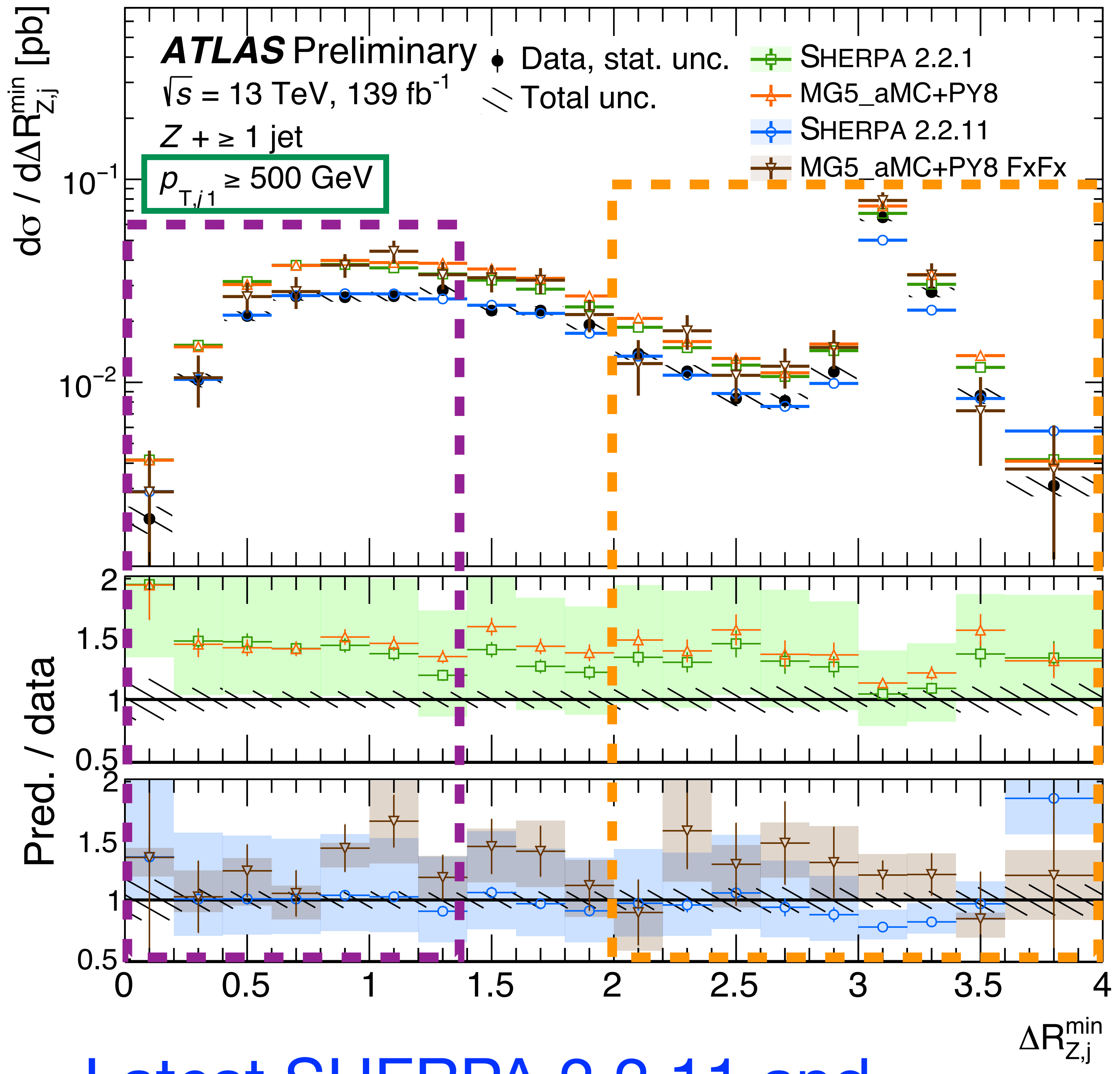
ATLAS-CONF-2021-033

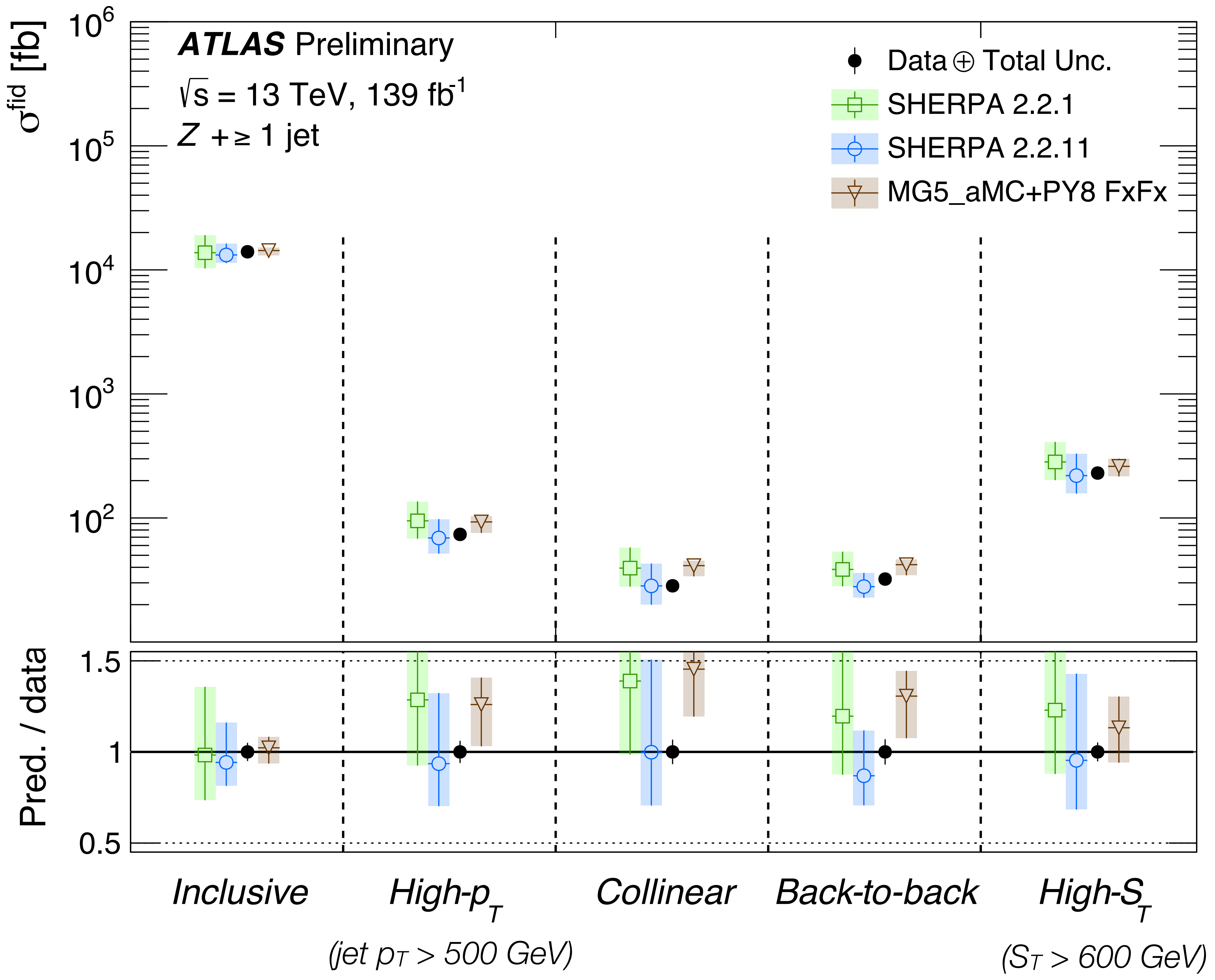
- Run 2: ~8 x 10[9] Z bosons produced

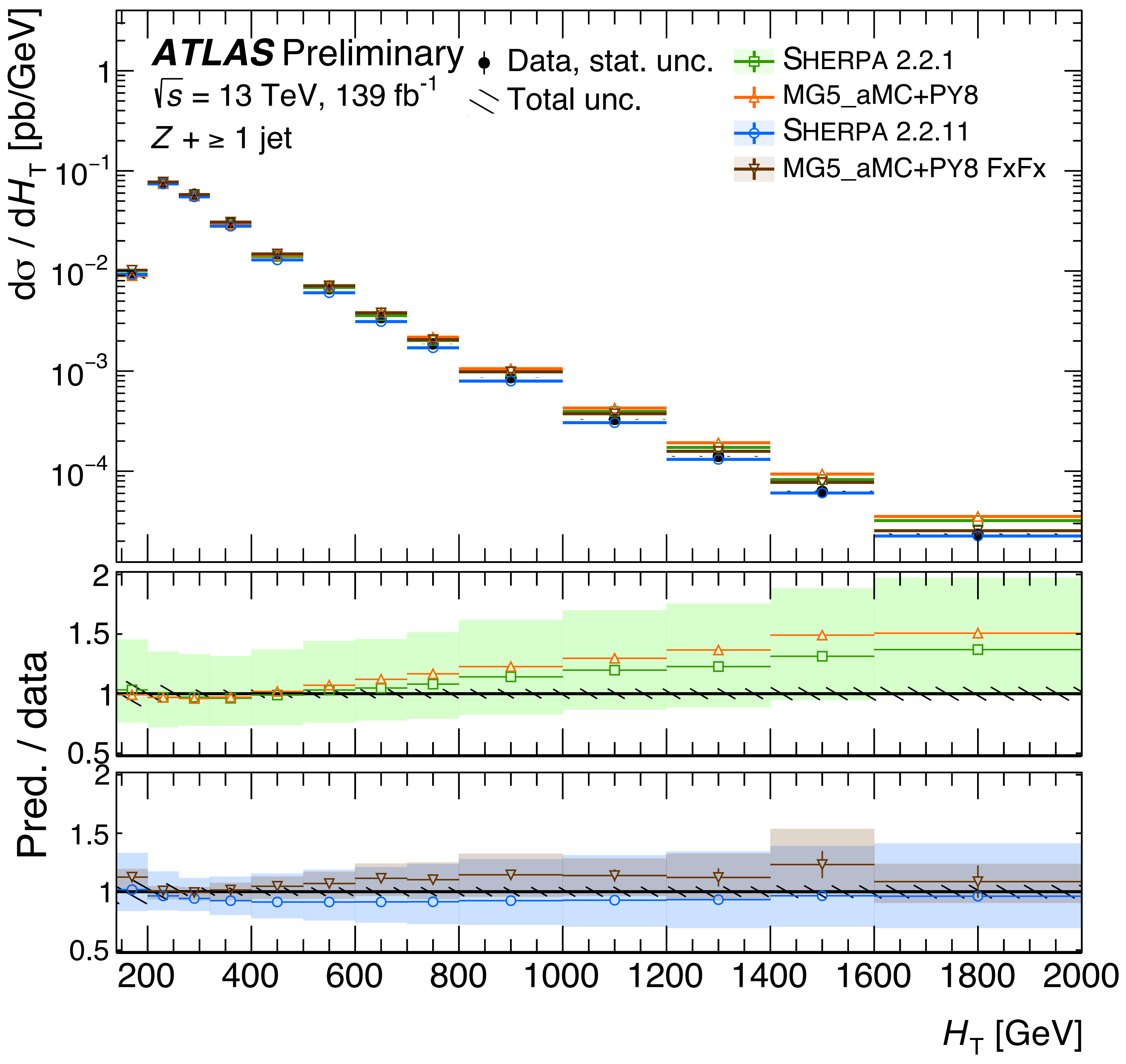
$$\mathcal{L}_{SM} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\psi}\not{D}\psi + \psi_i y_{ij}\psi_j\phi + \text{hc} + |D_\mu\phi|^2 - V(\phi)$$

- Test SM in events w/ $Z(\to ee, \mu\mu)$ and ≥ 1 jet with $p_T > 100$ GeV
  - SM predictions w/ event generators up to NLO QCD + NLO EW
  - Measure cross section in more extreme phase space: collinear vs. back-to-back jet emission, high jet p_T or high sum p_T









- Latest SHERPA 2.2.11 and MG5_aMC + Py8 (FxFx) provide improved modeling esp. in collinear region and at high p_T

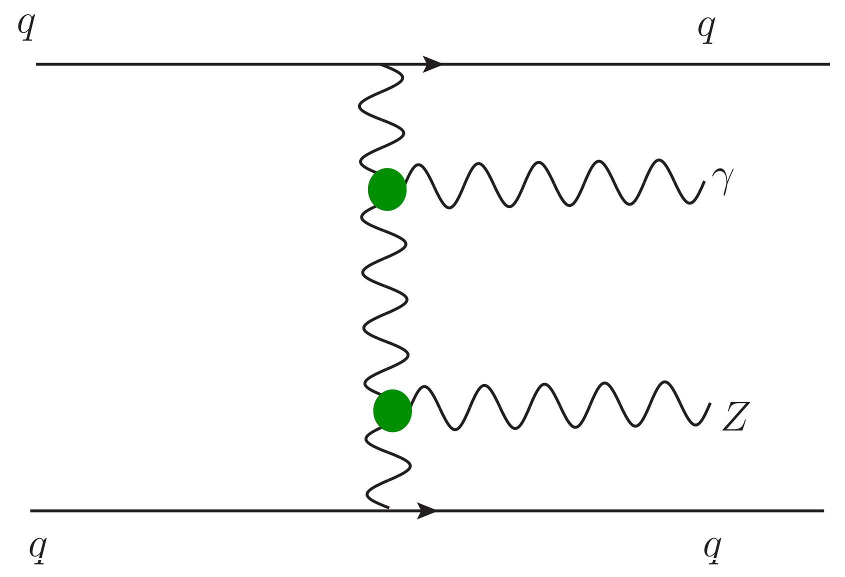
Vector-boson scattering

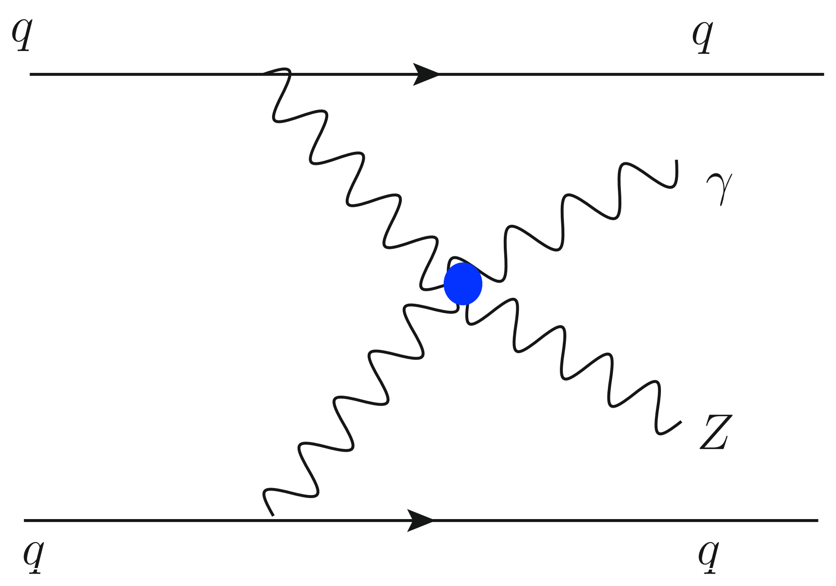
New

CERN-EP-2021-137 ATLAS-CONF-2021-038

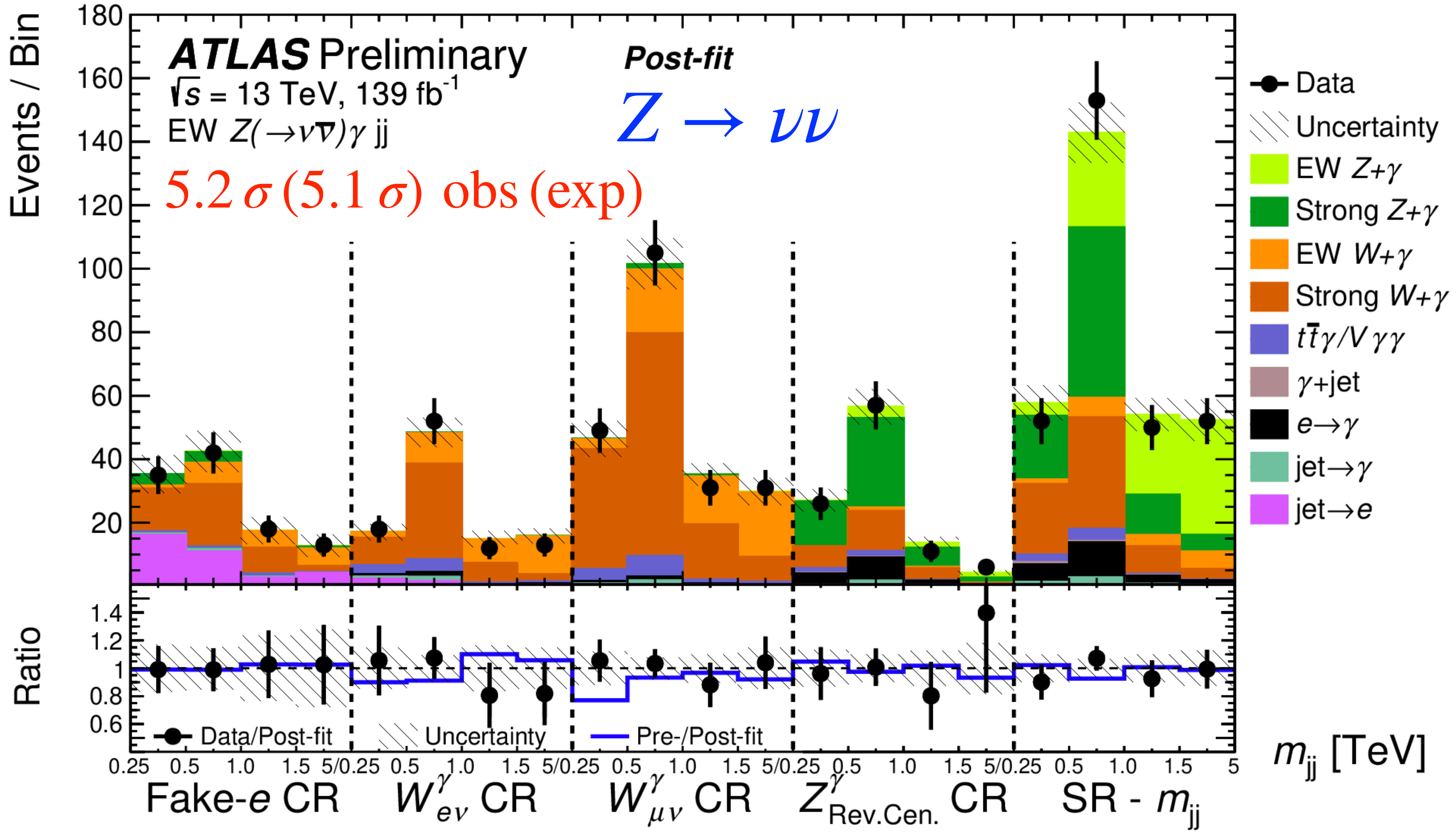
$$\mathscr{L}_{SM} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\overline{\psi}\not{D}\psi + \psi_i y_{ij} \psi_j \phi + \text{hc} + |D_\mu \phi|^2 - V(\phi)$$

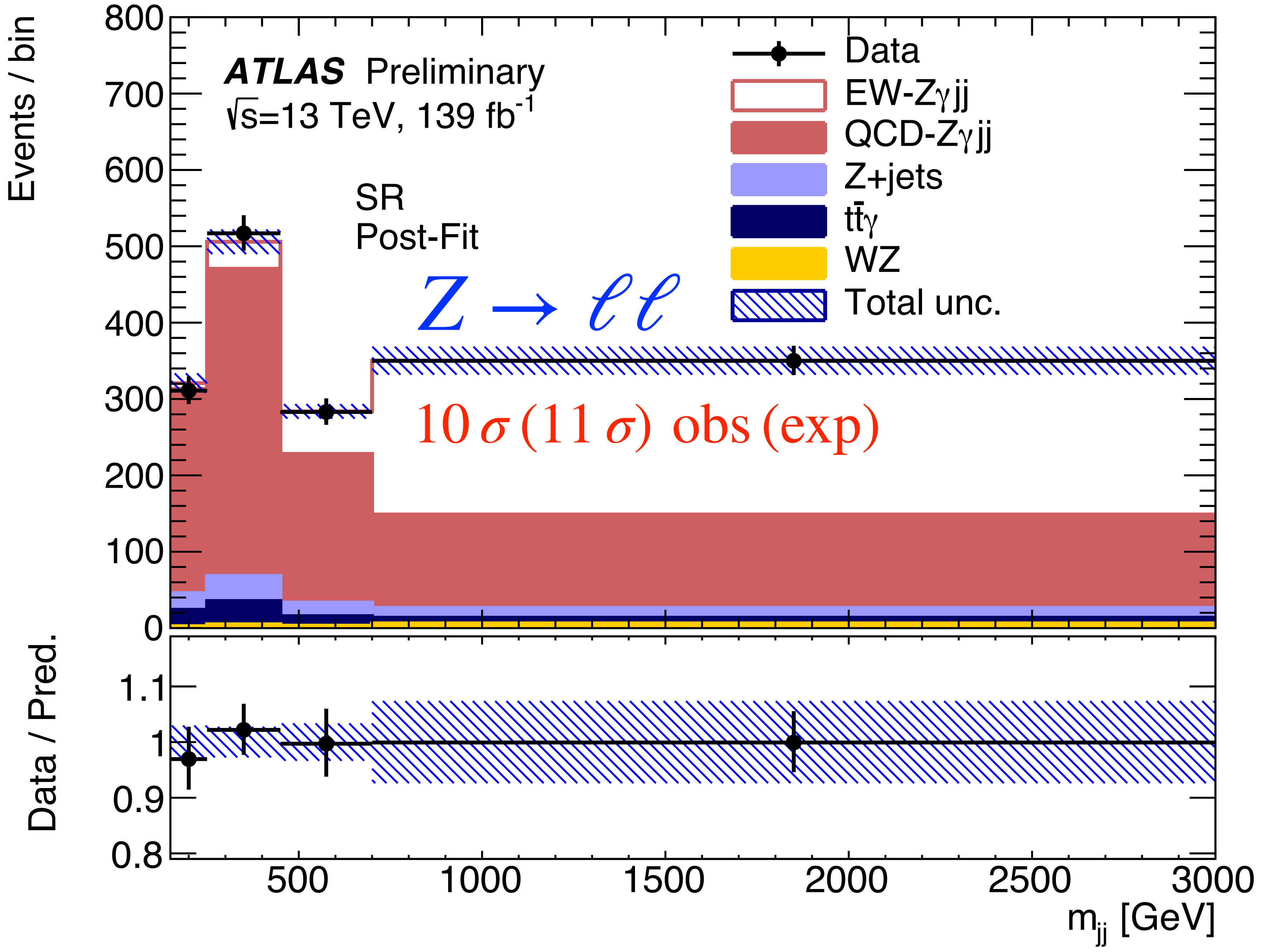
- Key test of EW symmetry
  —> **vector boson self-interactions**
  —> cubic and quartic couplings; previously observed all $VVjj$, except $Z\gamma jj$
- Events characterized by jets with large mass and rapidity gap
- Signal strength for $Z\gamma jj$ EW production (rel. to LO prediction)
  - $Z \to \nu\nu$: $\mu_{EW} = 1.03 \pm 0.16\,(\text{stat}) \pm 0.19\,(\text{syst})$
  - $Z \to \ell\ell$: $\mu_{EW} = 0.95 \pm 0.08\,(\text{stat}) \pm 0.11\,(\text{syst})$





most precise with 13% cross-section uncert.





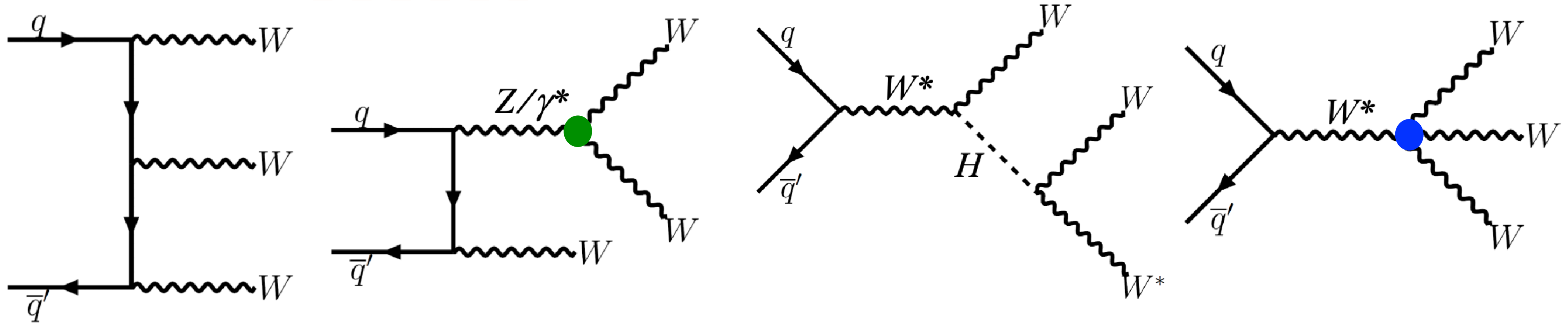
WWW production

New

ATLAS-CONF-2021-039

ATLAS EXPERIMENT

$$\mathscr{L}_{\rm SM} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\psi}\not{D}\psi + \psi_i y_{ij}\psi_j\phi + {\rm hc} + |D_\mu\phi|^2 - V(\phi)$$



- Rare process providing access to **W/Z self-interactions** —> cubic and quartic couplings

- Channels: $W^\pm W^\pm W^\mp \to \ell^\pm\nu\,\ell^\pm\nu\,qq'$ with $\ell = e, \mu$
  $\to \ell^\pm\nu\,\ell^\pm\nu\,\ell^\mp\nu$

- Main bkg: $WZ \to \ell\nu\,\ell\ell$ estimated w/ control regions

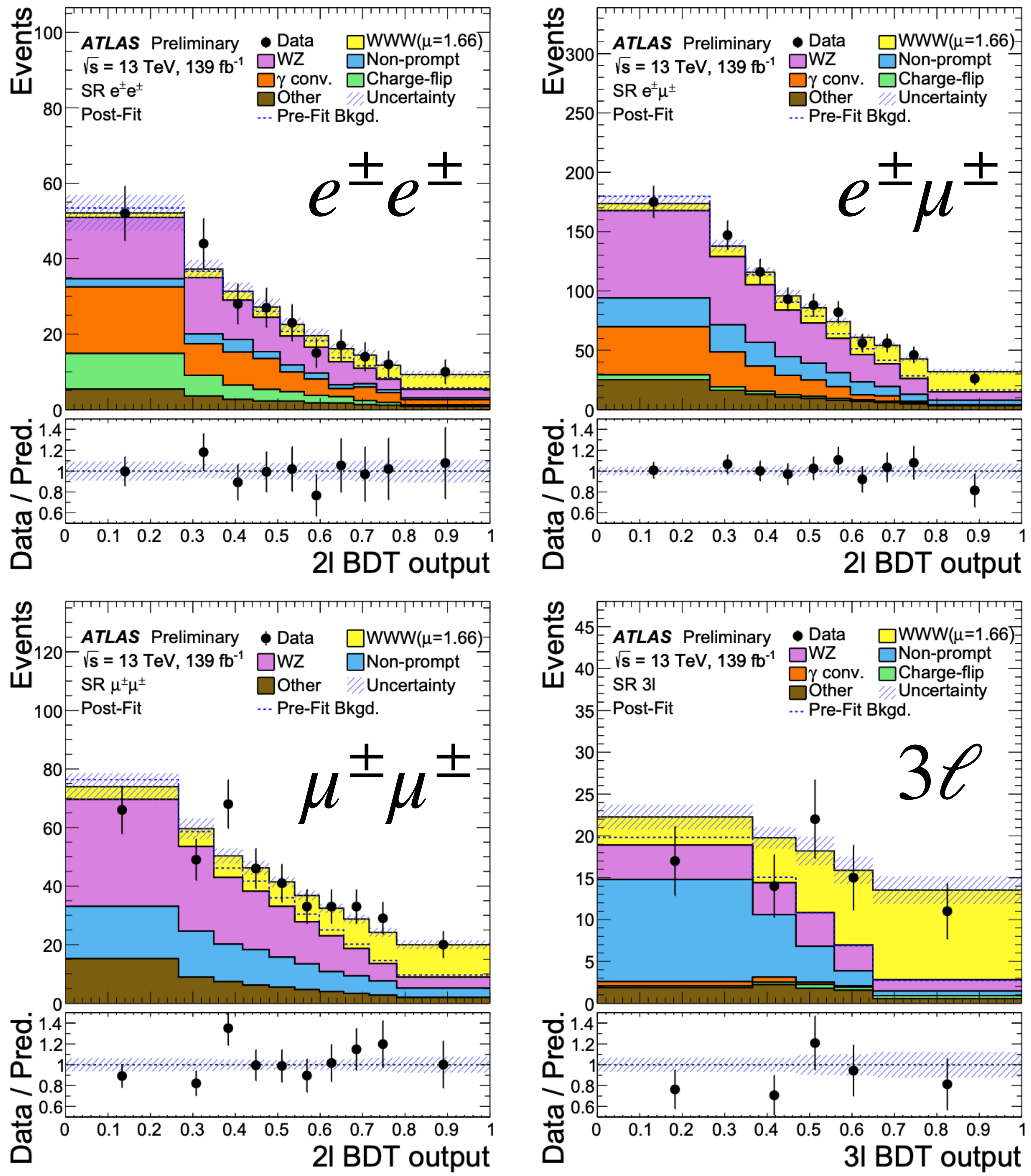
- Signal extracted w/ BDTs for 2ℓ and 3ℓ channels

- **First WWW observation** with significance of $8.2\,\sigma\,(5.4\,\sigma)$ obs (exp)

$$\sigma(pp \to W^\pm W^\pm W^\mp) = 850 \pm 100\,({\rm stat}) \pm 80\,({\rm syst})\,{\rm fb}$$

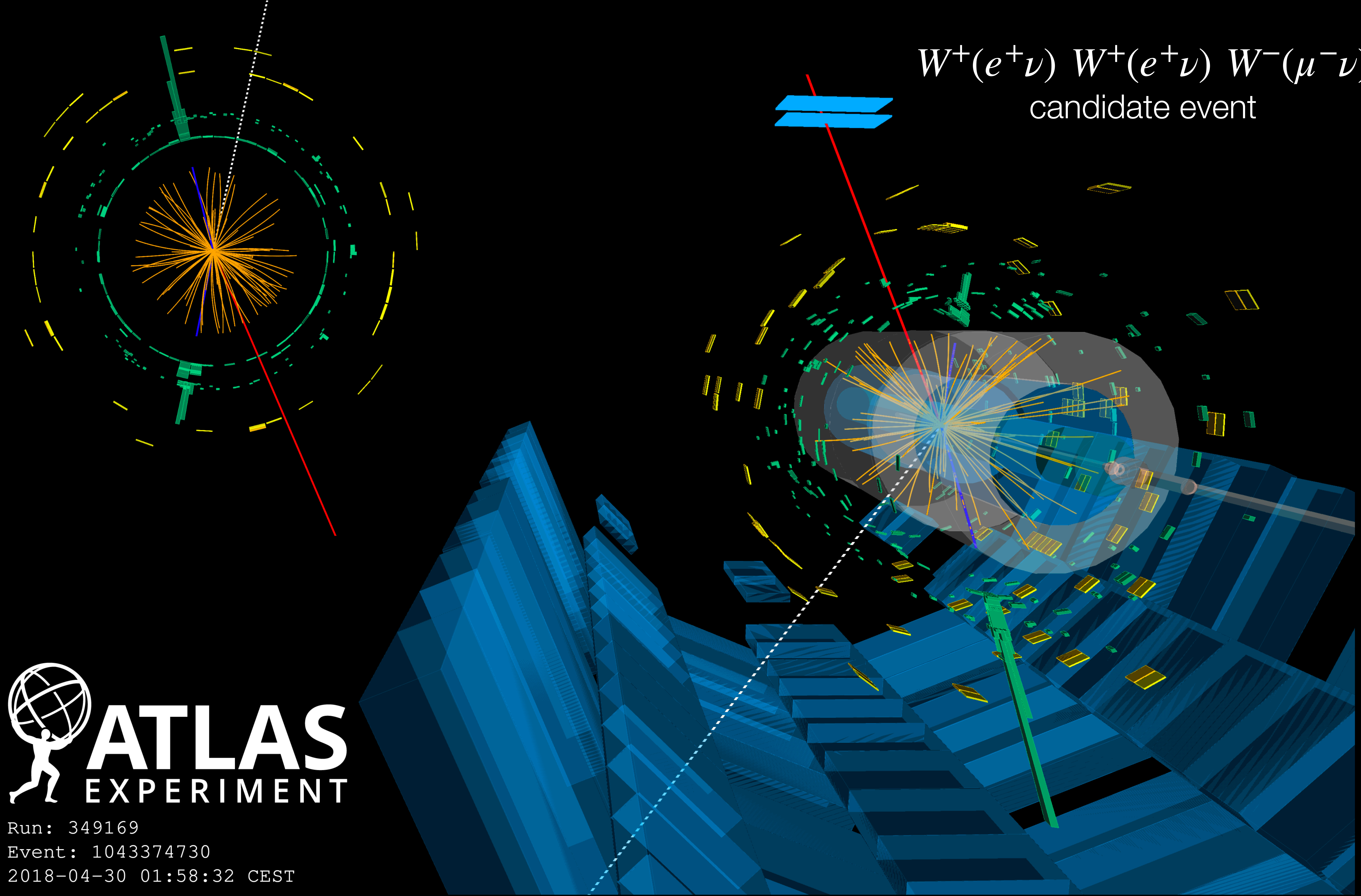
signal strength : 1.66 ± 0.28

SM for WWW + WH : 511 ± 42 fb at NLO QCD



$W^+(e^+\nu)\ W^+(e^+\nu)\ W^-(\mu^-\nu)$

candidate event



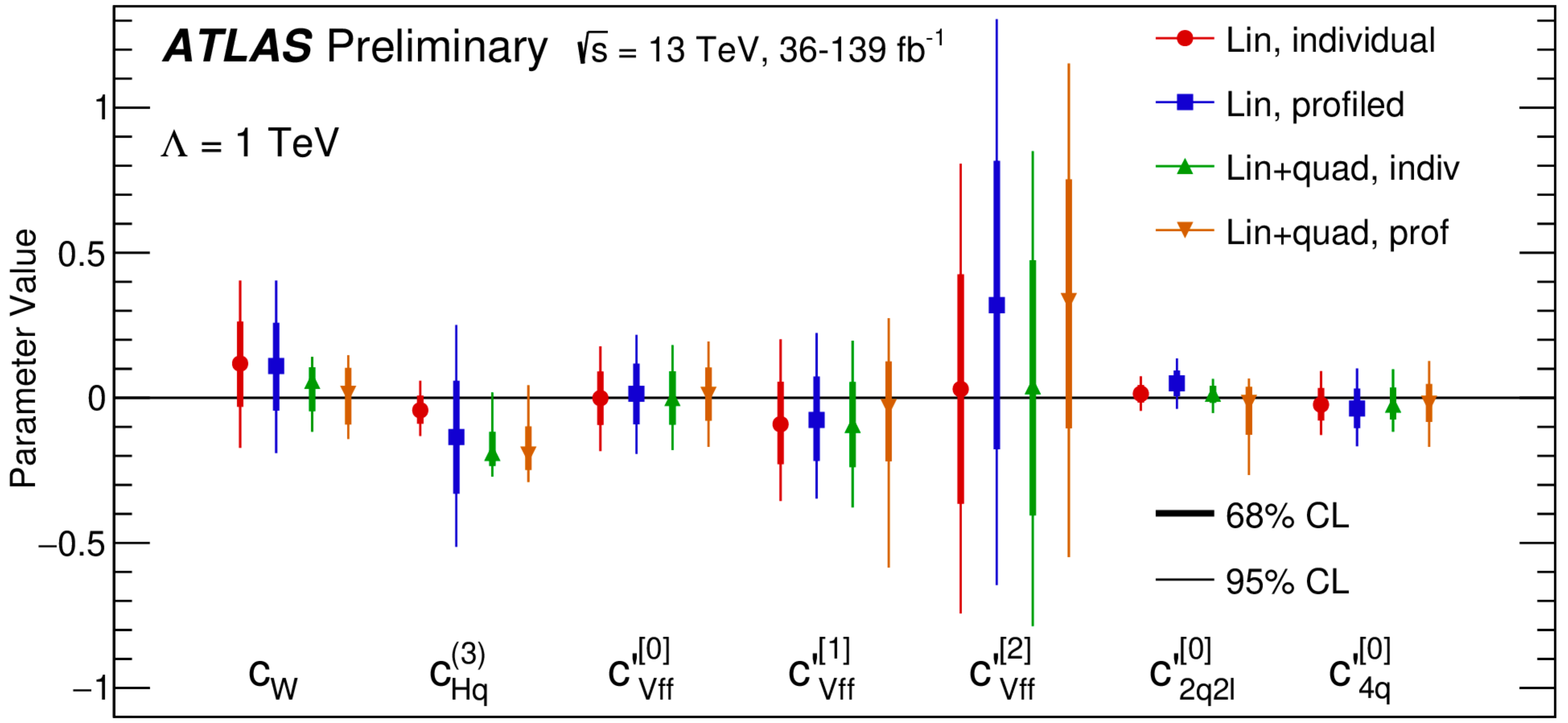
Effective field theory

ATL-PHYS-PUB-2021-022

- **EFT**: allows to systematically study impact of wide range of measts. on BSM physics at higher E

$$\mathscr{L}_{\mathrm{EFT}} = \mathscr{L}_{\mathrm{SM}} + \sum_i \frac{c_i^{(6)}}{\Lambda^2}\mathcal{O}_i^{(6)} + \sum_i \frac{c_i^{(8)}}{\Lambda^4}\mathcal{O}_i^{(8)} + \dots$$

- Study here is a step toward global EFT fits
- **Input**: 1 differential cross-section meast. for each of WW, WZ, 4-lepton (Z/ZZ*/ZZ), and VBF Z analyses
- **Output**: constrain operators affecting W/Z self-couplings, W/Z couplings to fermions, 4-fermion couplings



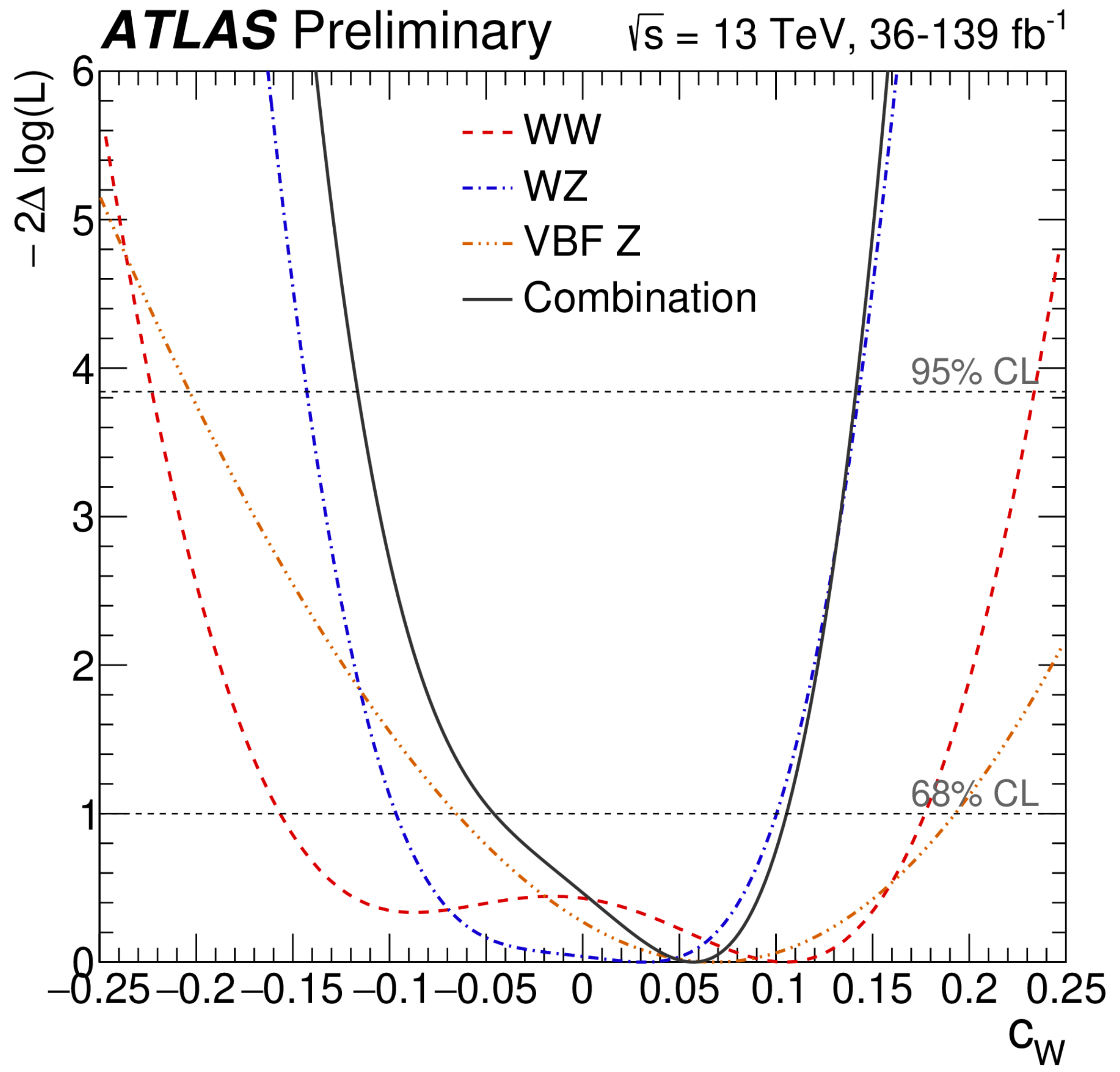
$c'^{[0]}_{Vff} \approx 0.81c_{HWB} + 0.38c_{HD} + 0.13c^{(1)}_{Hl} + 0.37c^{(3)}_{Hl} - 0.14c^{(1)}_{ll} + 0.12c^{(1)}_{Hq}$

$c'^{[1]}_{Vff} \approx 0.73c^{(1)}_{Hl} - 0.28c^{(3)}_{Hl} - 0.48c_{He} + 0.38c^{(1)}_{ll} + 0.13c^{(1)}_{Hq}$

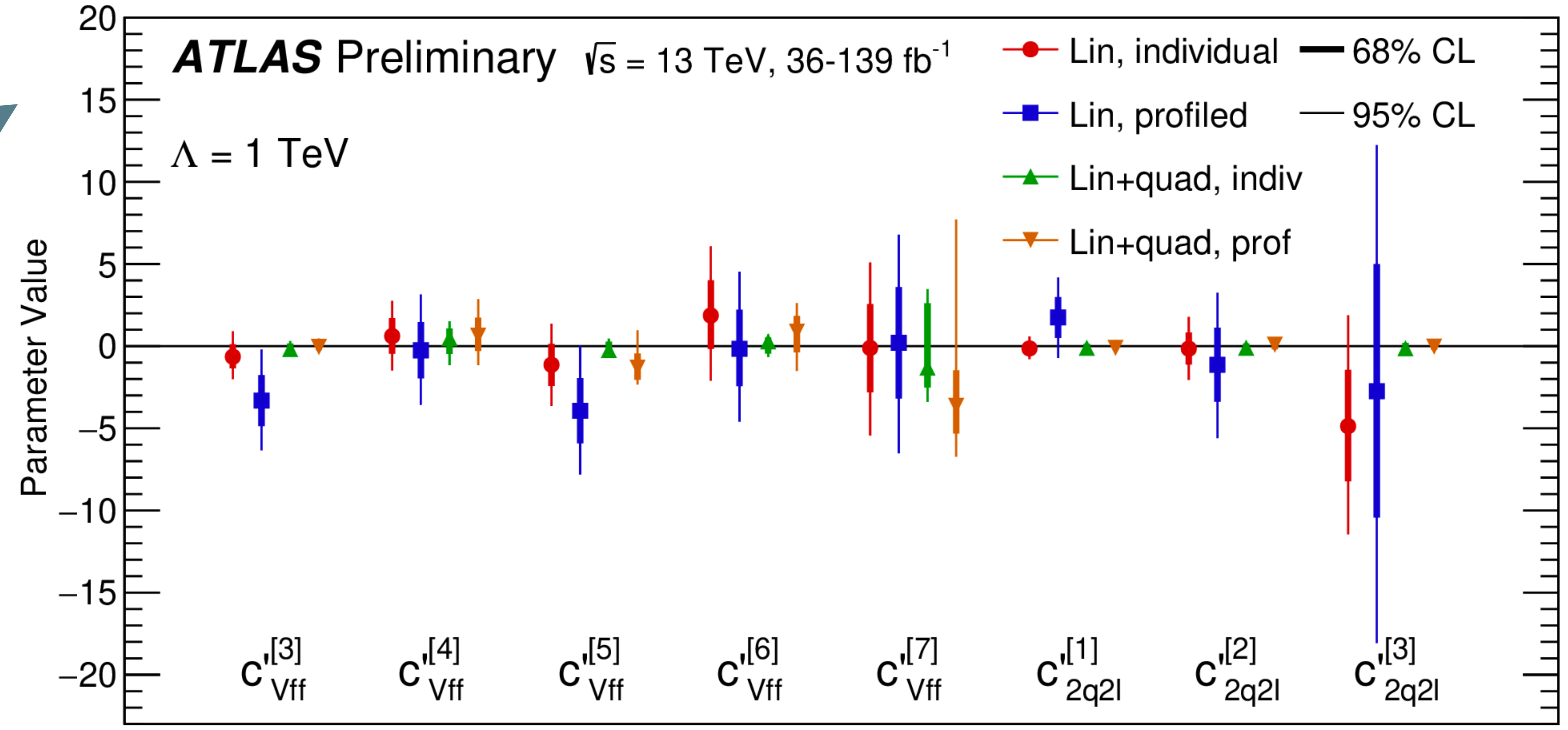
$c'^{[2]}_{Vff} \approx 0.37c_{HWB} + 0.17c_{HD} - 0.31c^{(1)}_{Hl} - 0.53c^{(3)}_{Hl} + 0.25c_{He} + 0.59c^{(1)}_{ll} - 0.21c^{(1)}_{Hq}$

$c'^{[0]}_{2q2l} \approx -0.37c^{(1)}_{lq} + 0.89c^{(3)}_{lq} - 0.11c_{lu} - 0.21c_{eu} - 0.13c_{qe}$

$c'^{[0]}_{4q} \approx 0.11c^{(11)}_{qq} + 0.22c^{(18)}_{qq} + 0.95c^{(31)}_{qq} - 0.2c^{(38)}_{qq}$



- 15 eigenvectors constrained individually or in combination ("profiled")
- coefficients of all 15 eigenvectors consistent with SM within 2σ



$c'^{[3]}_{Vff} \approx -0.19c^{(1)}_{Hl} - 0.14c^{(3)}_{Hl} + 0.86c^{(1)}_{Hq} + 0.41c_{Hu} - 0.17c_{Hd}$

$c'^{[4]}_{Vff} \approx -0.35c_{HWB} + 0.49c_{HD} + 0.26c^{(1)}_{Hl} + 0.35c^{(3)}_{Hl} + 0.51c_{He} + 0.38c^{(1)}_{ll} + 0.18c^{(1)}_{Hq}$

$c'^{[5]}_{Vff} \approx 0.25c_{HD} + 0.33c^{(1)}_{Hl} - 0.22c^{(3)}_{Hl} + 0.18c_{He} - 0.35c^{(1)}_{ll} - 0.3c^{(1)}_{Hq} + 0.71c_{Hu} - 0.16c_{Hd}$

$c'^{[6]}_{Vff} \approx -0.22c^{(1)}_{Hl} + 0.52c^{(3)}_{Hl} - 0.39c_{He} + 0.44c^{(1)}_{ll} - 0.22c^{(1)}_{Hq} + 0.52c_{Hu}$

$c'^{[7]}_{Vff} \approx -0.28c_{HWB} + 0.71c_{HD} - 0.31c^{(1)}_{Hl} - 0.21c^{(3)}_{Hl} - 0.5c_{He} - 0.14c^{(1)}_{ll}$

$c'^{[1]}_{2q2l} \approx 0.56c^{(1)}_{lq} + 0.44c^{(3)}_{lq} + 0.61c_{eu} - 0.1c_{ed} + 0.34c_{qe}$

$c'^{[2]}_{2q2l} \approx 0.68c^{(1)}_{lq} + 0.15c^{(3)}_{lq} + 0.33c_{lu} - 0.51c_{eu} + 0.13c_{ed} - 0.37c_{qe}$

$c'^{[3]}_{2q2l} \approx -0.27c^{(1)}_{lq} + 0.79c_{lu} - 0.39c_{ld} + 0.26c_{eu} - 0.22c_{ed} - 0.16c_{qe}$

Top-quark production

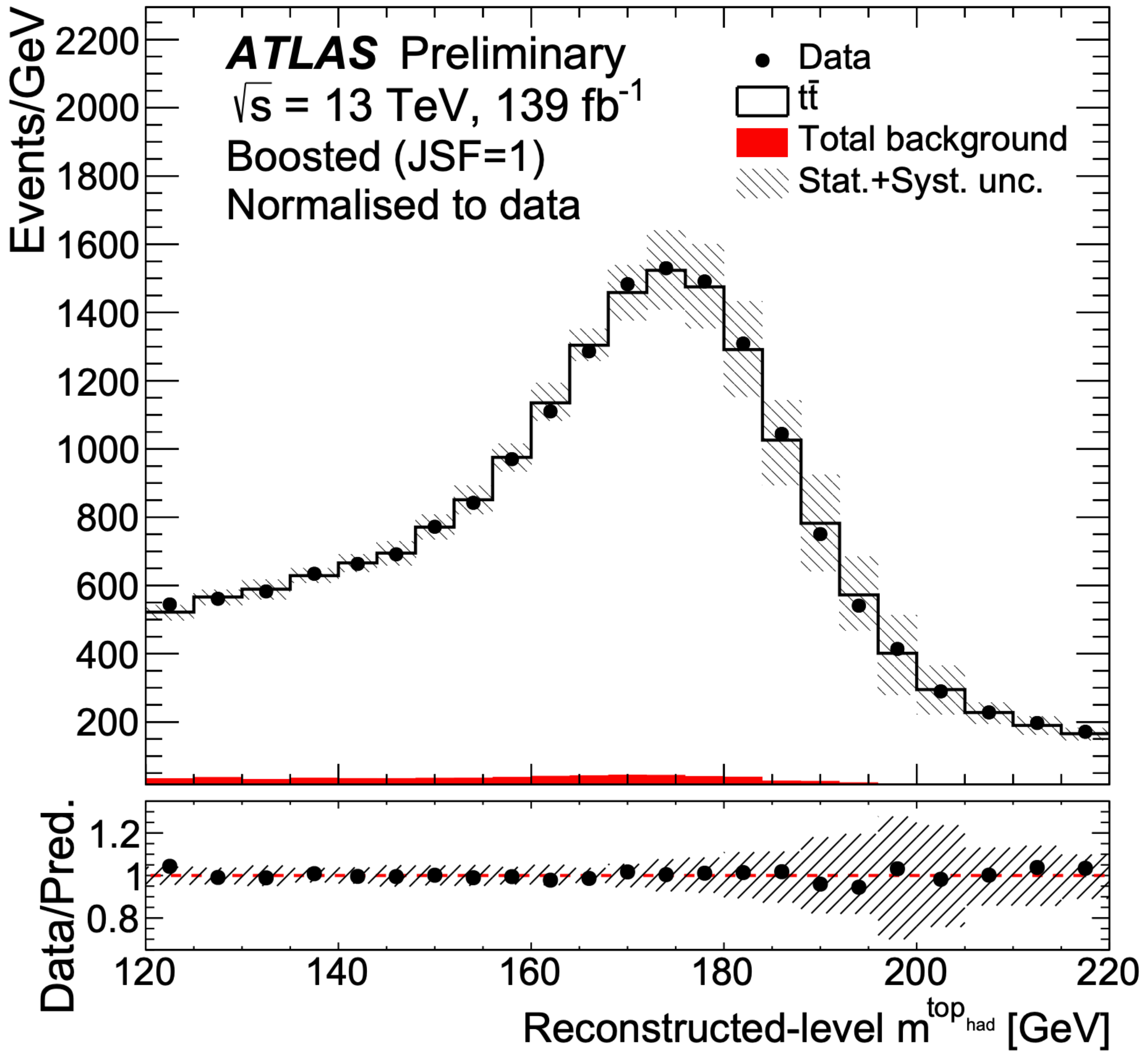
New

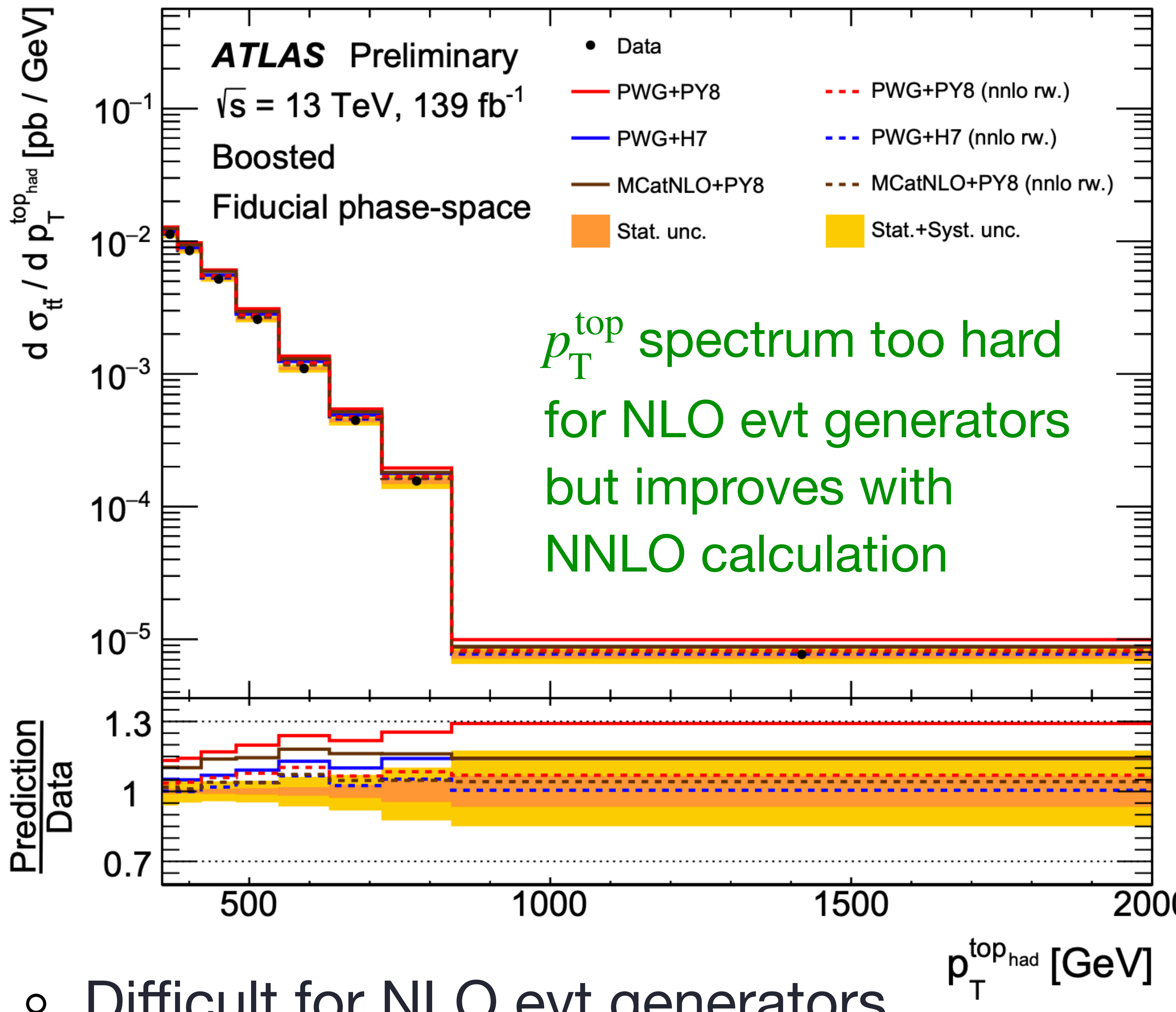
ATLAS-CONF-2021-031

ATLAS EXPERIMENT

$$\mathscr{L}_{SM} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\psi}\not{D}\psi + \psi_i y_{ij}\psi_j\phi + \text{hc} + |D_\mu\phi|^2 - V(\phi)$$

- Run 2: ~1.2 x 10⁸ $t\bar{t}$ produced
- Test SM at high p_T^{top}, where deviations expected from BSM, measure both $t\bar{t}$ system and radiation
  - SM predictions at NNLO QCD + NLO EW
- l+jets channel: $t\bar{t} \to Wb\,Wb \to \ell\nu b\, qq'b$
  - Reconstruct hadronic top as reclustered R=1.0 anti-kt jet w/ p_T > 355 GeV, |η|<2.0, and mass ∈ 120-220 GeV
  - Reduce jet energy scale uncertainties by using mass of reconstructed hadronic top
    —> jet energy scale factor
    —> ~30% reduction in σ_{syst}^{tot}
  - Differential cross sections provided for 16 variables
    (8 for the first time for boosted top quarks)





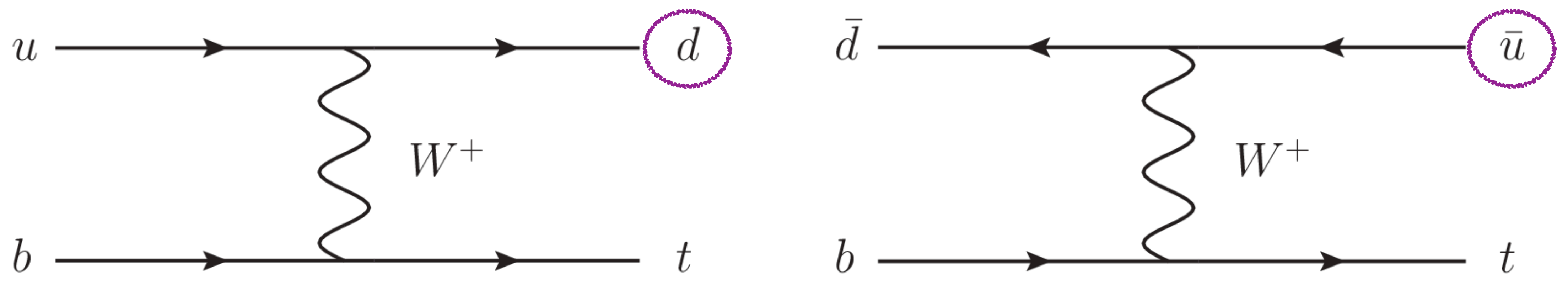
p_T^{top} spectrum too hard for NLO evt generators but improves with NNLO calculation

- Difficult for NLO evt generators to model additional radiation
- Constraints placed on EFT operators $\mathcal{O}_{tG}$ and $\mathcal{O}_{tq}^{(8)}$

Single-top quark polarization

ATLAS-CONF-2021-027

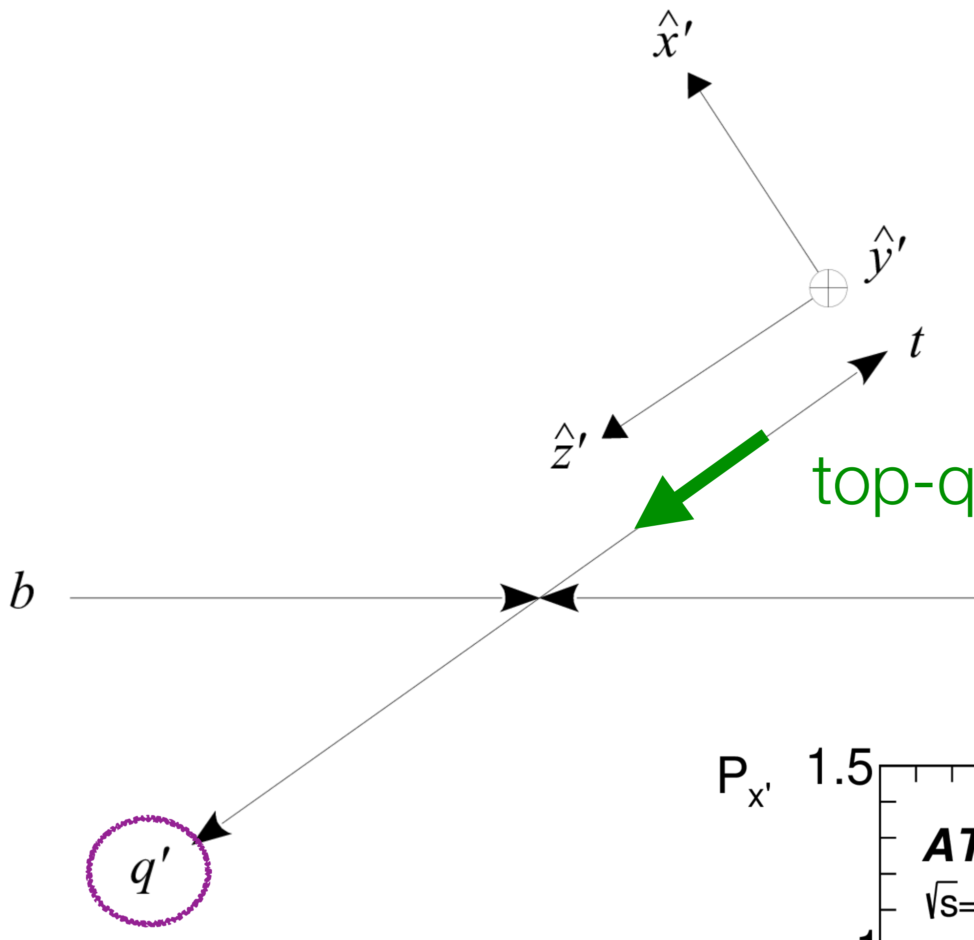
- *t*-channel dominates single top-quark production



spectator quark q'

$$\mathscr{L}_{SM} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\psi}\not{D}\psi + \psi_i y_{ij} \psi_j \phi + \text{hc} + |D_\mu \phi|^2 - V(\phi)$$

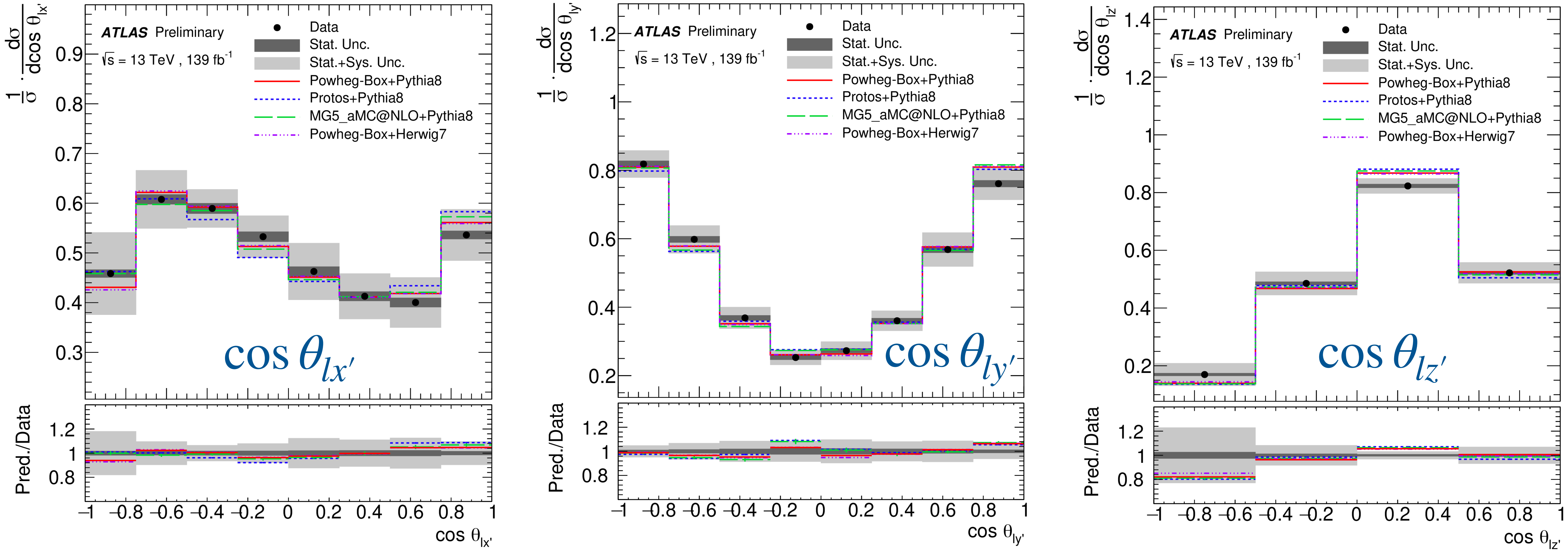
coord. system in b+q rest frame

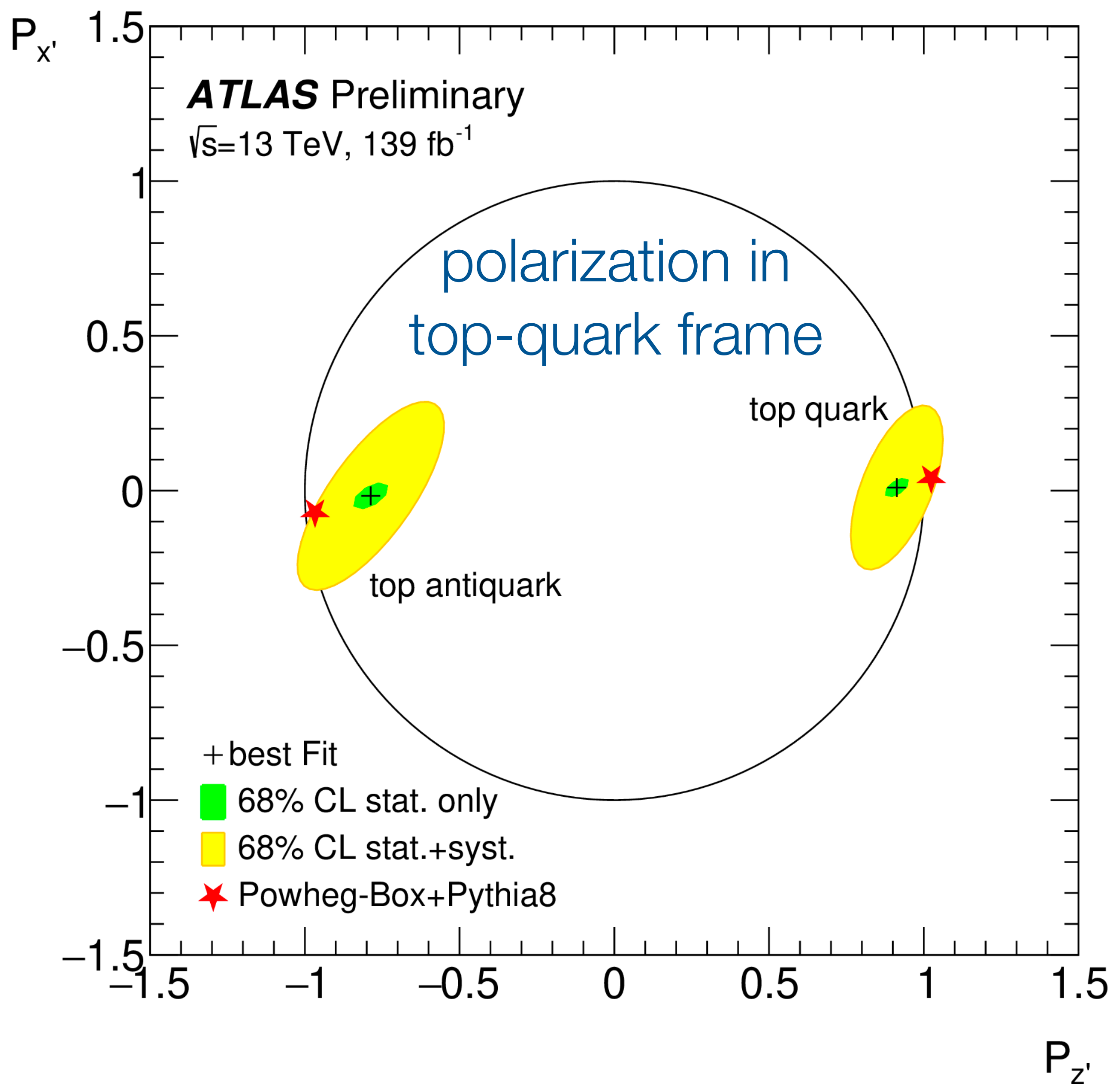


top-quark spin direction

- High polarization expected from V-A structure of CC weak interaction + test BSM impact on tWb vertex

- First measurement of polarization vector in 3-D via angular distributions of lepton (e or μ) from $t \to b\ell\nu$ decay





- Constraints placed on Re and Im parts of EFT operator $\mathscr{O}_{tW}$

Higgs couplings to τ leptons

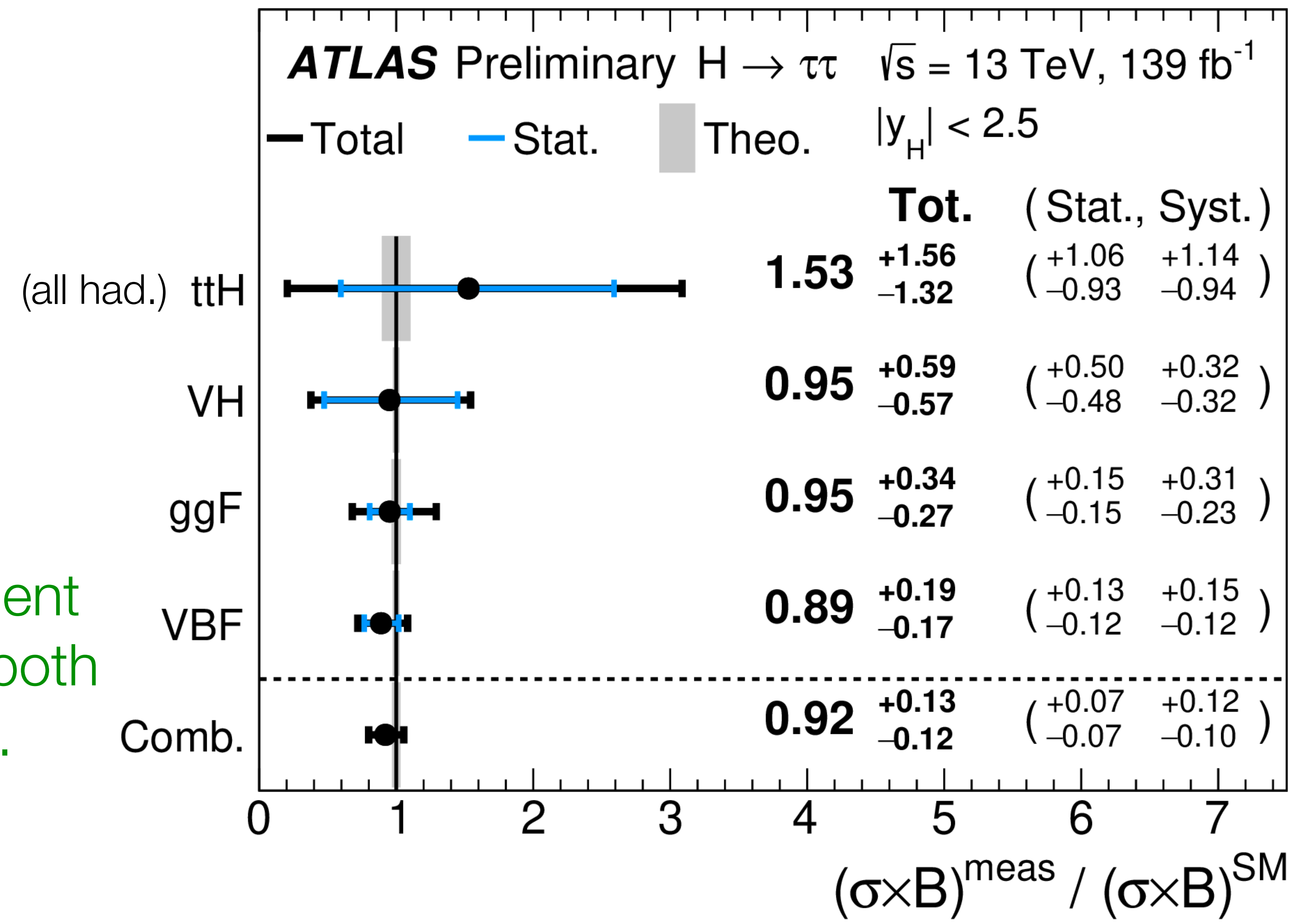
New

ATLAS-CONF-2021-044

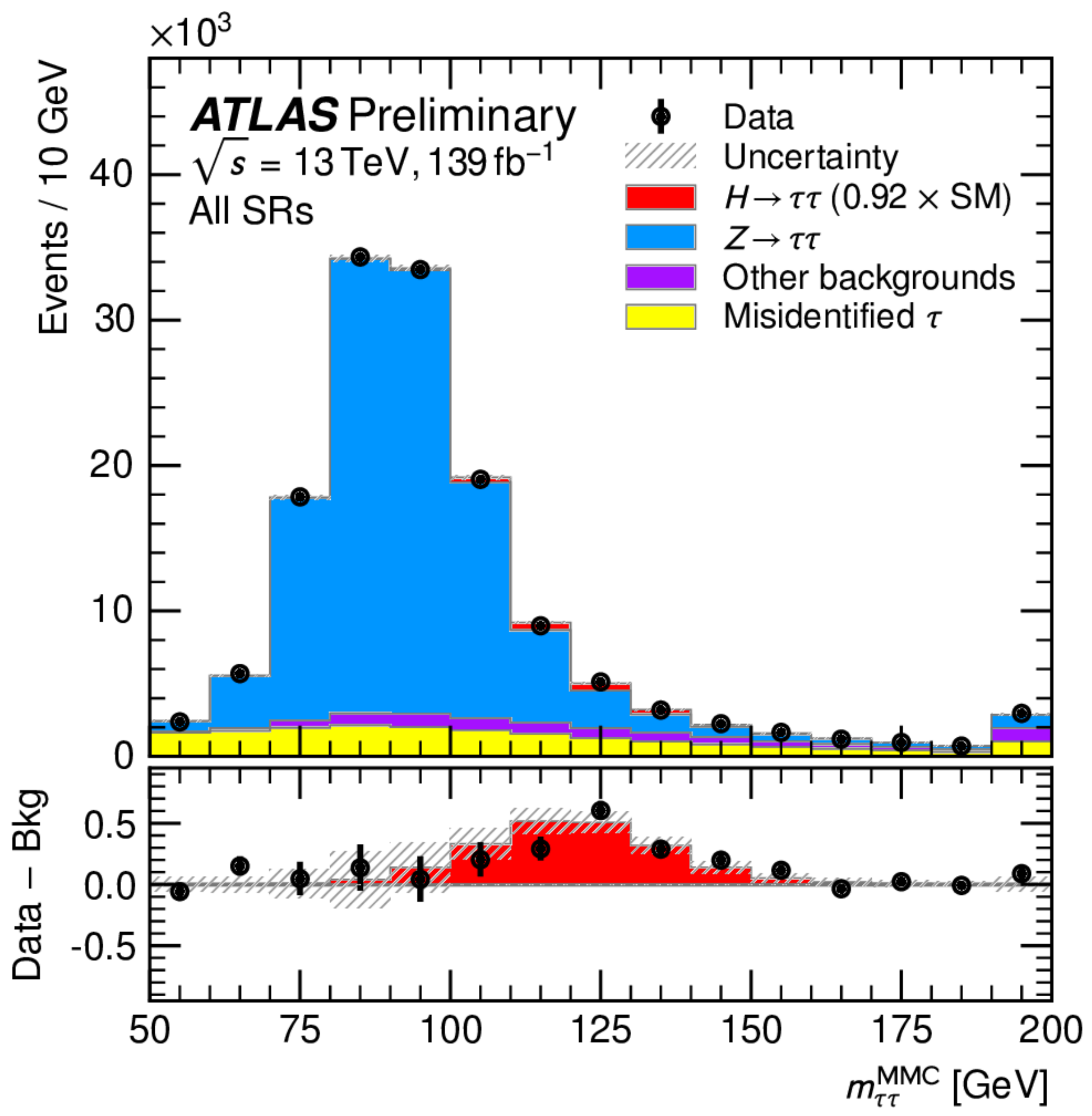
ATLAS EXPERIMENT

$$\mathscr{L}_{\mathrm{SM}} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\psi}\not{D}\psi + \psi_i y_{ij} \psi_j \phi + \mathrm{hc} + |D_\mu \phi|^2 - V(\phi)$$

- Run 2: ~8 x 10^6 Higgs bosons produced
- $\mathscr{B}(H \to \tau\tau) = 6.3\,\%$ —> test **Yukawa interactions with leptons**
- Expt. challenge: 2-4 neutrinos in final state, poor mass resolution
- Multiple BDTs used to suppress $Z \to \tau\tau$ and $t\bar{t}$ background, and categorize event purity for each production mechanism
- Dominant $Z \to \tau\tau$ background from MC, controlled with $Z \to \ell\ell$ data via kinematic embedding procedure

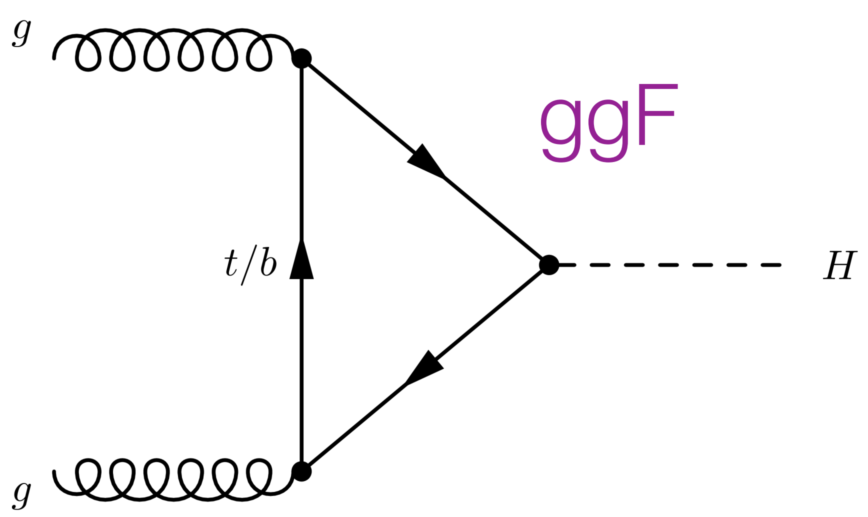


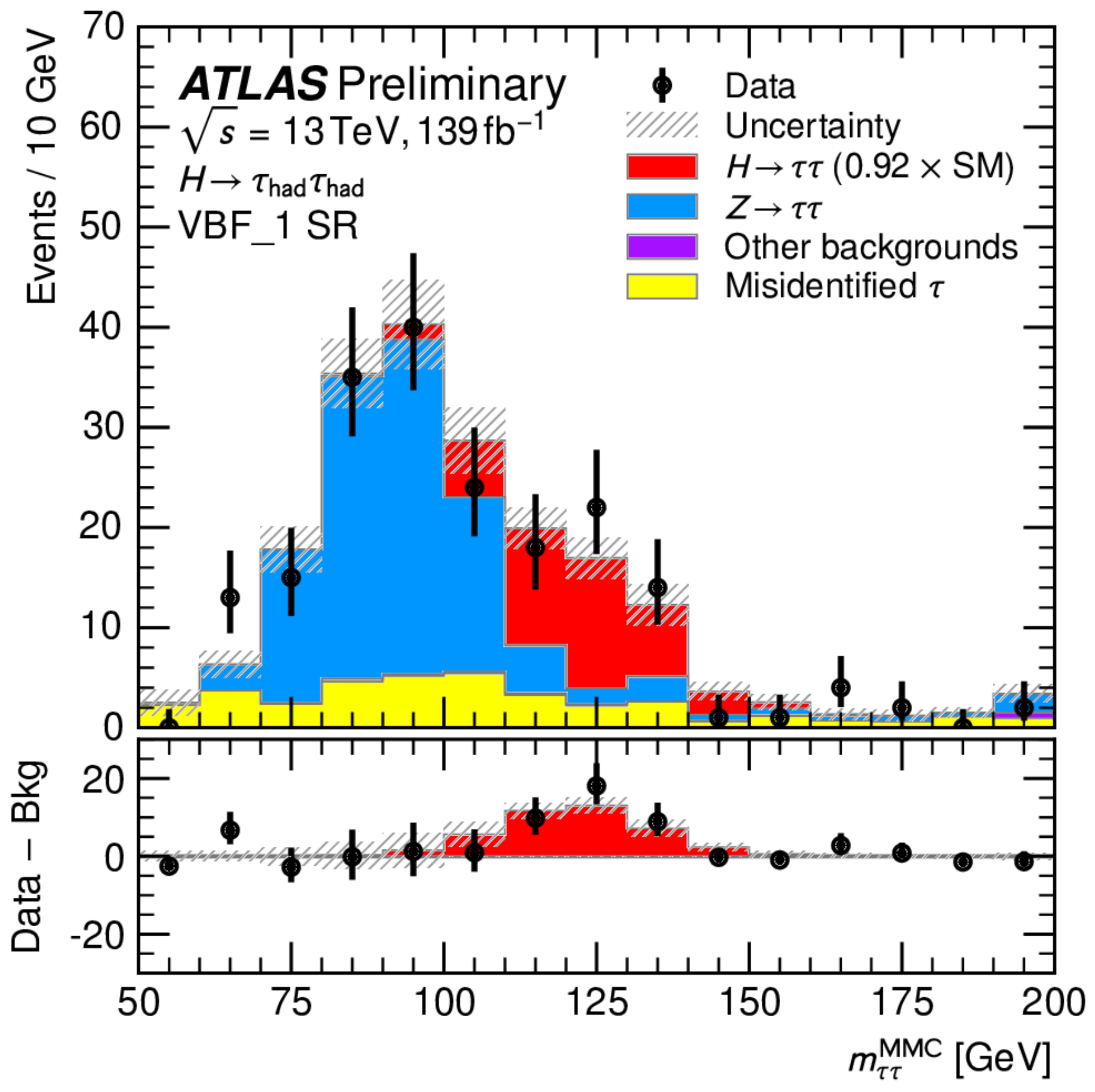
factor of 2.5 improvement over 36 fb^{-1} analysis in both stat and syst uncert.



- ggF significance

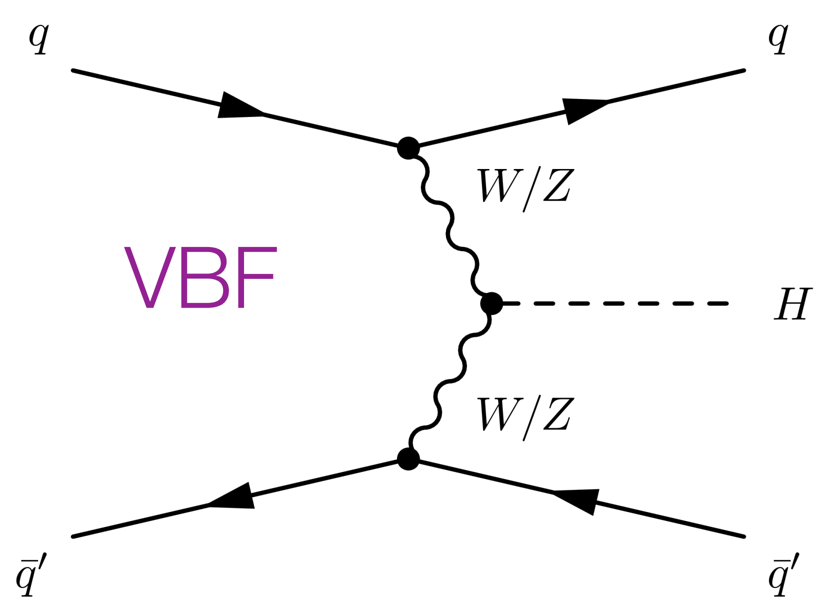
  $3.9\,\sigma\,(4.6\,\sigma)$ obs (exp)





- VBF significance

  $5.3\,\sigma\,(6.2\,\sigma)$ obs (exp)



Higgs couplings to 2nd gen quarks

ATLAS-CONF-2021-021

ATLAS EXPERIMENT

$$\mathscr{L}_{SM} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\psi}\not{D}\psi + \psi_i y_{ij}\psi_j\phi + \text{hc} + |D_\mu\phi|^2 - V(\phi)$$

- Test of **Yukawa interactions w/ 2nd generation fermions**: evidence for leptons only
- **Search for H—> cc** in associated $V(\ell\ell, \ell\nu, \nu\nu)\,H$ production
- Dedicated charm tagging
- Results:

$VW(\to cq)$ with $3.8\,\sigma\,(4.6\,\sigma)$ obs (exp)

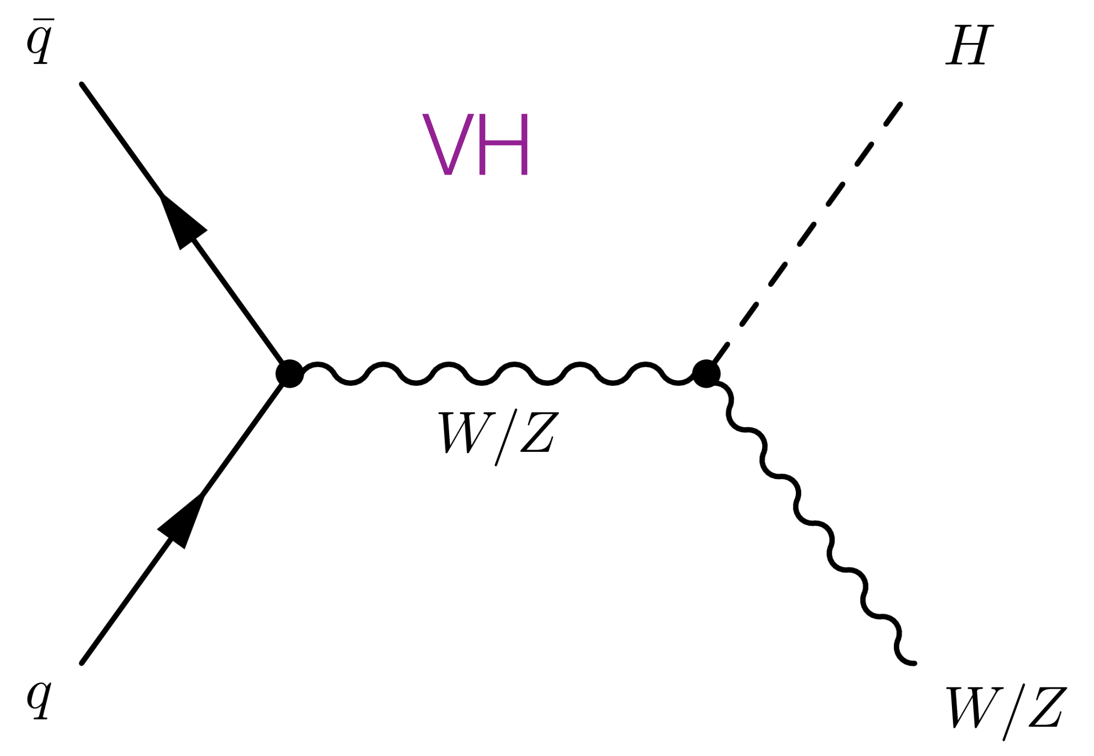
$VZ(\to cc)$ with $2.6\,\sigma\,(2.2\,\sigma)$ obs (exp)

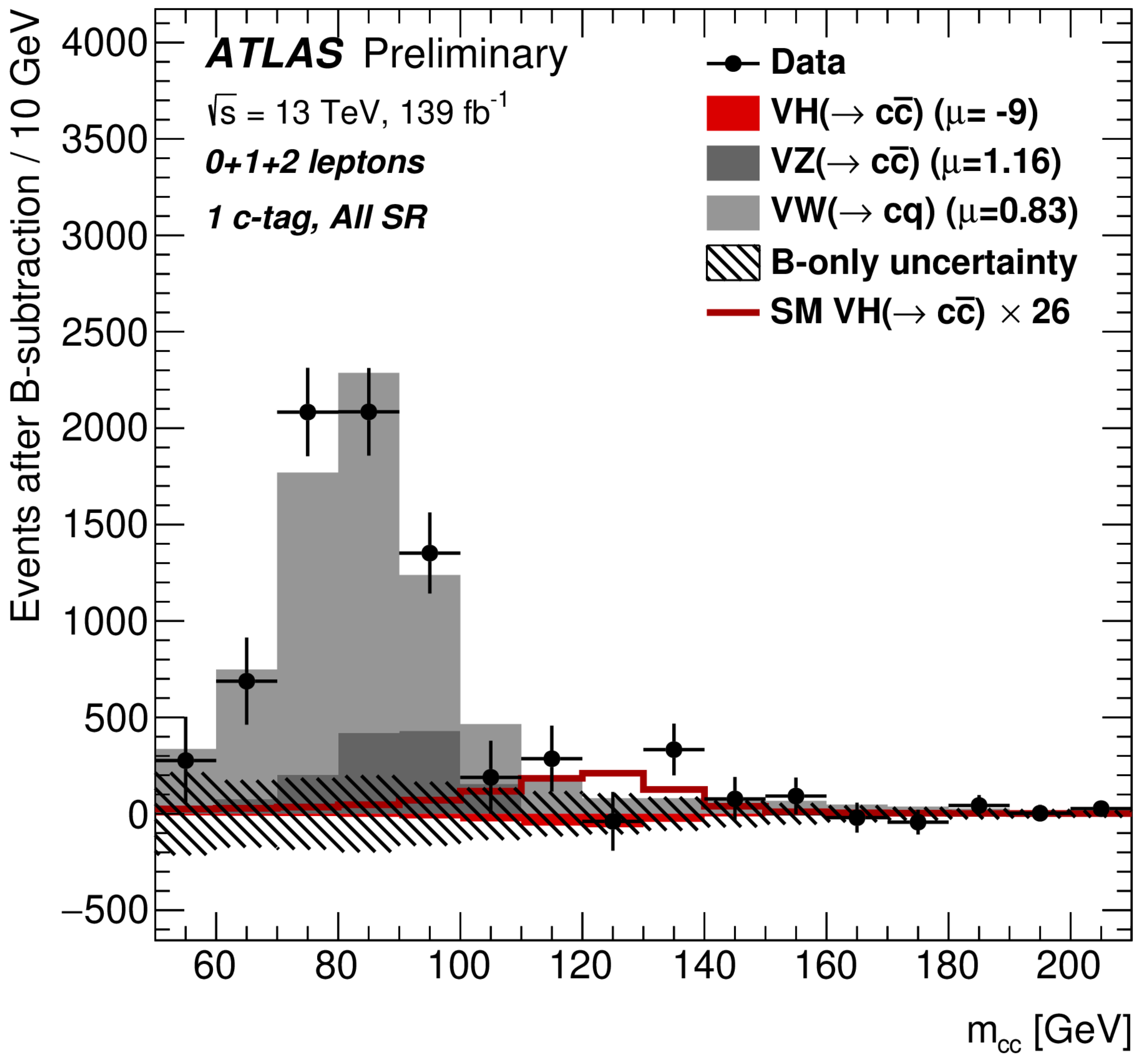
$VH(\to cc) < 26\,(31)\,\sigma_{SM}$ obs (exp)

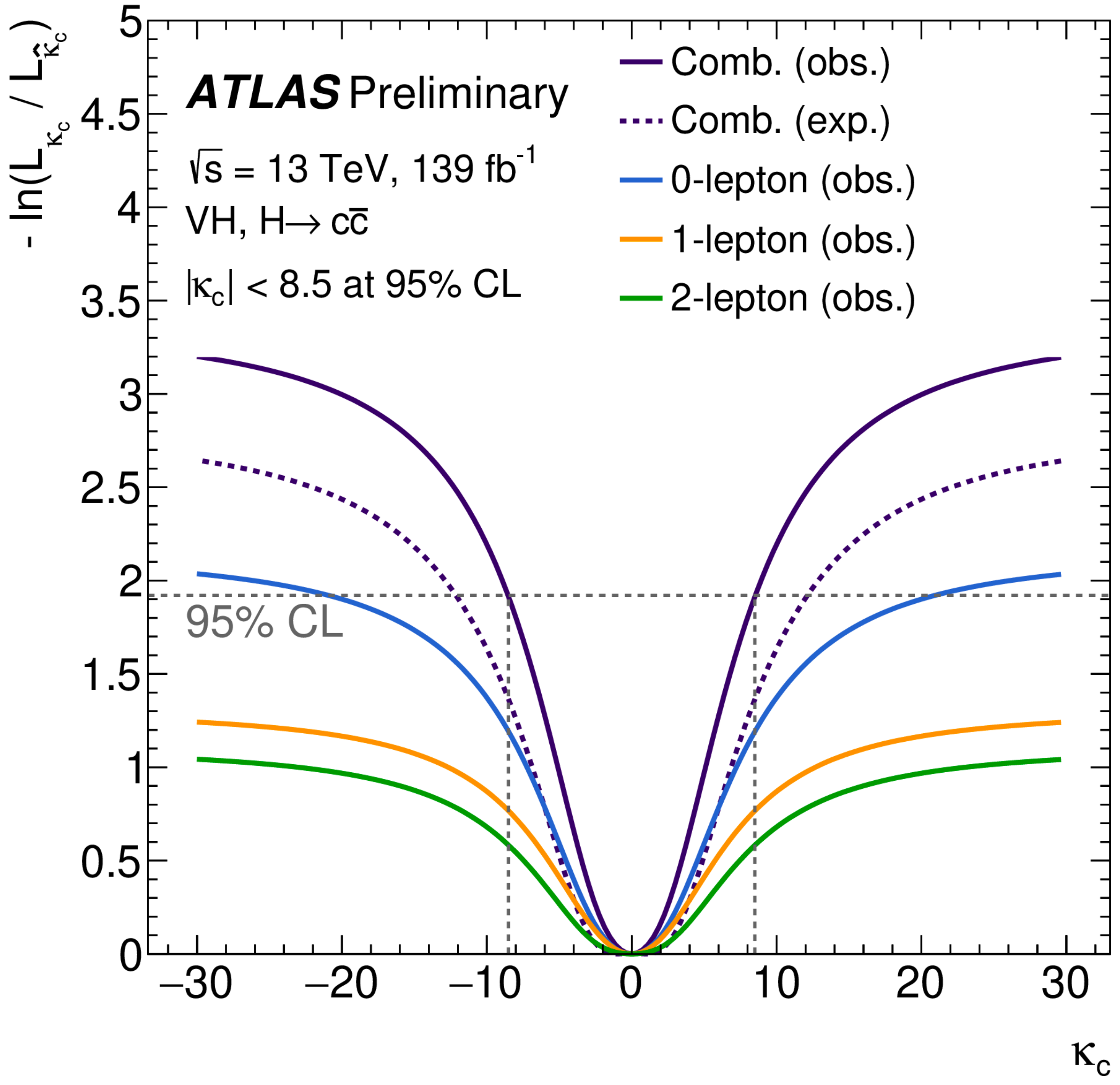
- Charm Yukawa modifier

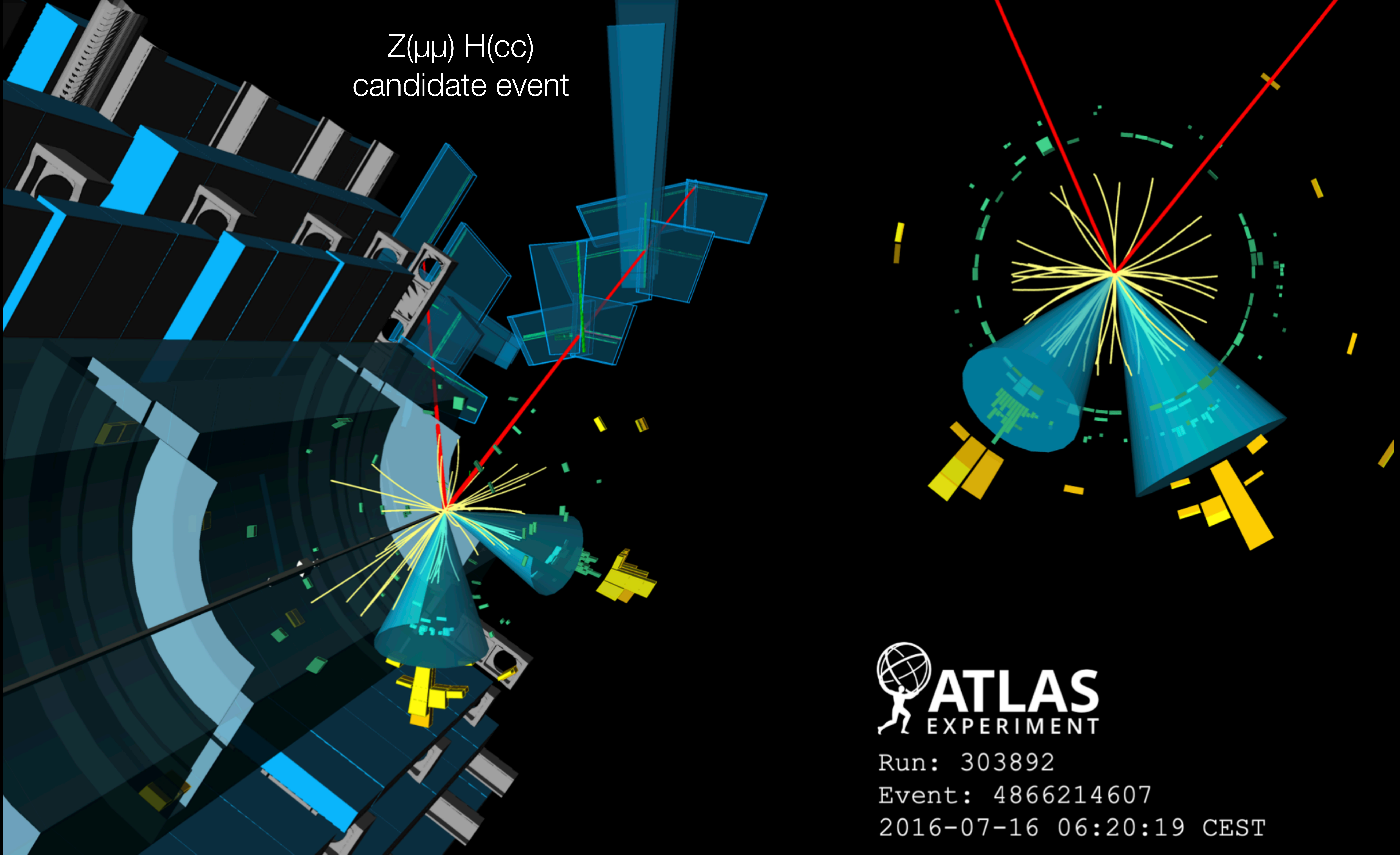
$|\kappa_c| < 8.5\,(12.4)$ obs (exp)

first direct constraint








Z(μμ) H(cc)
candidate event
ATLAS
EXPERIMENT
Run: 303892
Event: 4866214607
2016-07-16 06:20:19 CEST

Di-Higgs production

ATLAS-CONF-2021-030

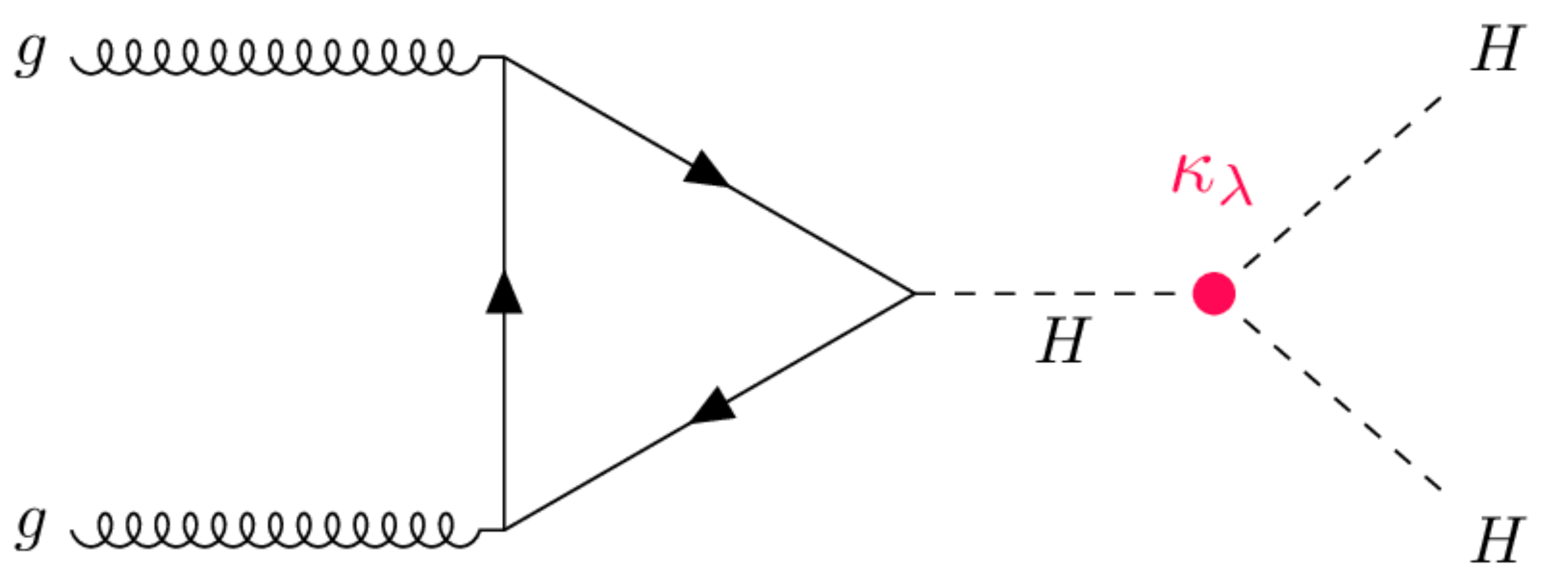
ATLAS EXPERIMENT

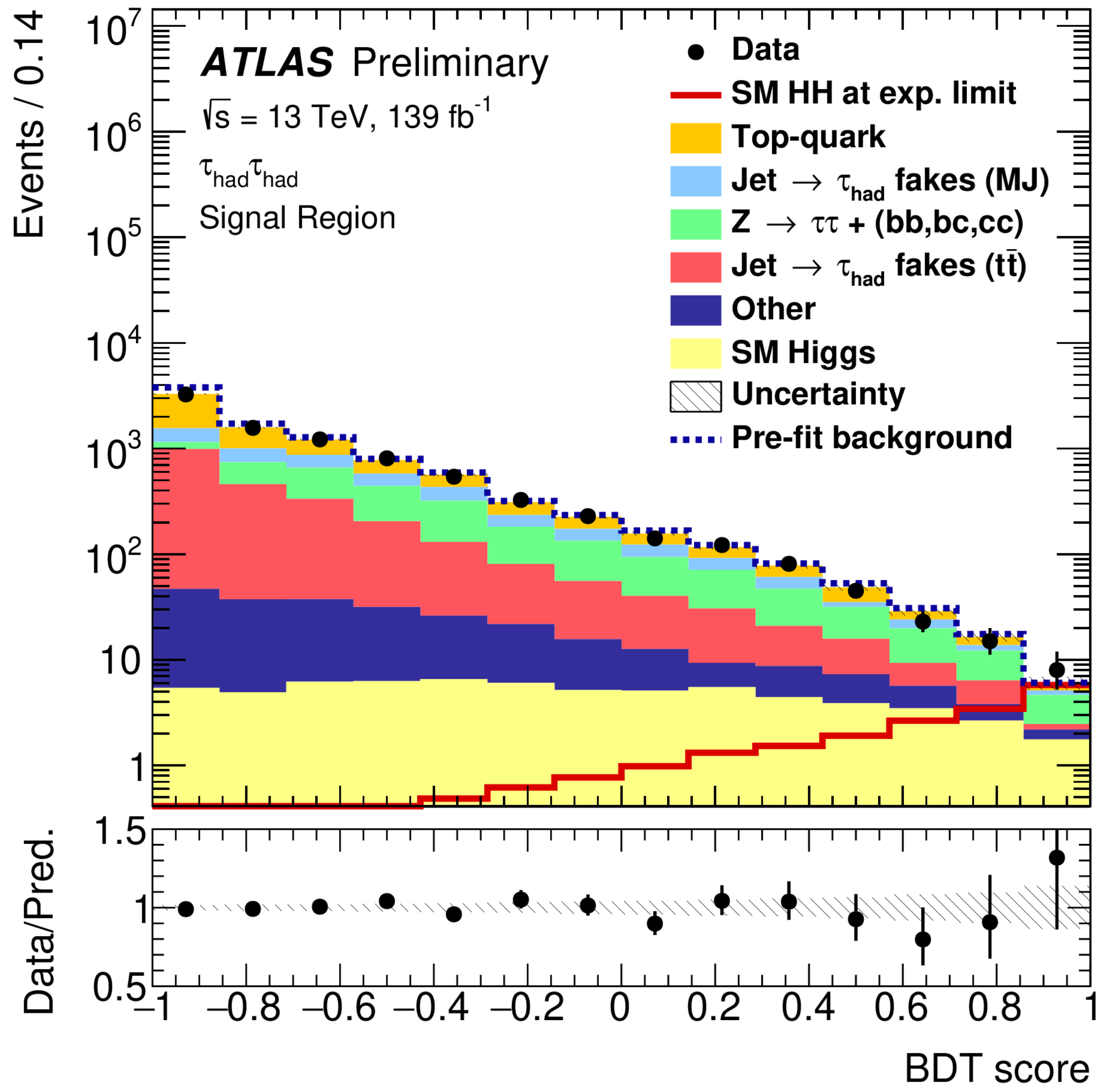
- **Direct access to Higgs potential**
  - Last part of SM needing direct test
  - Small HH XS (ggF 31 fb @NNLO)
- HH —> bbbb (33%), bbττ (7.3%), bbγγ (0.3%)
- **HH —> bbττ channel**
  - Trigger: single lepton, lepton+τ_{had}, single τ_{had}, di-τ_{had}
  - MVAs (BDT and NN) used for signal vs. bkg
  - $Z(\ell\ell)$+heavy flavor CR
  - multiple fake-tau CRs
  - most sensitive channel to non-resonant HH

$$\sigma_{HH}/\sigma_{HH}^{SM} < 4.7\ (3.9)\ \mathrm{obs\ (exp)}$$

factor of 4 improvement over 36 fb^{-1} analysis

$$\mathscr{L}_{SM} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\psi}\not{D}\psi + \psi_i y_{ij}\psi_j\phi + \mathrm{hc} + |D_\mu\phi|^2 - V(\phi)$$





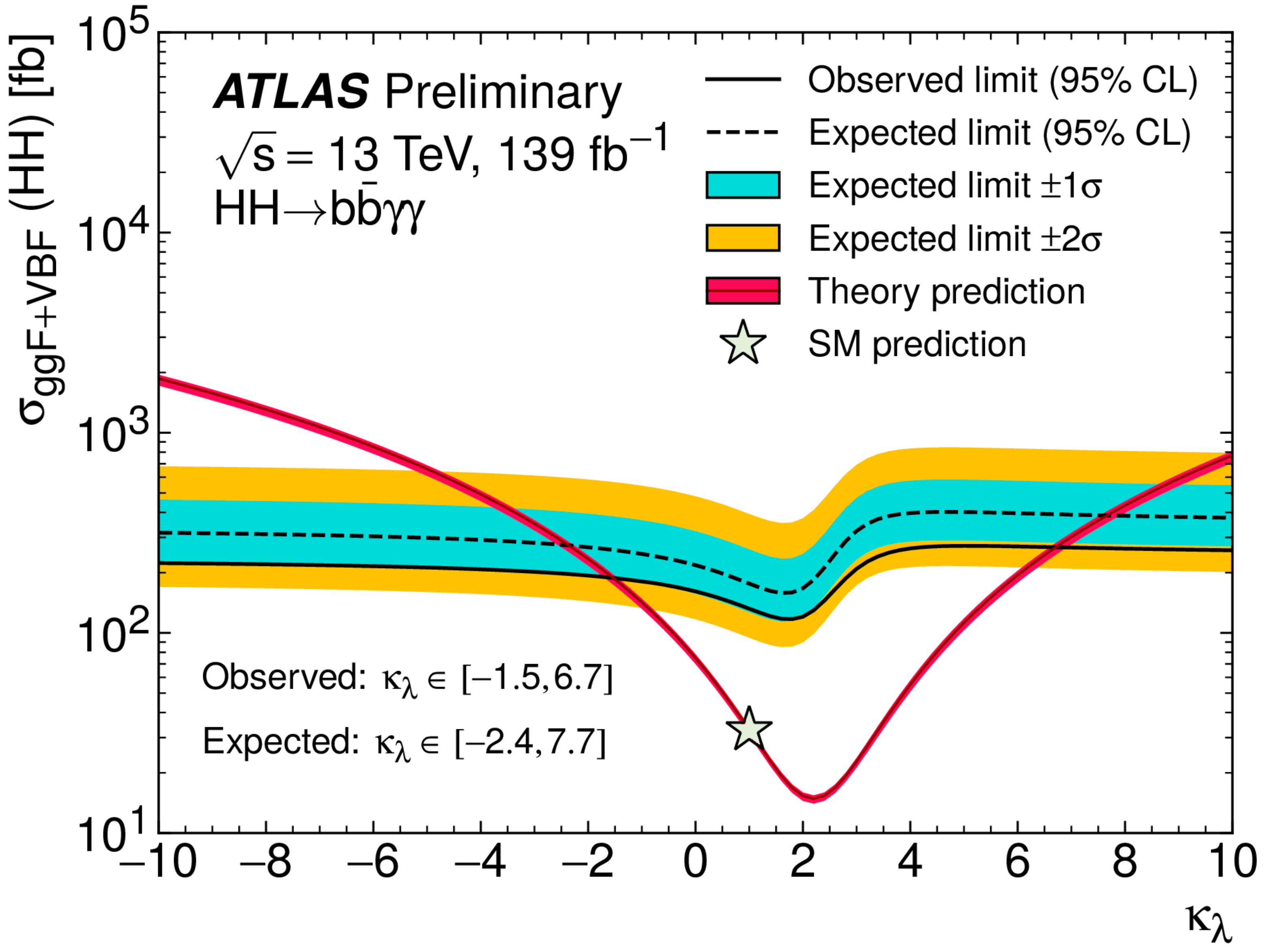
H(bb) H(ττ)
candidate event
ATLAS
EXPERIMENT
Run: 351223
Event: 1338580001
2018-05-26 17:36:20 CEST

Di-Higgs production

ATLAS-CONF-2021-016 ATLAS-CONF-2021-035

$$\mathscr{L}_{SM} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\psi}\not{D}\psi + \psi_i y_{ij}\psi_j\phi + \text{hc} + |D_\mu\phi|^2 - V(\phi)$$

- **HH —> bbγγ**



$\sigma_{HH}/\sigma_{HH}^{SM} < 4.1\ (5.5)$ obs (exp)

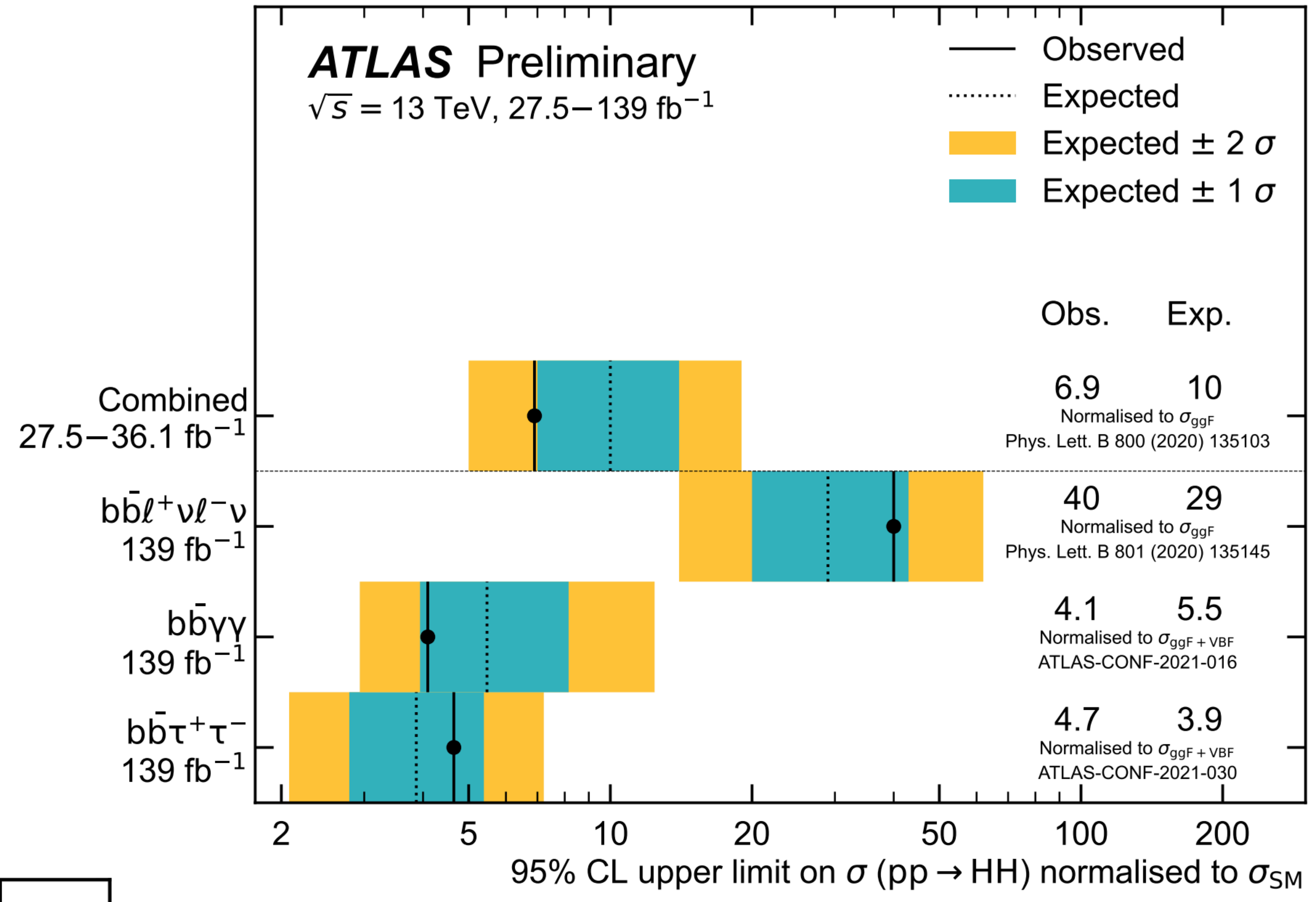
factor of 5 improvement over 36 fb^{-1} analysis

self-coupling modifier κ_λ

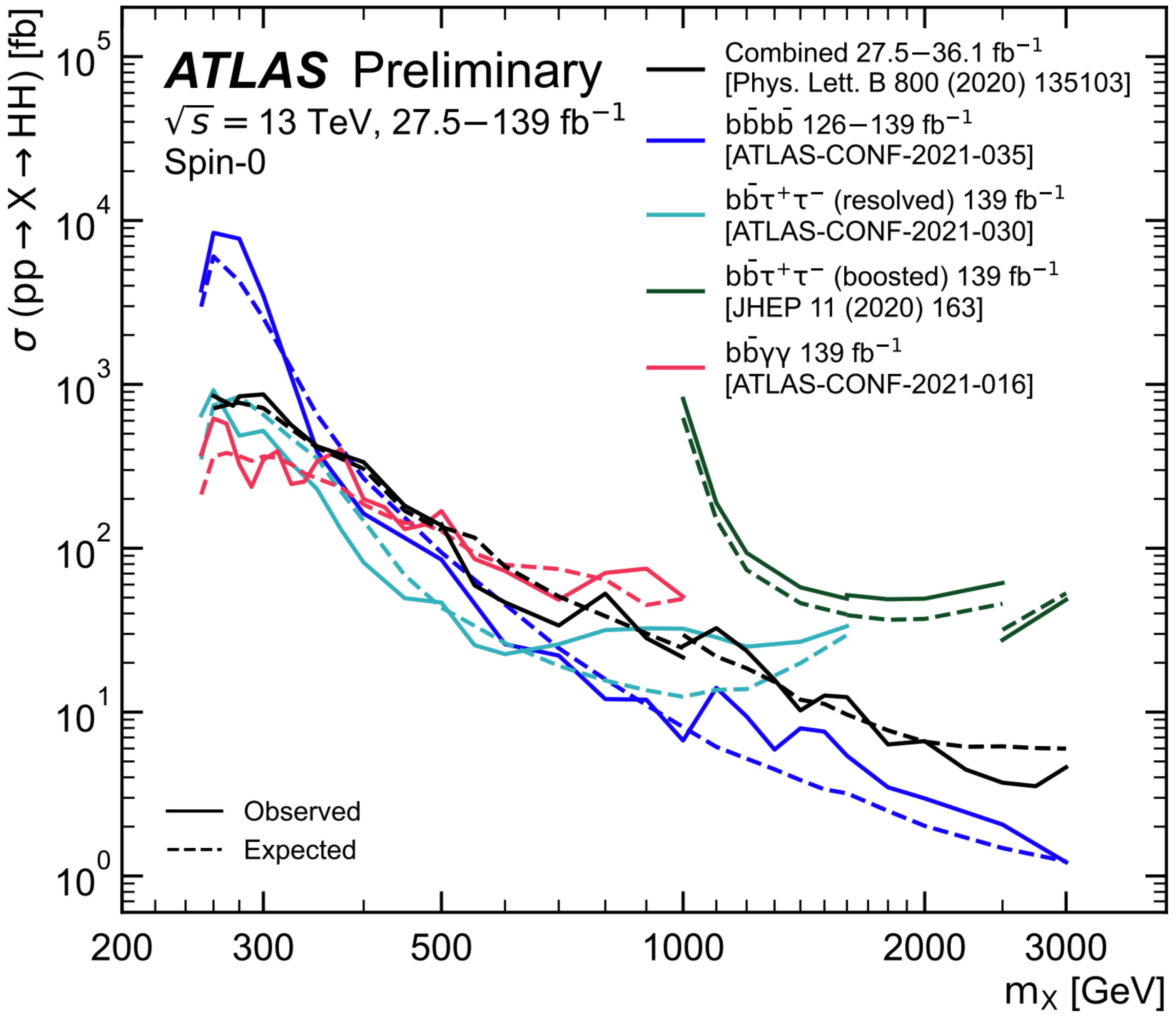
$\lambda_{HH}/\lambda_{HH}^{SM} \in [-1.5, 6.7]$

(exp $[-2.4, 7.7]$)

strongest constraint



- **Search for HH resonances** New
  - HH —> bbbb, bbττ, bbγγ
  - HH —> bbbb with both resolved and merged topologies
    - Data-driven bkg
    - Dominates for m(X) > 700 GeV



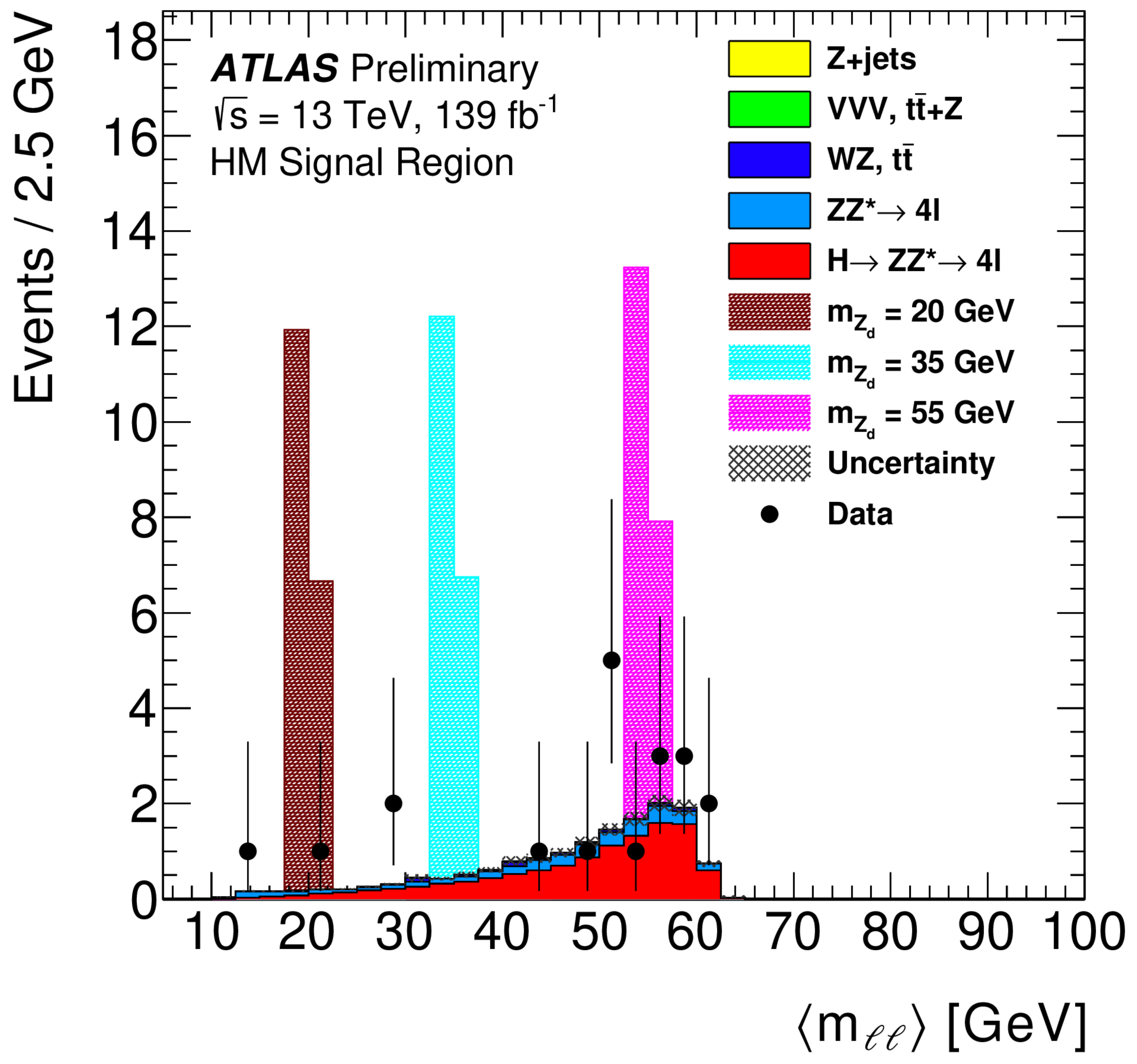
Higgs exotic decays

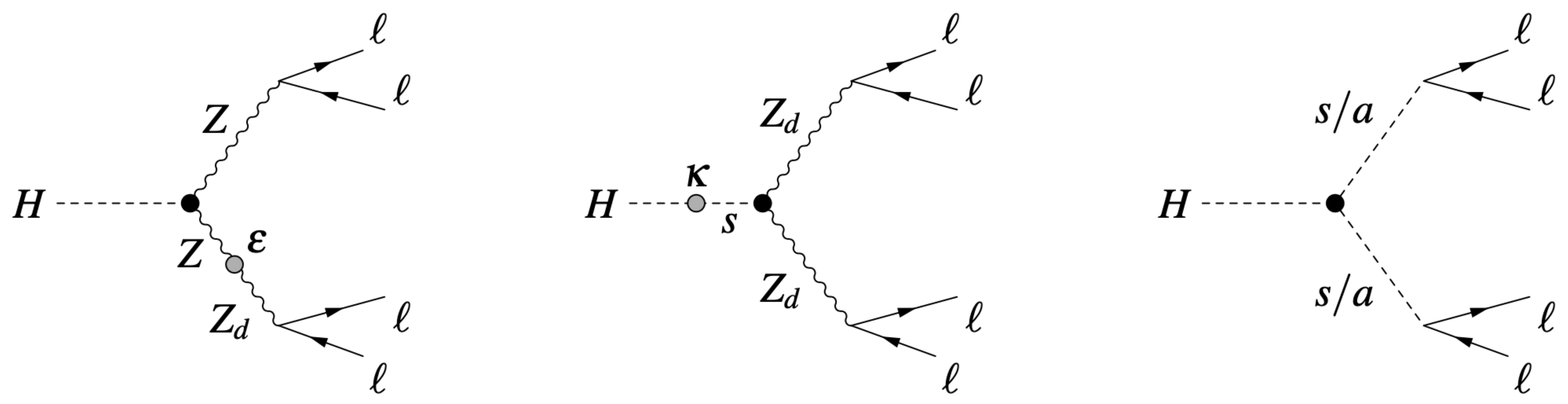
New

ATLAS-CONF-2021-034

$\mathscr{L} = \mathscr{L}_{SM} + \mathscr{L}_{BSM}$

- Combination of Higgs measurements ca. July 2020 ATLAS-CONF-2020-027 imply that B(H —> *undetected*) up to 19% still possible (if $\kappa_{W,Z} \leq 1$)
- Given $\Gamma_H^{SM} = 4$ MeV, even small Higgs coupling to BSM could give measurable branching fraction
- **Dark matter models with scalar/vector portal** include mediator X btw dark/hidden sector and SM —> motivates searches for $H \to XX$ with $X \to \gamma\gamma, gg, ee, \mu\mu, \tau\tau, bb$ (spin 0 or spin 1)



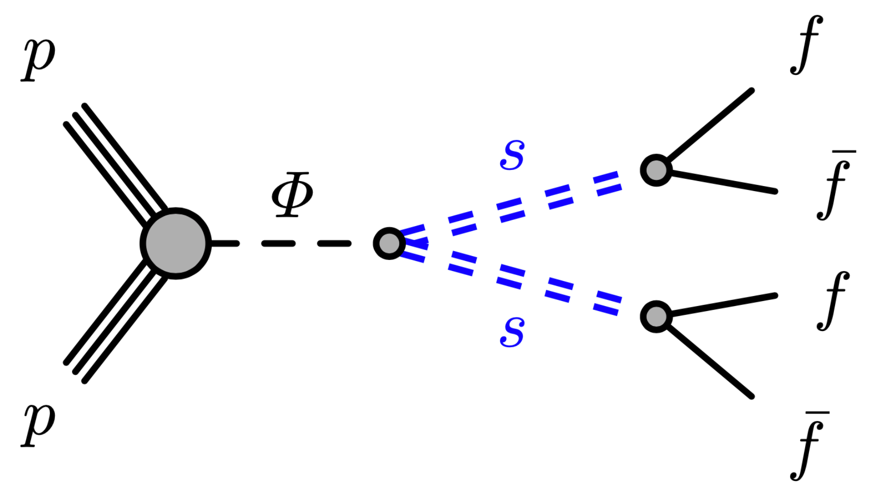


- Search for X in $H \to 4\ell$ with $\ell = e, \mu$
- Exclude $\mathscr{B}(H \to Z_d Z_d)$ as low as 2-8 x 10^{-5}
- Limits also set on other channels and for other interpretations

Higgs / scalar exotic decays

ATLAS-CONF-2021-032

- **Higgs portal** / Hidden sector models predict exotic Higgs decays to LLP (*s*)

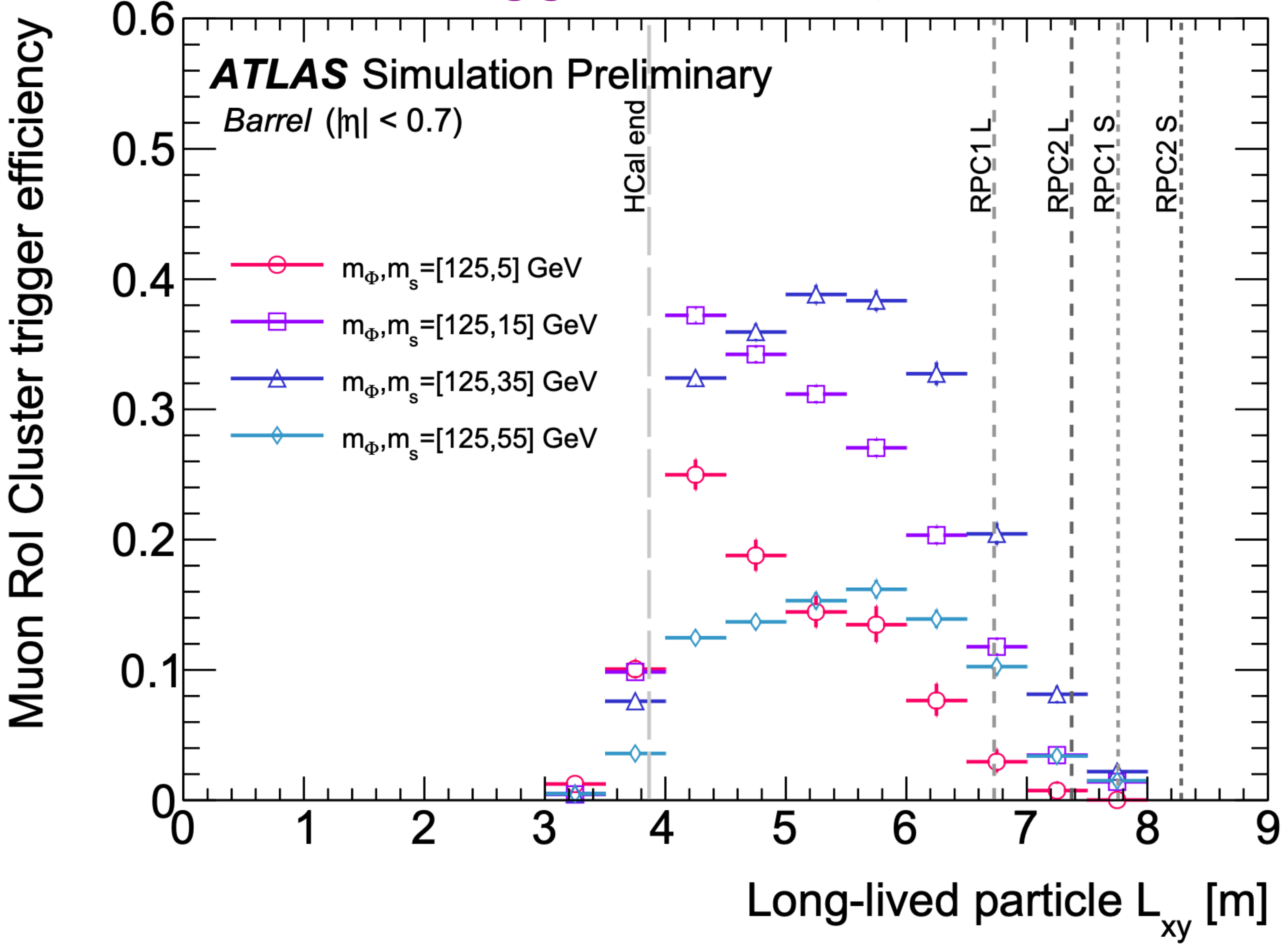


$\mathscr{L} = \mathscr{L}_{SM} + \boxed{\mathscr{L}_{BSM}}$

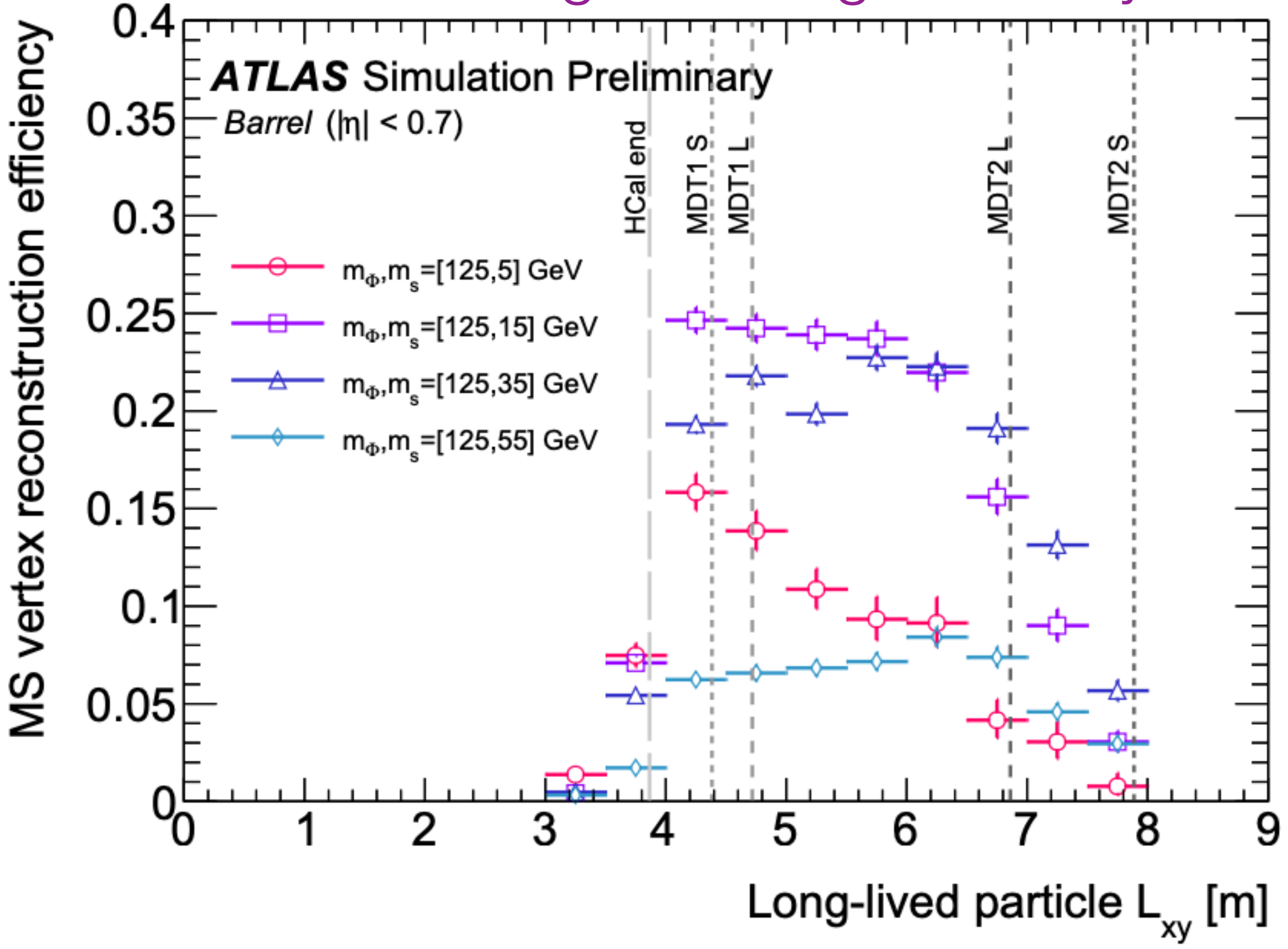
- Dedicated muon spectrometer (MS) multi-RoI trigger + track segment and vtx reconstruction in barrel & endcap MS
- Background from punch-through jets suppressed with track & calo isolation
- Remaining backgrounds estimated using zero-bias trigger data
- Require 2 DVs: 0 events observed w/ 0.32 +/- 0.05 expected bkg

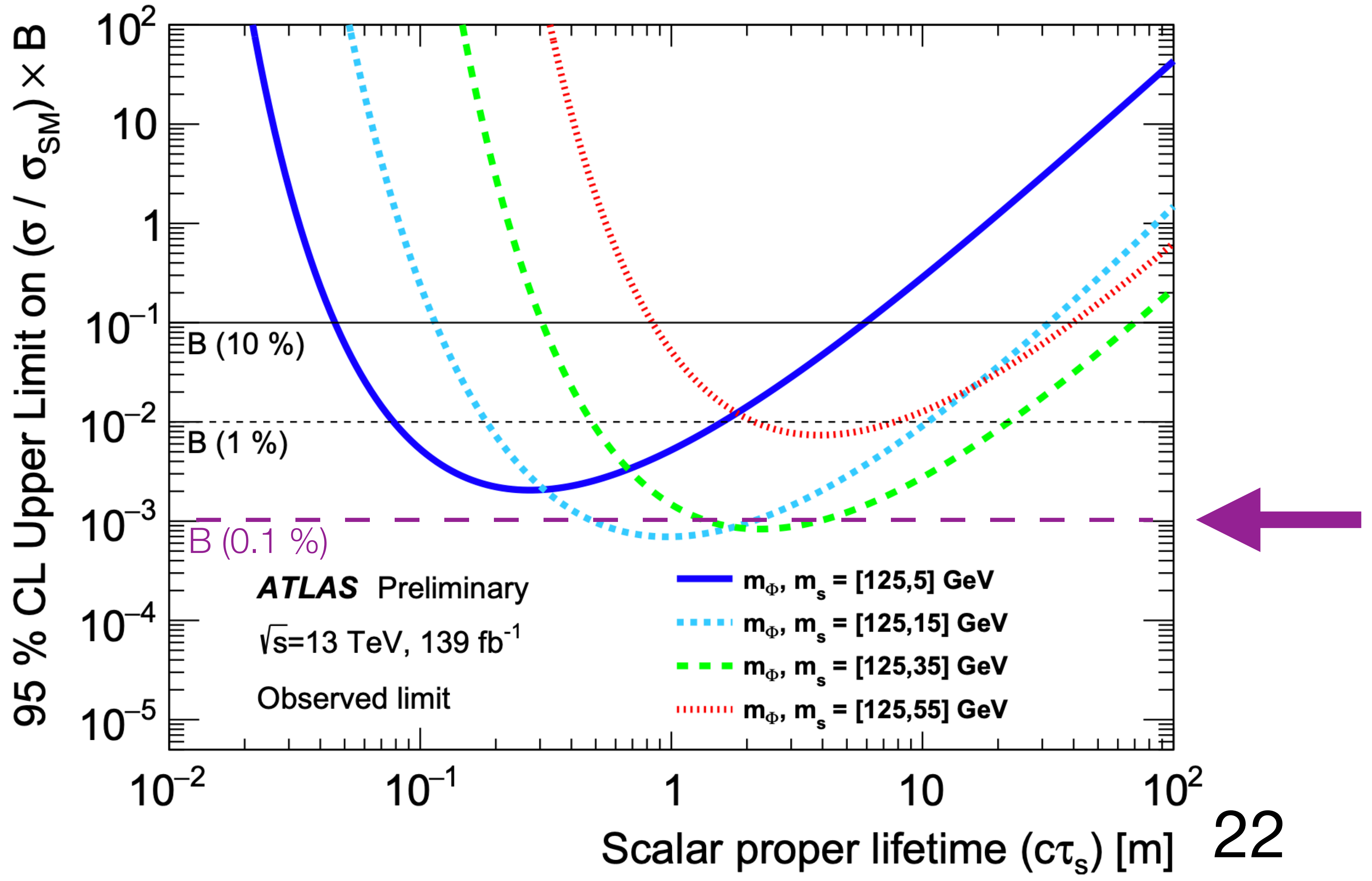
BF(Φ(125)—>*ss*) =10%
excluded for cτ(*s*) in range
4 cm — 7.8 m
for m(s) = 5 GeV

trigger efficiency



tracking/vertexing efficiency





Heavy particle searches

New

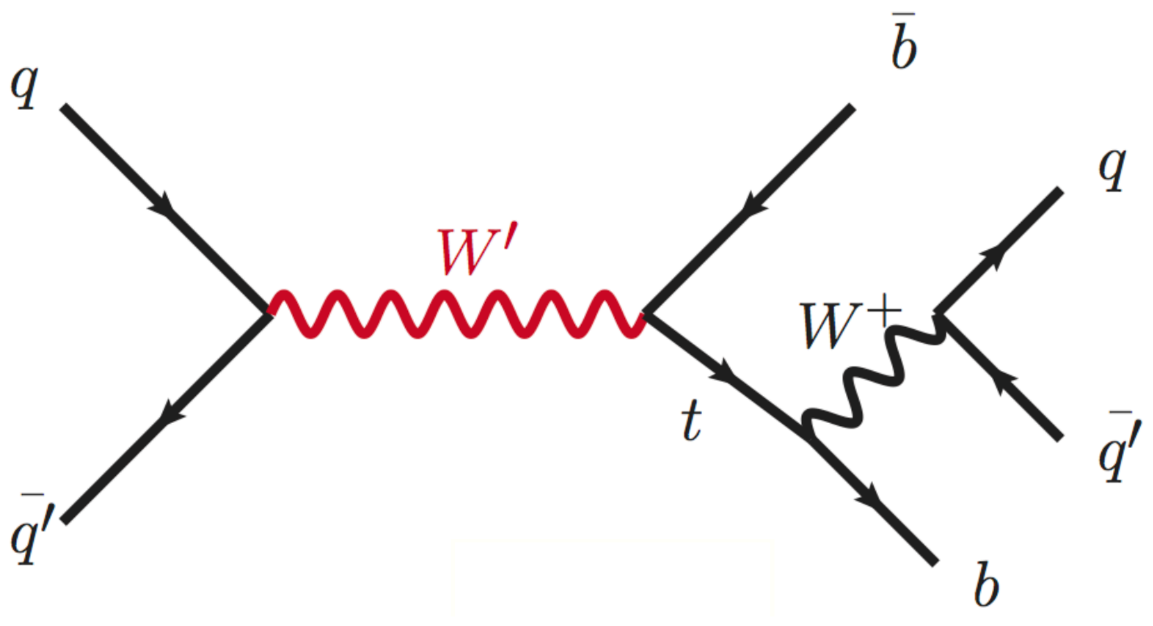
ATLAS-CONF-2021-043 ATLAS-CONF-2021-040

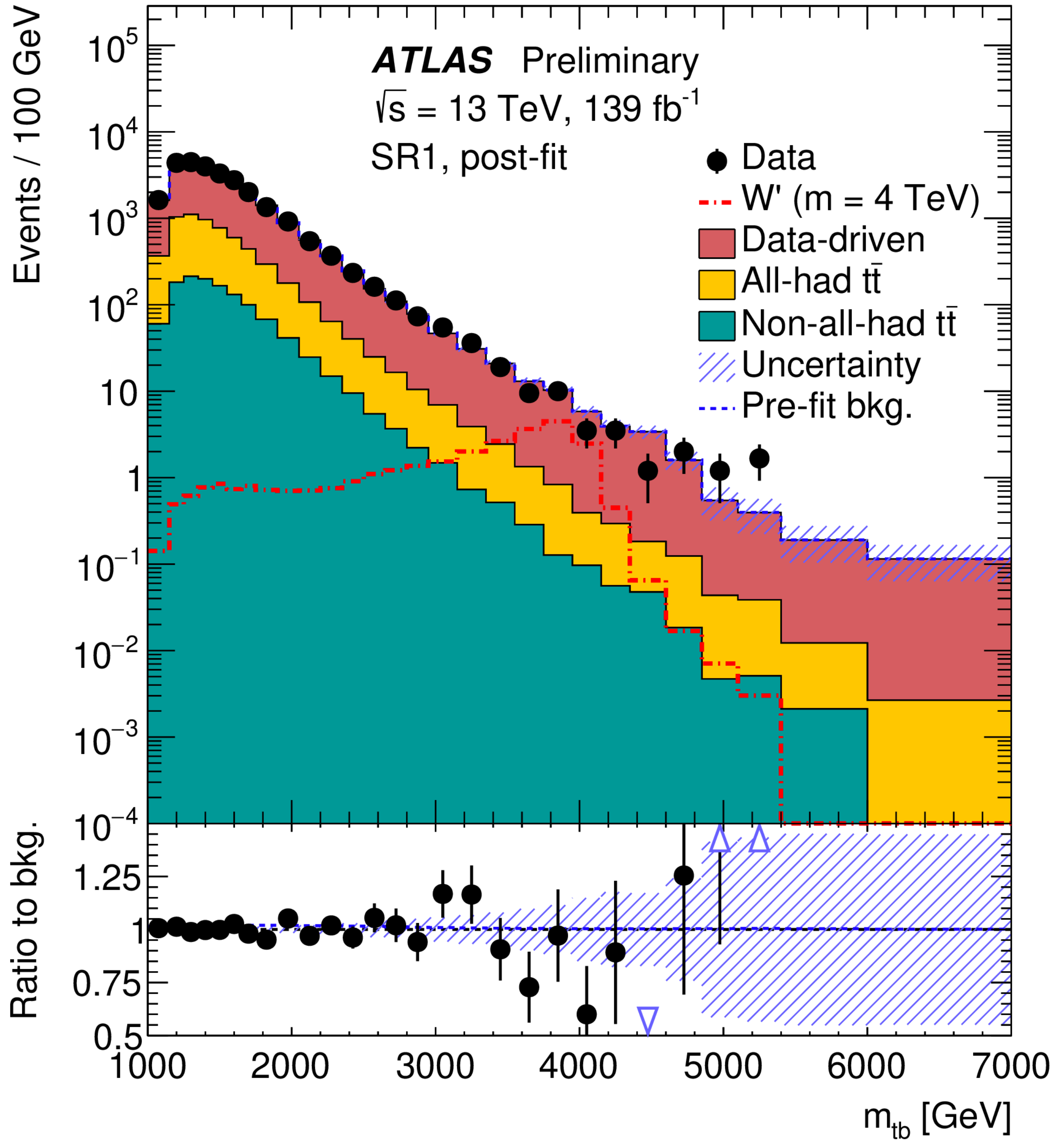
ATLAS EXPERIMENT

$\mathscr{L} = \mathscr{L}_{SM} + \mathscr{L}_{BSM}$

- Motivated by hierarchy problem —> new physics at TeV scale

- **Heavy gauge boson** with right-handed couplings
  - Top-tagged large-R jet + b-tagged small-R jet
  - Deep NN top tagger using jet substructure
  - Discriminant: m_{tb}



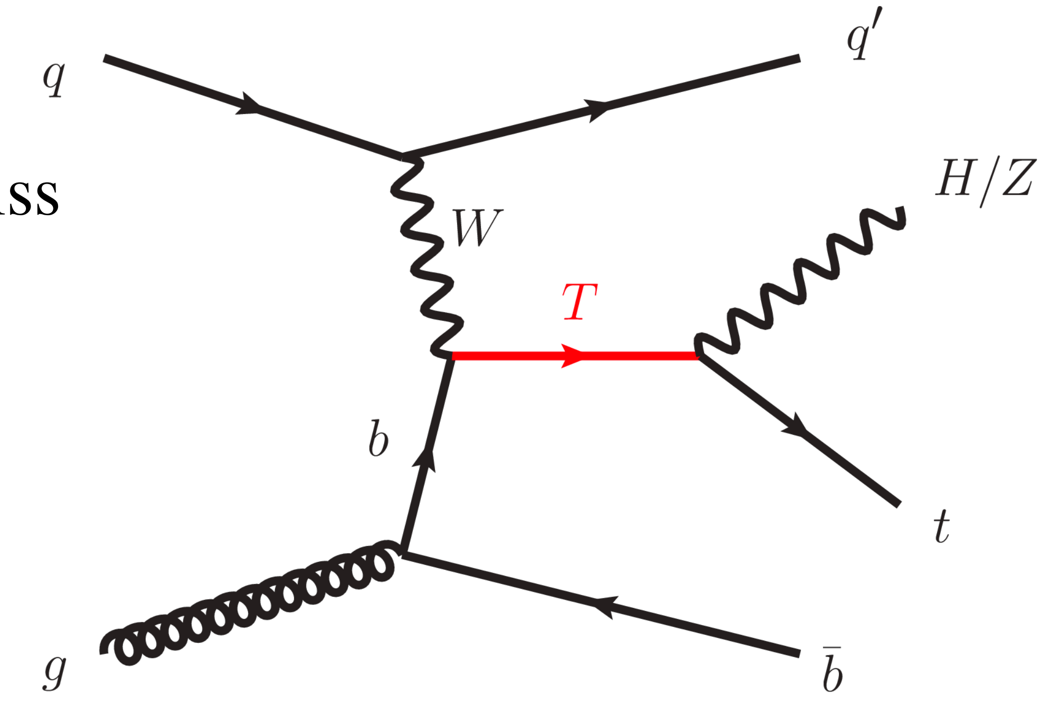


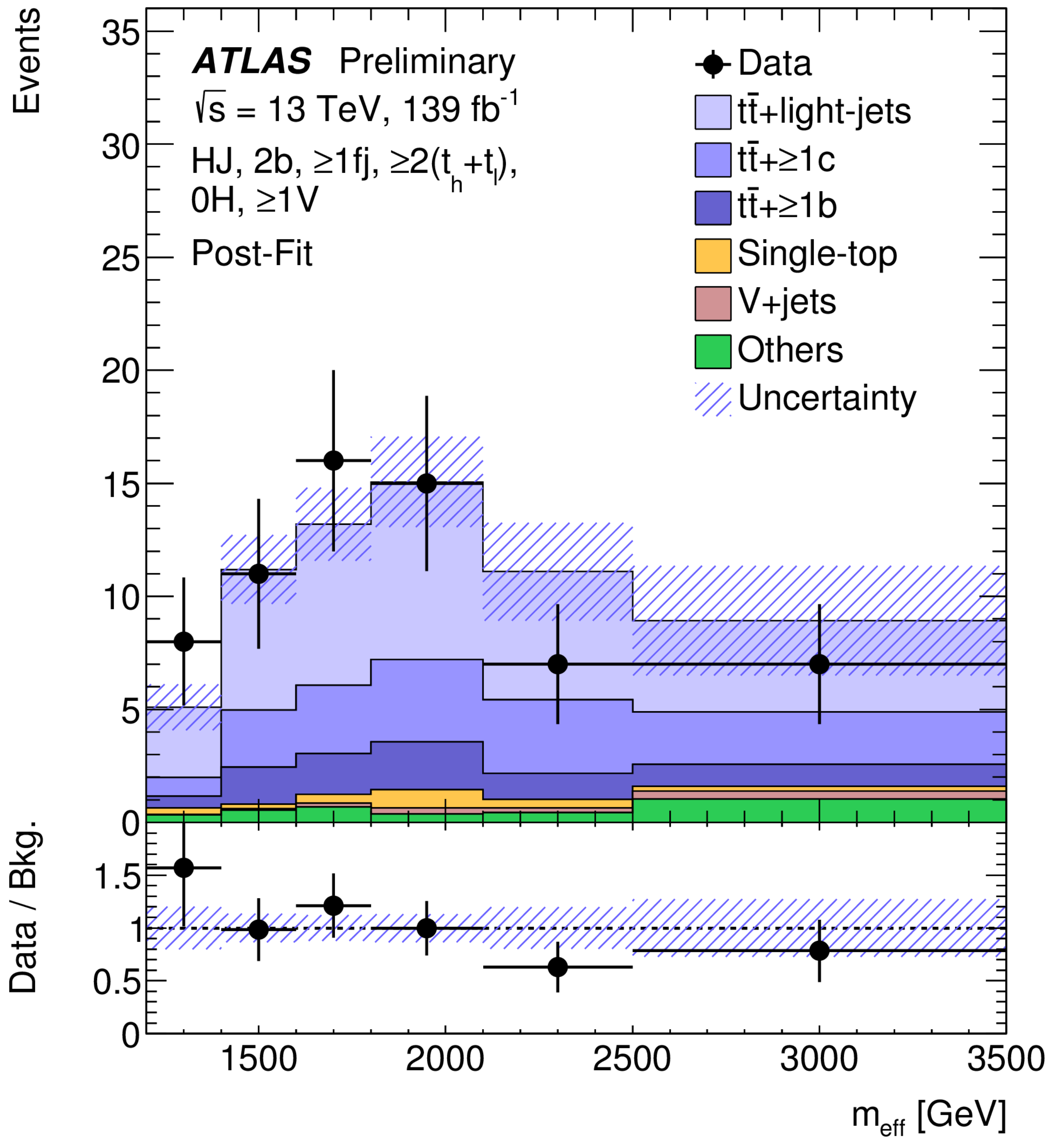
$m(W'_R) > 4.4\,\text{TeV}\ (4.1\,\text{TeV})$

obs (exp)

lower limit improves upon best previous limit by 1 TeV

- **Vector-like top quark** (single production)
  - e/μ + Z/H-tagged large-R jet + small-R jets (some b-tagged)
  - Discr.: $m_{\text{eff}} = \sum_i p_{T_i} + E_T^{\text{miss}}$





$m(T) > 1.8\,\text{TeV}\ (1.5\,\text{TeV})$

obs (exp)

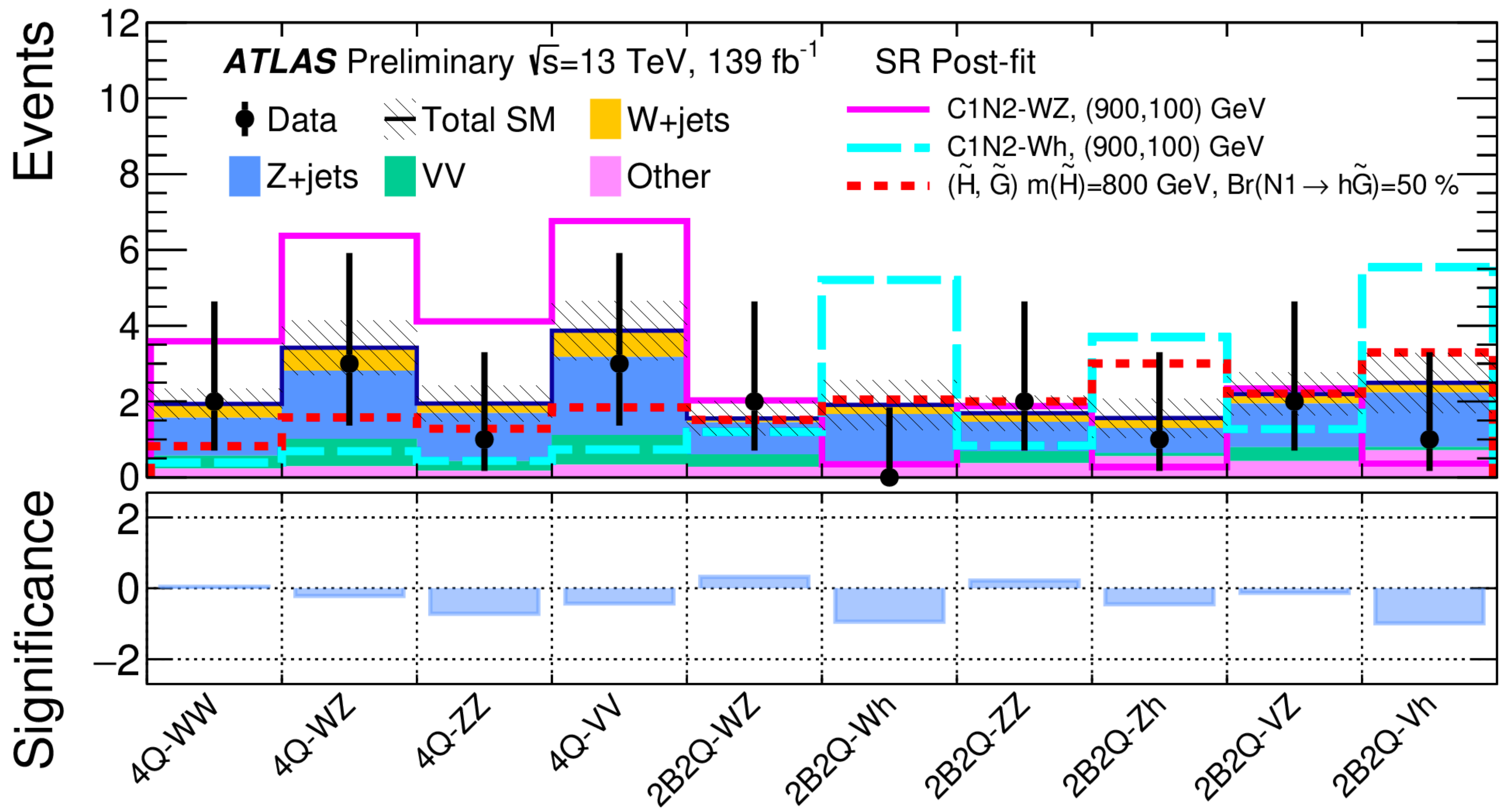
for coupling $\kappa \geq 0.5$

SUSY: Electroweak production

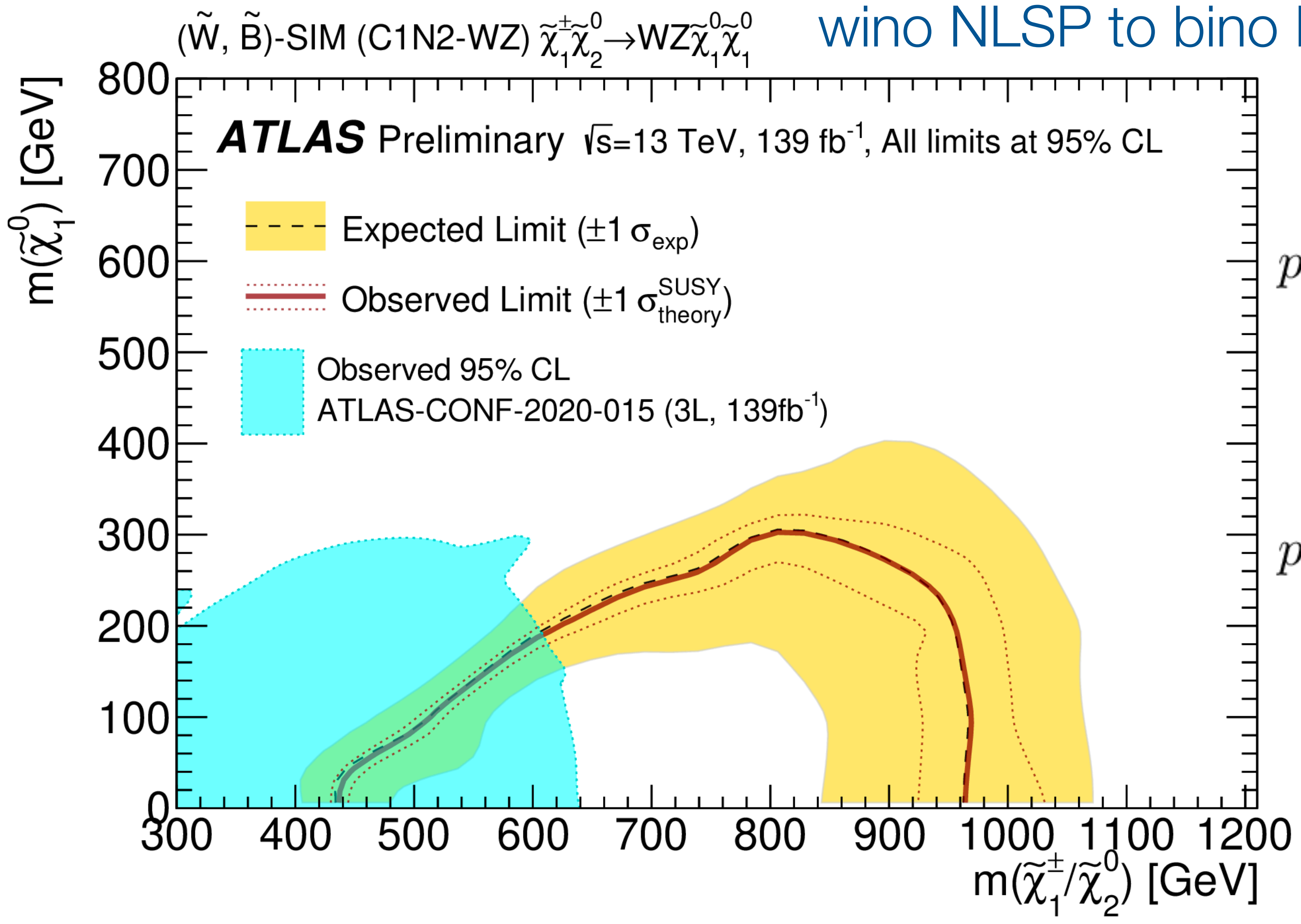
ATLAS-CONF-2021-022

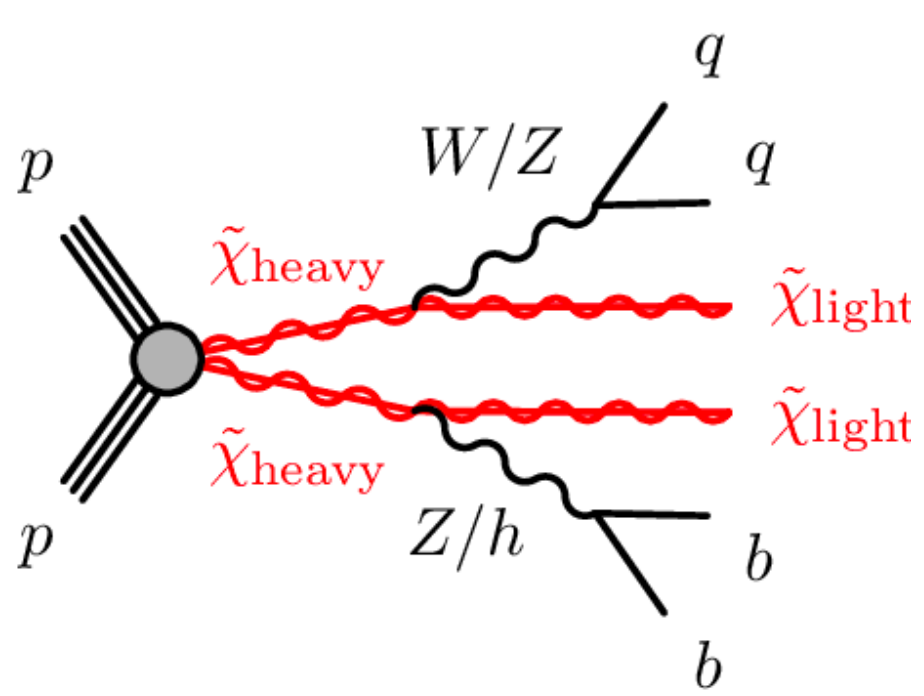
$\mathscr{L} = \mathscr{L}_{SM} + \mathscr{L}_{SUSY}$

- **Electroweakinos** with mass ~0.1—1 TeV well motivated:
  - Neutralino LSP as dark matter, naturalness problem, muon g-2 anomaly
- Target mass splitting between NLSP and LSP > 400 GeV
- *First SUSY EW search* with fully hadronic final state using large-R jets tagged as W/Z or H jets
- Strongest limits at high electroweakino mass

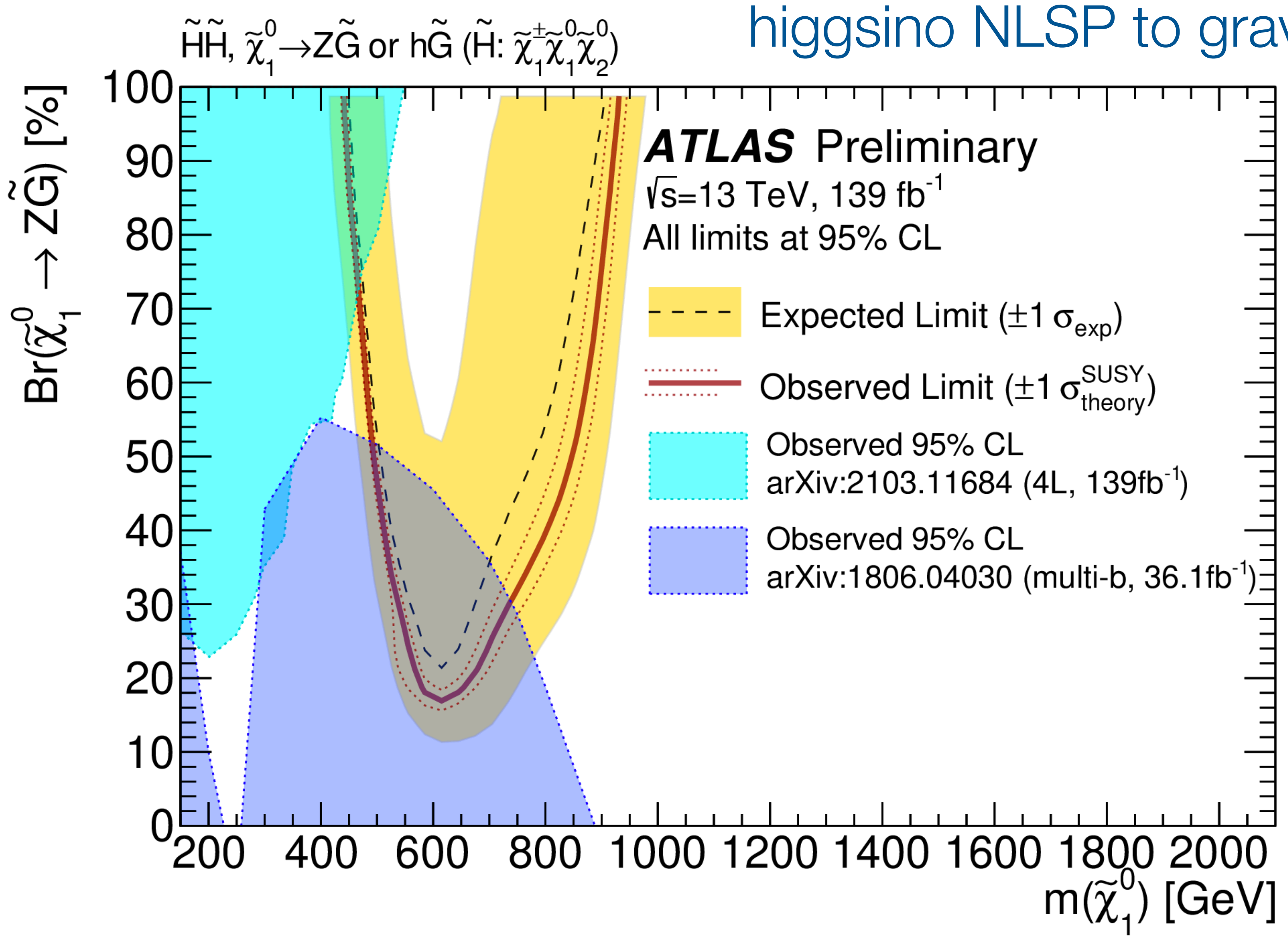


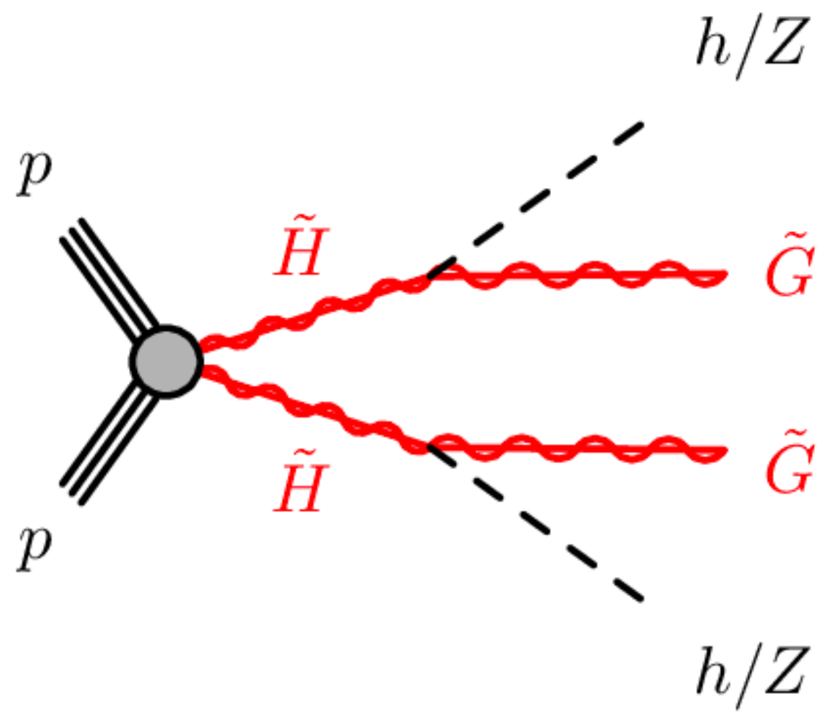
wino NLSP to bino LSP





higgsino NLSP to gravitino LSP

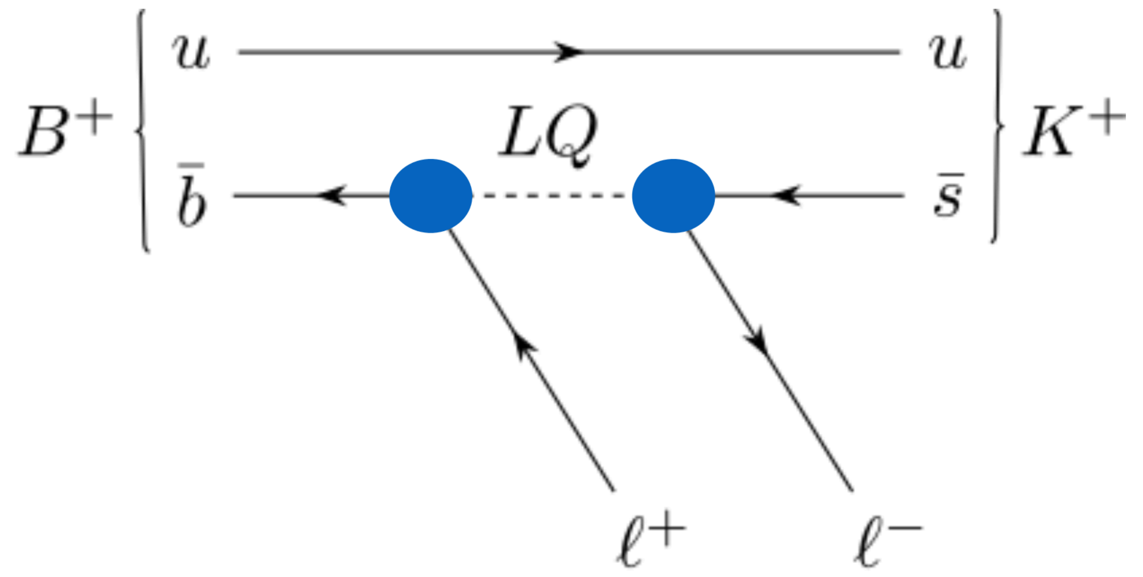


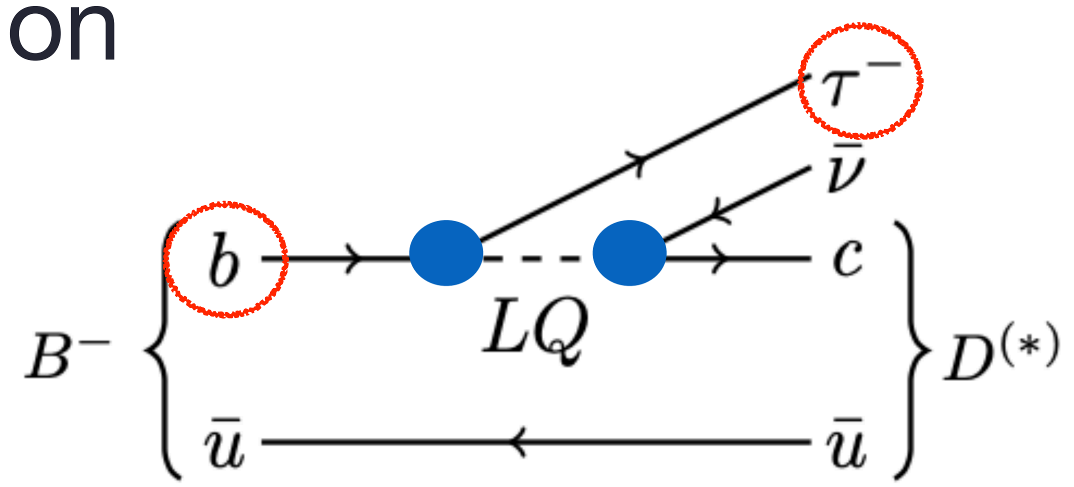


Flavor anomalies

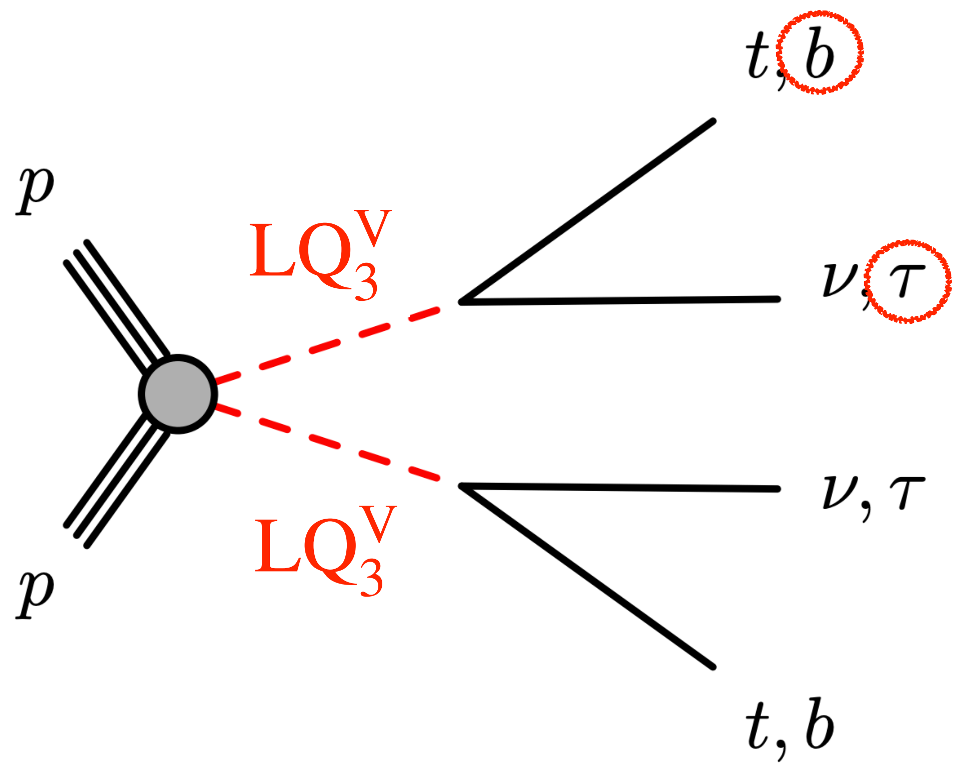
(diagrams by LHCb and D.Zanzi)

- Recent results from B decays indicate deviations from lepton-flavor universality
  - $R(K^{(*)}) = \dfrac{\mathscr{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathscr{B}(B \to K^{(*)}e^+e^-)}$ and $R(D^{(*)}) = \dfrac{\mathscr{B}(B \to D^{(*)}\tau\nu)}{\mathscr{B}(B \to D^{(*)}\ell\nu)}$ (with $\ell = e, \mu$) both disagree w/ SM at ~3σ
  - Vector leptoquarks a potential explanation

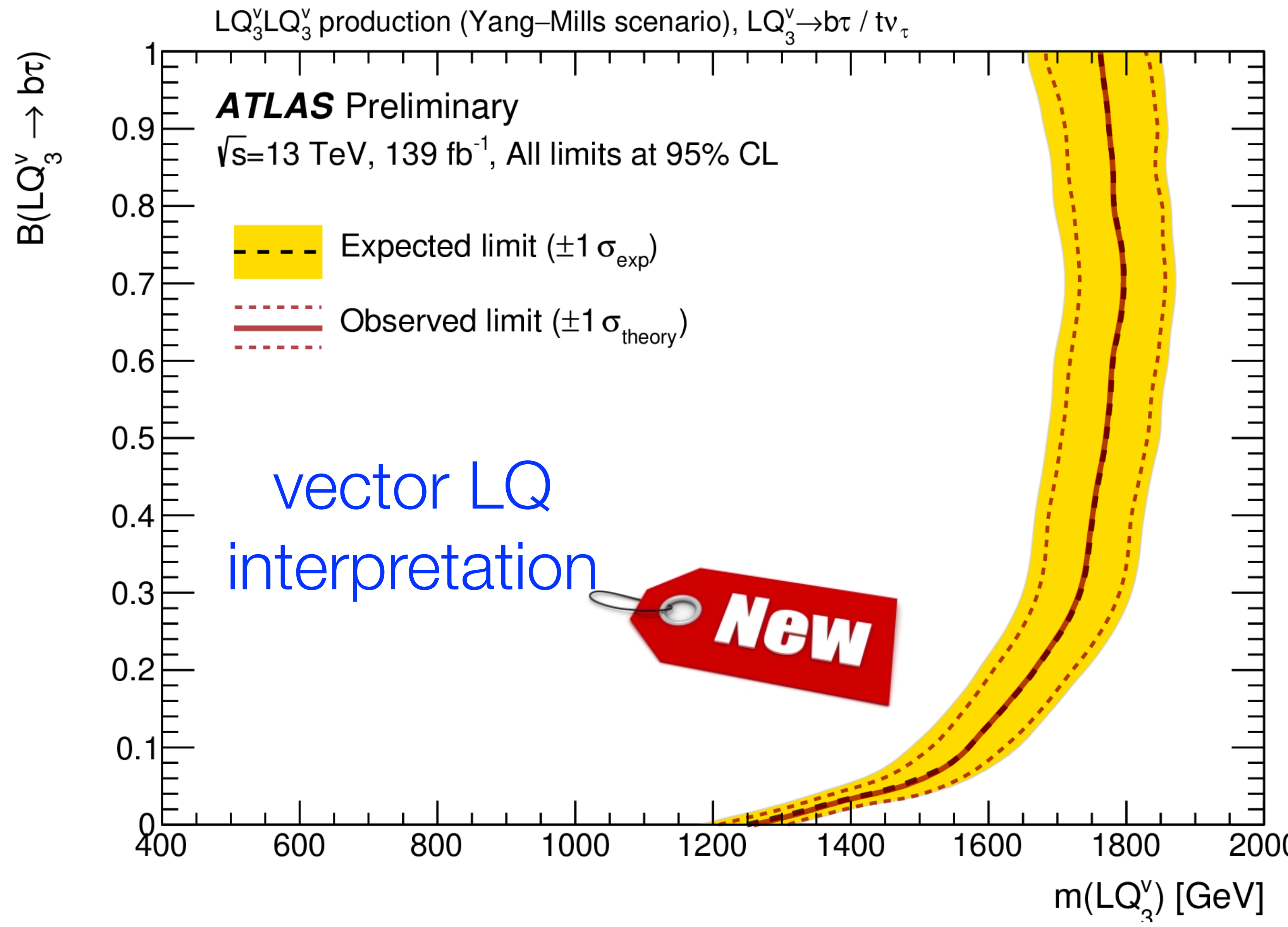




- **Search for LQ pair production*** (other relevant searches not covered here)
  - Trigger on E_T^{miss} + require offline E_T^{miss} > 280 GeV, 1 τ_{had}, ≥ 2 b-tagged jets
  - Main bkg: $t\bar{t}$ and single top from CRs
  - $m(LQ_3^V) > 1.8$ TeV for $\mathscr{B}(LQ_3^V \to b\tau) \sim 0.5$
  - Addresses $R(D^{(*)})$ anomaly at ~expected scale



ATLAS-CONF-2021-008



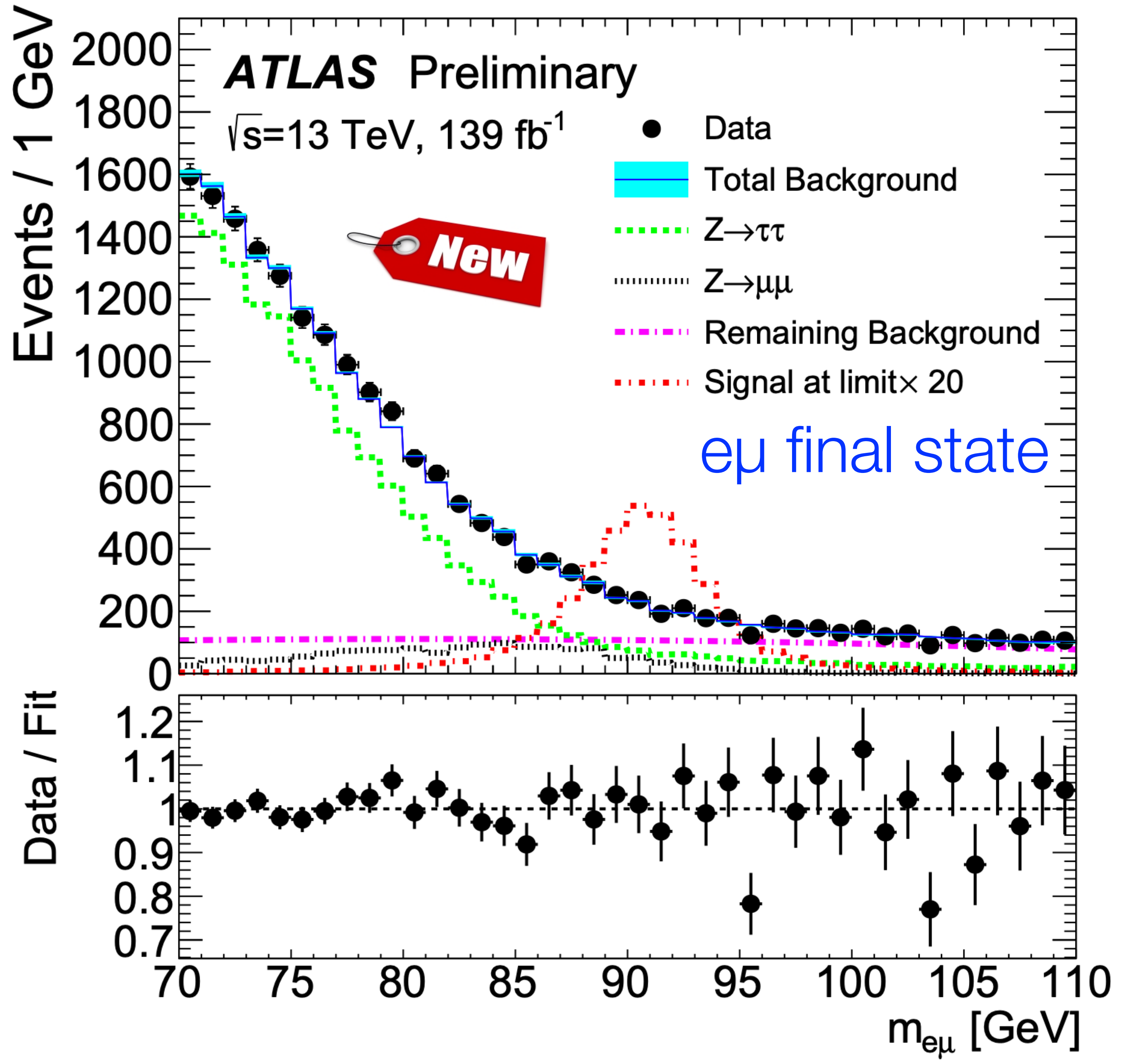
* search also targeting SUSY stop to stau production

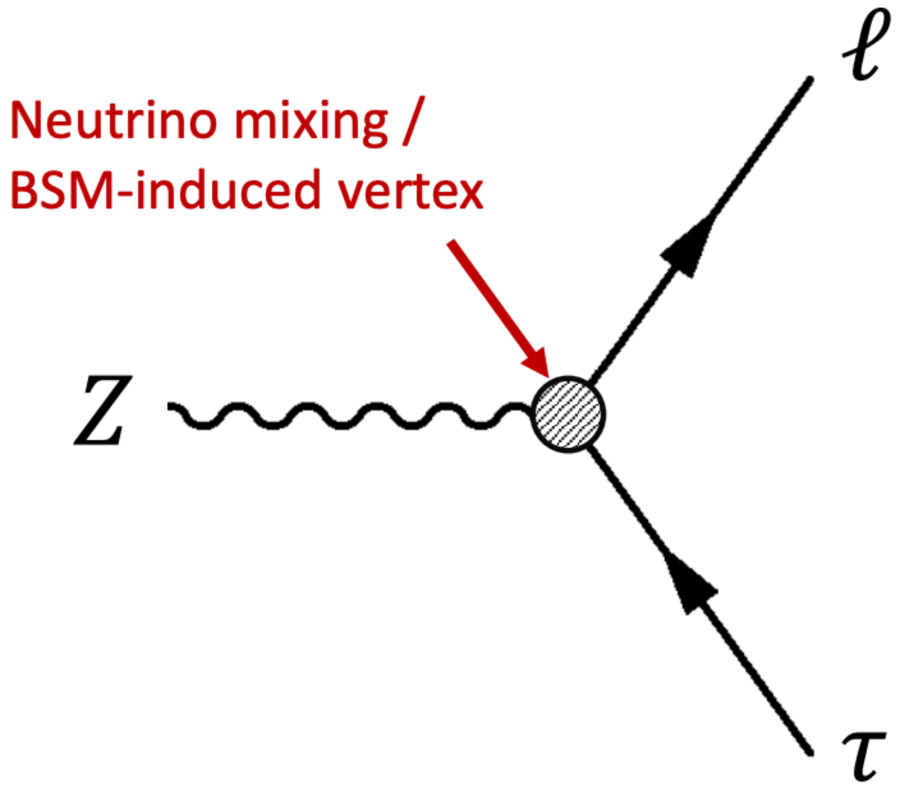
Lepton flavor violation

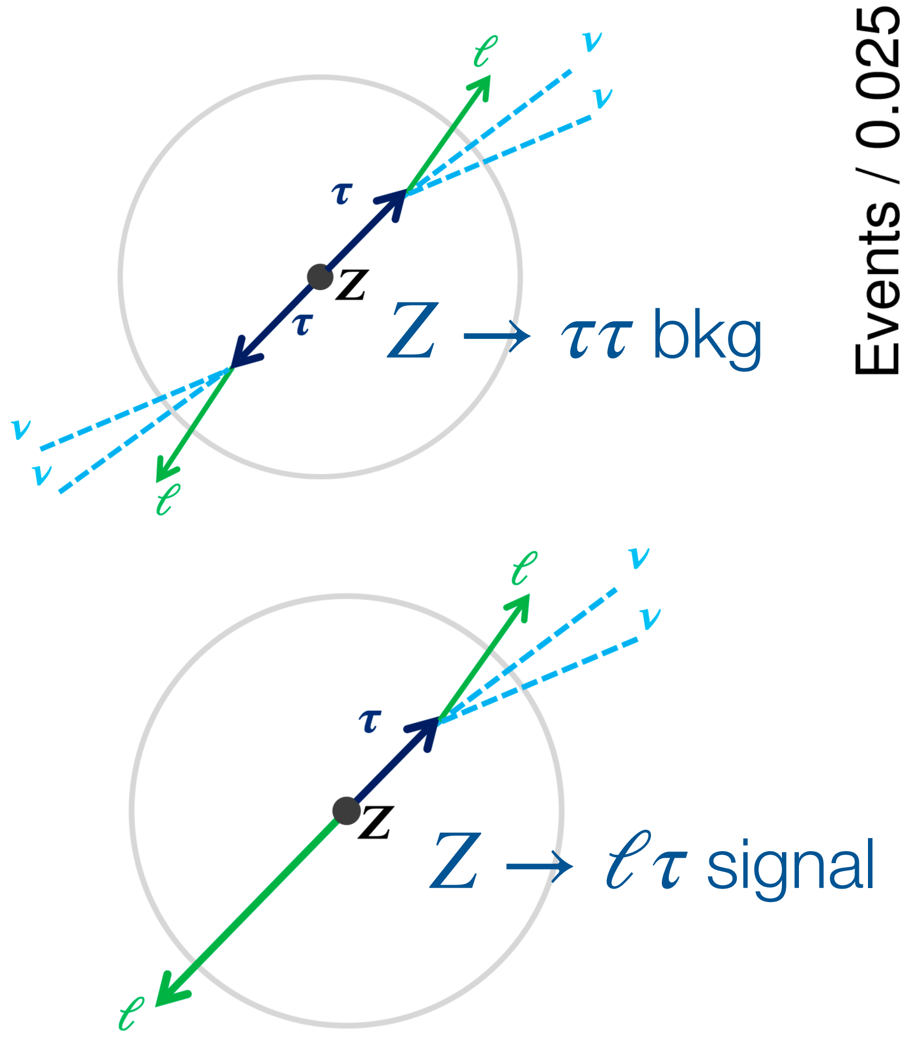
ATLAS-CONF-2021-042 arXiv:2105.12491

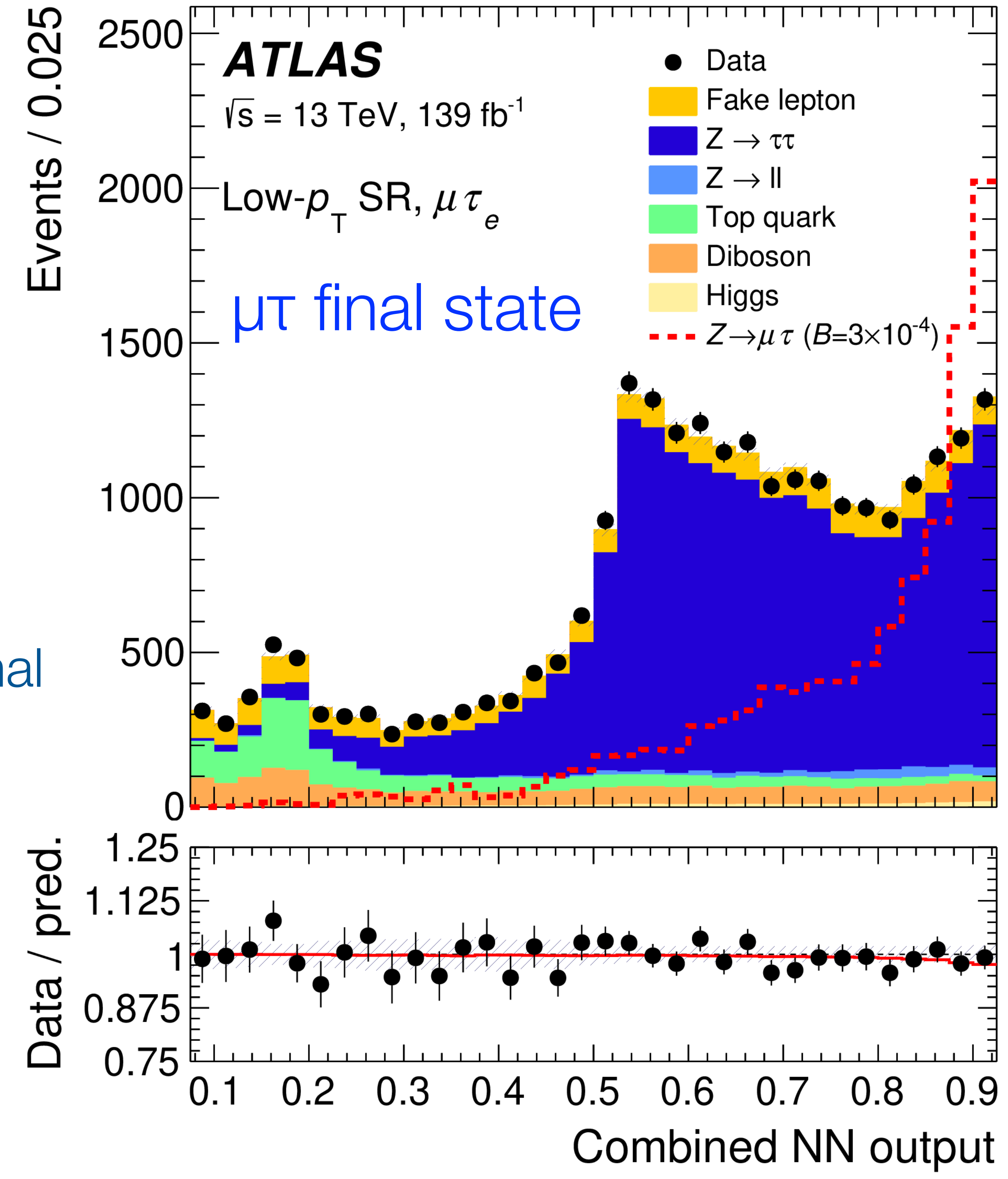
$\mathscr{L} = \mathscr{L}_{SM} + \mathscr{L}_{BSM}$

- Run 2: ~8 x 10⁹ Z bosons produced
- Lepton flavor violation only observed in neutrino oscillations, ~negligible for $\ell^{\pm}$ in SM
- Z —> e μ search based on $m_{\ell\ell'}$ w/ reduced uncert. normalizing to Z—>ee, μμ
- Z —> e τ, μ τ search w/ NNs to suppress $Z \to \tau\tau$, $t\bar{t}$, VV & $W \to \ell\nu$ + jets bkg







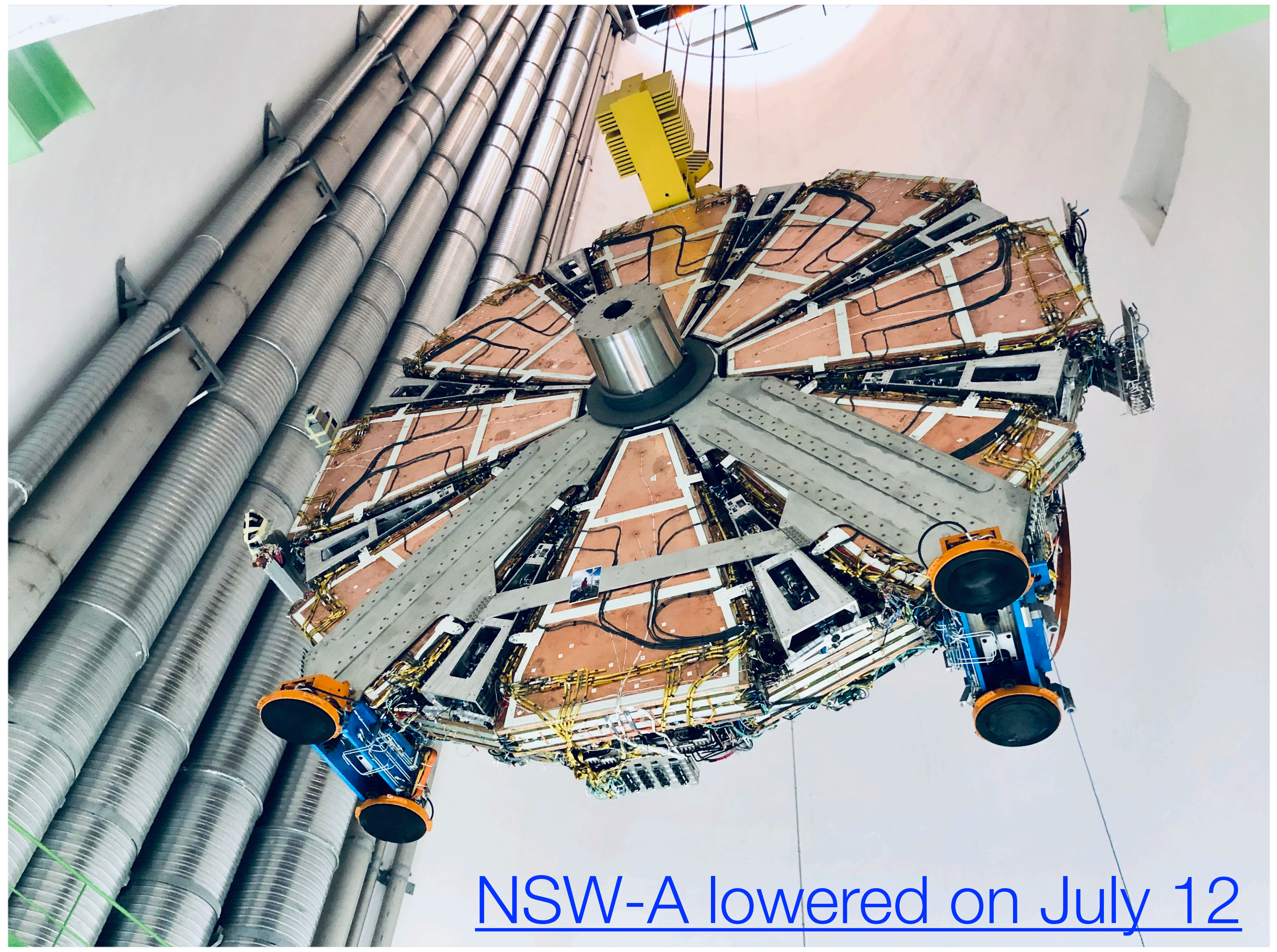


- LEP limits surpassed by factors of 5 ($Z \to e\mu$) and 2 ($Z \to e\tau, \mu\tau$)

Upper limits at 95% CL	ATLAS	LEP
B(Z —> e μ)	0.34 × 10^{-6}	1.7 × 10^{-6} (OPAL)
B(Z —> e τ)	5.0 × 10^{-6}	9.8 × 10^{-6} (OPAL)
B(Z —> μ τ)	6.5 × 10^{-6}	12 × 10^{-6} (DELPHI)

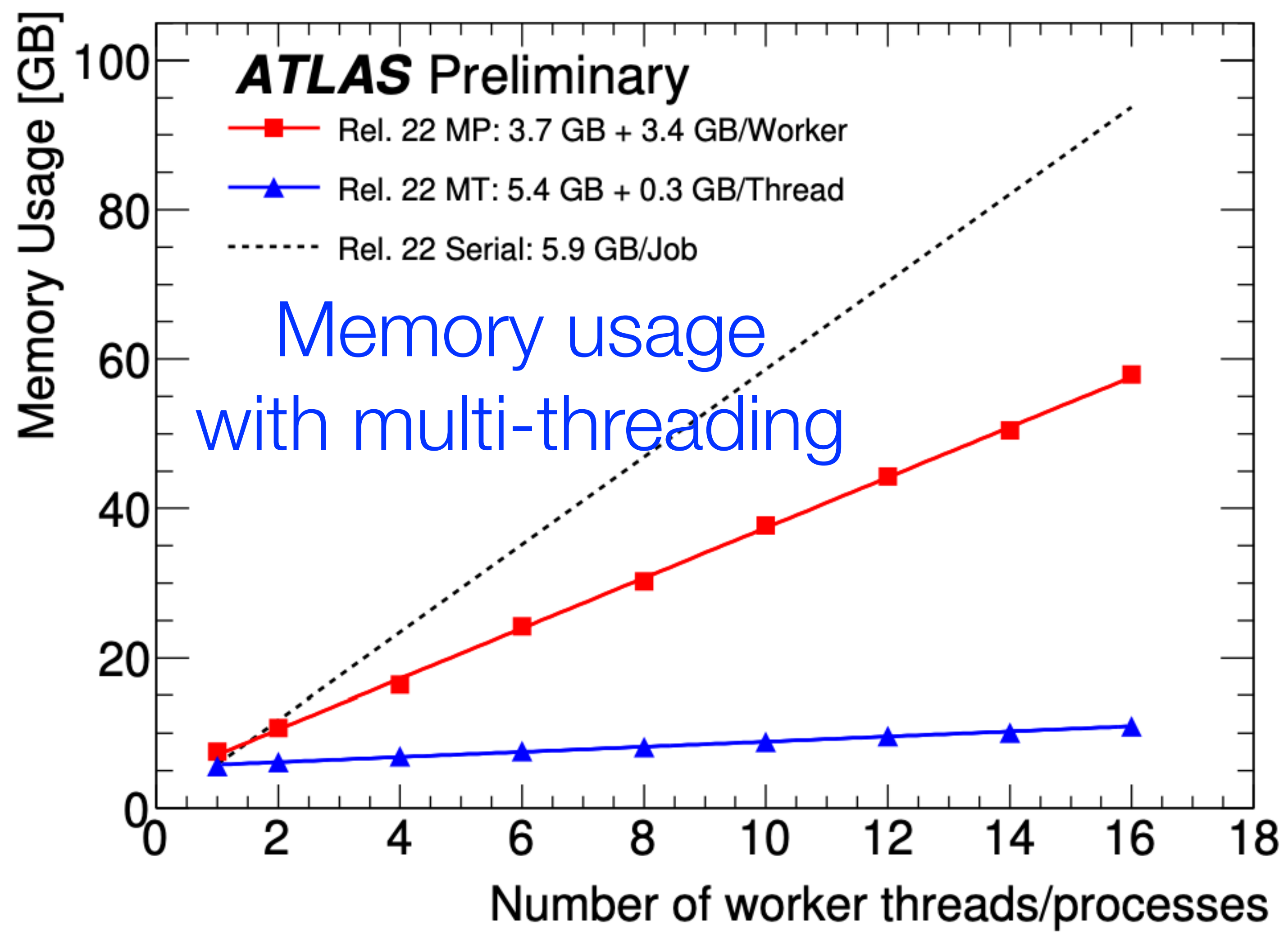
Run 3

- Preparations ongoing w/ maintenance and multiple improvements to trigger, detector, and computing systems, as well as software
- **New for Run 3:**
  - L1Calo, L1Muon, and L1Topo trigger
  - Increased availability of tracking at HLT
  - New Small Wheel (NSW) for the muon spectrometer
  - AFP with time-of-flight
  - Increased performance of software algorithms

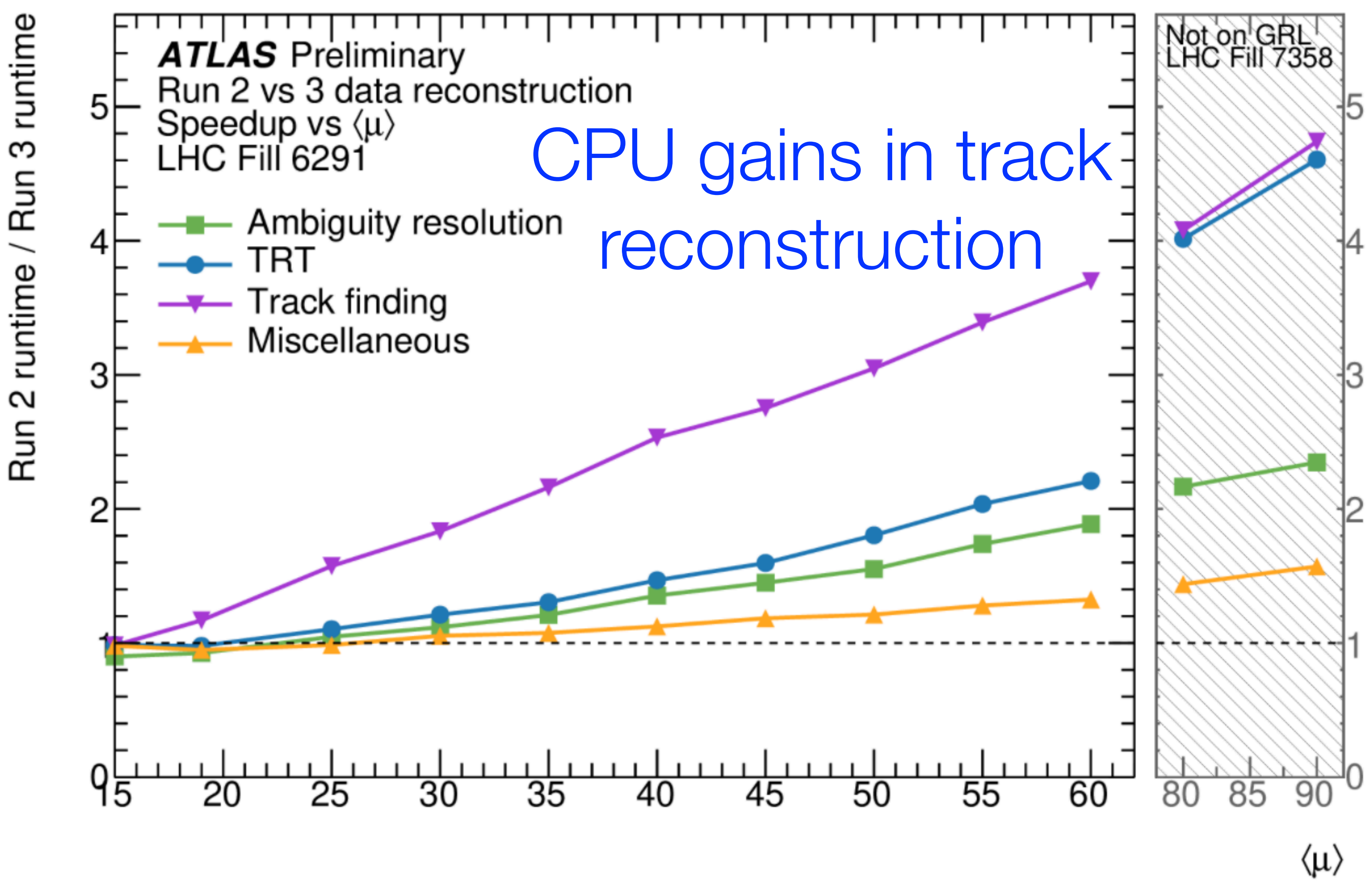


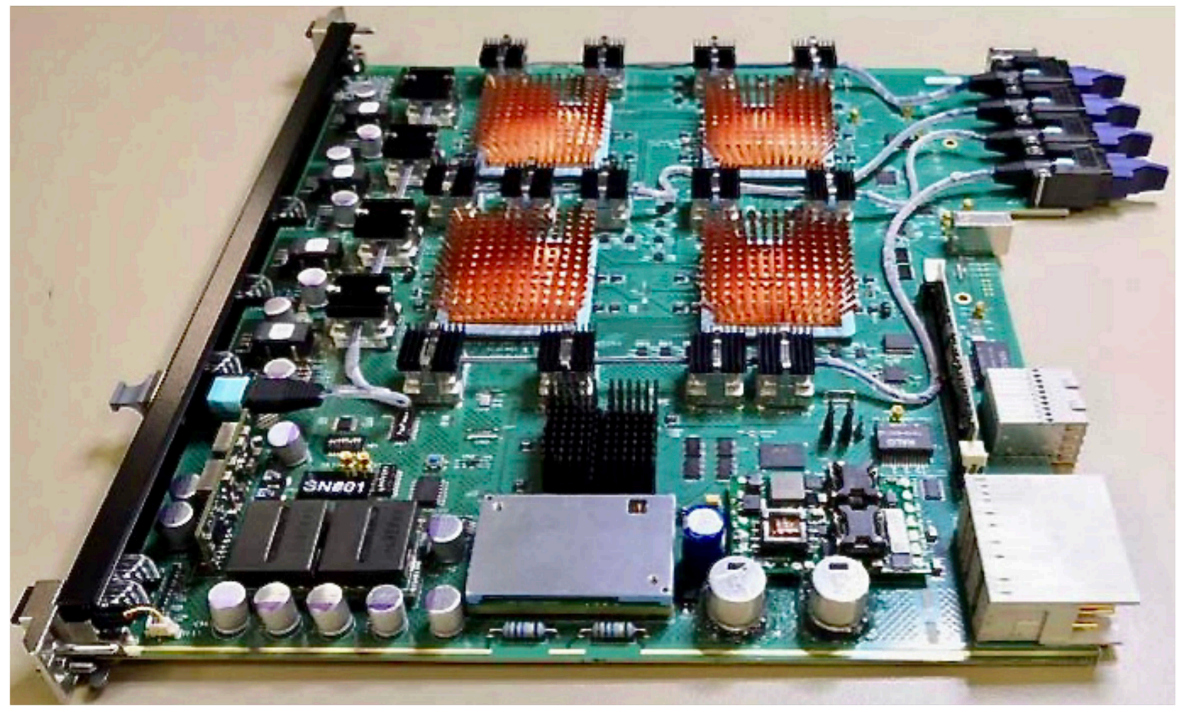
NSW-A lowered on July 12

ATL-SOFT-PUB-2021-002



ATL-PHYS-PUB-2021-012





electron trigger feature extraction

Conclusion

- **Vibrant ATLAS physics program** continues to exploit the Run 2 data gold mine
  - 26 new results released for EPS-HEP
  - Precision measurements
    - Deeper tests of the SM, including more extreme phase space
    - Important to keep improving event generators with higher-order effects
    - Progress toward more global approaches, esp. global EFT fits
  - Observation/study of rare processes
    - Large dataset to explore rare processes: tttt (4.7σ), WWW (8.2σ), or HH prod. $(\sigma_{HH}/\sigma_{HH}^{SM} < 4.1)$
  - Searches at high-energy and low-coupling frontiers
    - Broad net deployed, incl. more difficult areas like compressed scenarios or LLP
- **Preparations for Run 3 underway**
  - Looking forward to extend physics reach beyond Run 2
- **Very significant effort on Phase-II upgrade for high-luminosity LHC**
  - Moving to (pre)production

New ATLAS results released for EPS-HEP 2021

ATLAS EXPERIMENT

Topic	Reference	Topic	Reference
Bc —> J/psi Ds(*)	ATLAS-CONF-2021-046	LFV Z —> eμ	ATLAS-CONF-2021-042
b-quark fragment. in B^+ —> J/ψ K^+	CERN-EP-2021-123	eμ charge asymmetry	ATLAS-CONF-2021-045
collinear Z + jets	ATLAS-CONF-2021-033	dark matter in Z(ll) + ETmiss	ATLAS-CONF-2021-029
diphoton cross section	arXiv:2107.09330	dark matter combination 2HDM+a	ATLAS-CONF-2021-036
EFT analysis of WW, WZ, ZZ, VBF Z	ATL-PHYS-PUB-2021-022	SUSY in photon + jets + ETmiss	ATLAS-CONF-2021-028
VBS Z(ll) + γ	ATLAS-CONF-2021-038	W' —> tb (all hadronic)	ATLAS-CONF-2021-043
VBS Z(νν) + γ	CERN-EP-2021-137	W/Z γ resonances	ATLAS-CONF-2021-041
WWW	ATLAS-CONF-2021-039	VLQ single production in Ht/Zt	ATLAS-CONF-2021-040
H —> ττ couplings	ATLAS-CONF-2021-044	HH —> bb ττ	ATLAS-CONF-2021-030
boosted top cross section	ATLAS-CONF-2021-031	HH —> bb bb	ATLAS-CONF-2021-035
top mass w/ boosted top	ATL-PHYS-PUB-2021-034	H —> XX/XZ —> 4l	ATLAS-CONF-2021-034
E/p from W—>τν	CERN-EP-2021-147	t —> bH+(cb)	ATLAS-CONF-2021-037
ETmiss performance with NN	ATL-PHYS-PUB-2021-025	LLP in muon spectrometer	ATLAS-CONF-2021-032

New results featured in review talks, parallel sessions and poster sessions

Extra material

Vector-boson scattering

- Cross-section measurement for EW Z(ll) γ jj

EW: $\sigma_{EW} = 4.49 \pm 0.40\text{ (stat.)} \pm 0.42\text{ (syst.) fb}$

	Data stat	MC stat	Background	Reco	EW mod.	QCD mod.	Total
$\Delta\sigma_{EW}$	±0.08	±0.01	±0.01	±0.05	$^{+0.05}_{-0.04}$	±0.04	$^{+0.13}_{-0.12}$

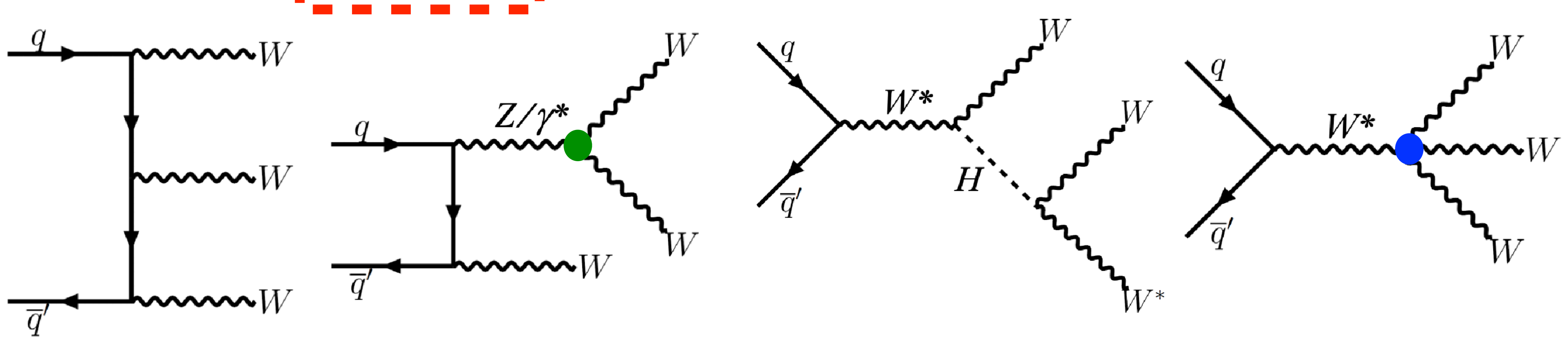
$$\sigma_{EW}^{pred} = 4.73 \pm 0.01\text{ (stat.)} \pm 0.15\text{ (PDF)}^{+0.23}_{-0.22}\text{ (scale) fb}$$

WWW production

New

ATLAS-CONF-2021-039

$$\mathcal{L}_{SM} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\psi}\not{D}\psi + \psi_i y_{ij}\psi_j\phi + \text{hc} + |D_\mu\phi|^2 - V(\phi)$$



- Rare process providing access to **W/Z self-interactions** —> cubic and quartic couplings

- Channels: $W^\pm W^\pm W^\mp \rightarrow \ell^\pm\nu\,\ell^\pm\nu\,qq'$ with $\ell = e, \mu$
  $\rightarrow \ell^\pm\nu\,\ell^\pm\nu\,\ell^\mp\nu$

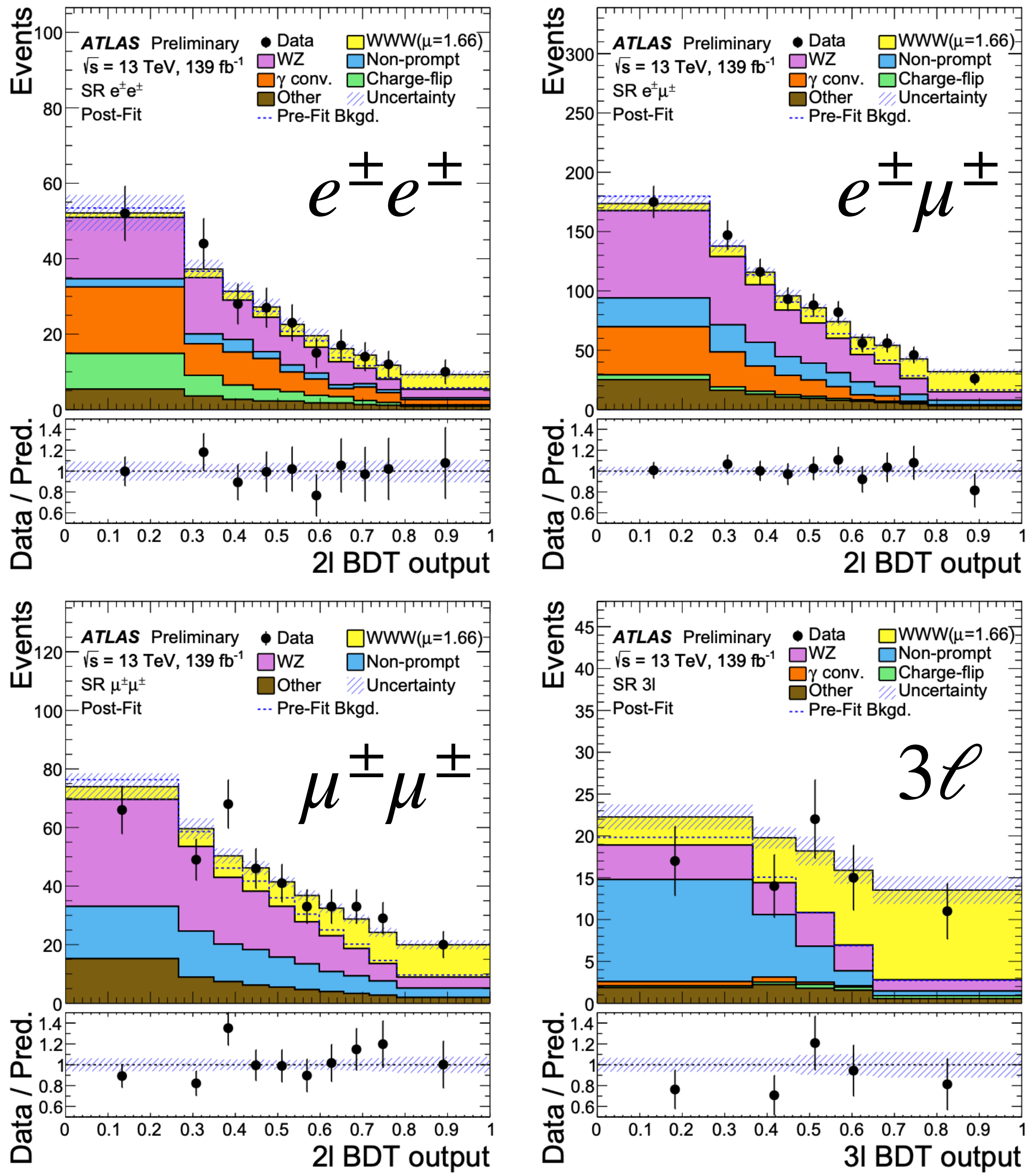
- Main bkg: $WZ \rightarrow \ell\nu\,\ell\ell$ estimated w/ control regions

- Signal extracted w/ BDTs for 2ℓ and 3ℓ channels

- **First WWW observation** with significance of $8.2\,\sigma\,(5.4\,\sigma)$ obs (exp)

$$\sigma(pp \rightarrow W^\pm W^\pm W^\mp) = 850 \pm 100\,(\text{stat}) \pm 80\,(\text{syst})\,\text{fb}$$

signal strength : 1.66 ± 0.28



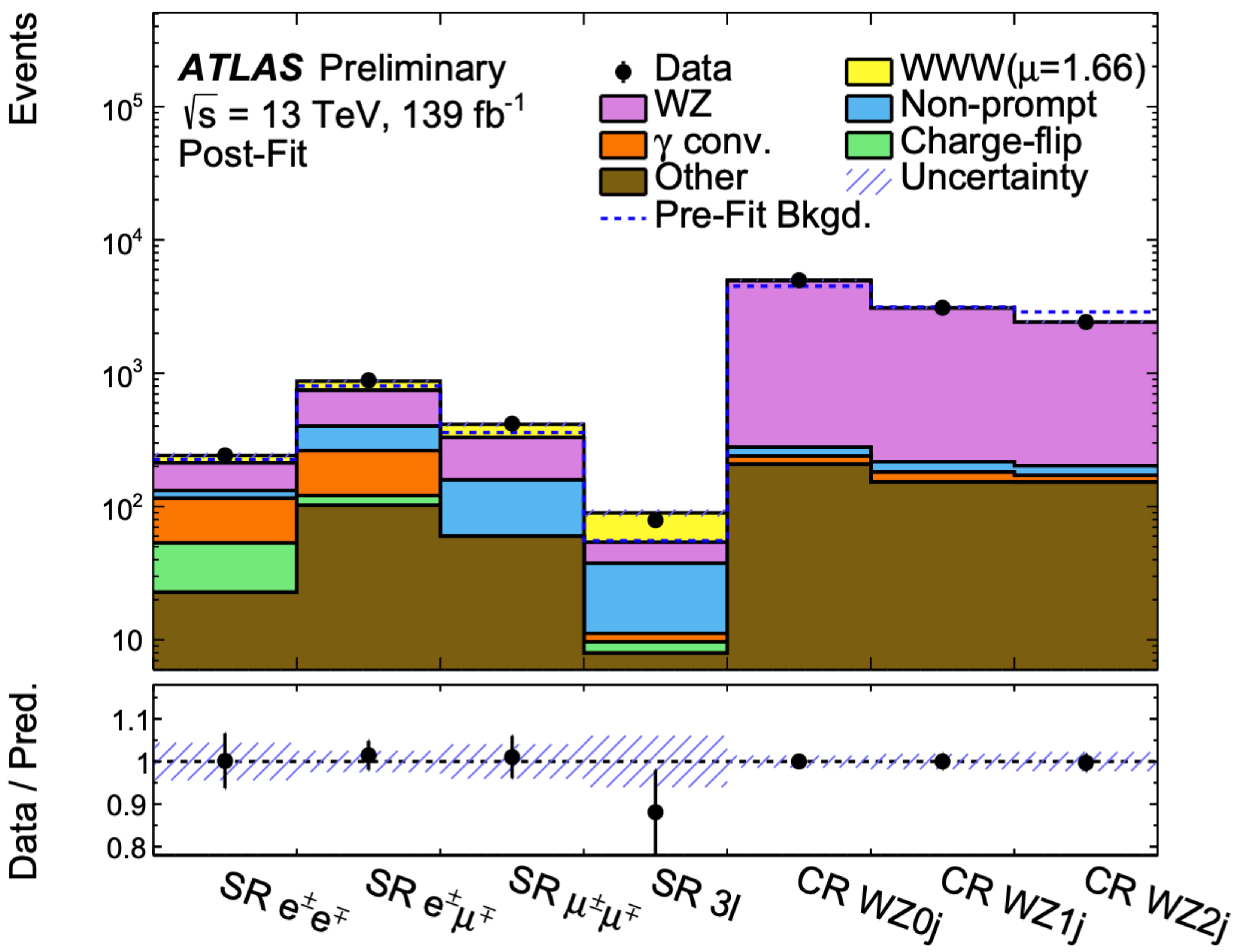
Fixed-order calculations

$$\sigma(pp \rightarrow W^+W^+W^-) = 136^{+6}_{-5}\,(\text{scale}) \pm 4\,(\text{PDF})\,\text{fb} \quad \text{at NLO QCD + NLO EW}$$

$$\sigma(pp \rightarrow W^-W^-W^+) = 76^{+4}_{-3}\,(\text{scale}) \pm 2\,(\text{PDF})\,\text{fb} \quad \text{at NLO QCD + NLO EW}$$

$$\sigma(pp \rightarrow WH \rightarrow WWW^*) = 293^{+1}_{-2}\,(\text{scale})^{+6}_{-5}\,(\text{PDF}) \pm 3\,(\alpha_s)\,\text{fb} \quad \text{at N}^3\text{LO QCD + NLO EW}$$

WWW production

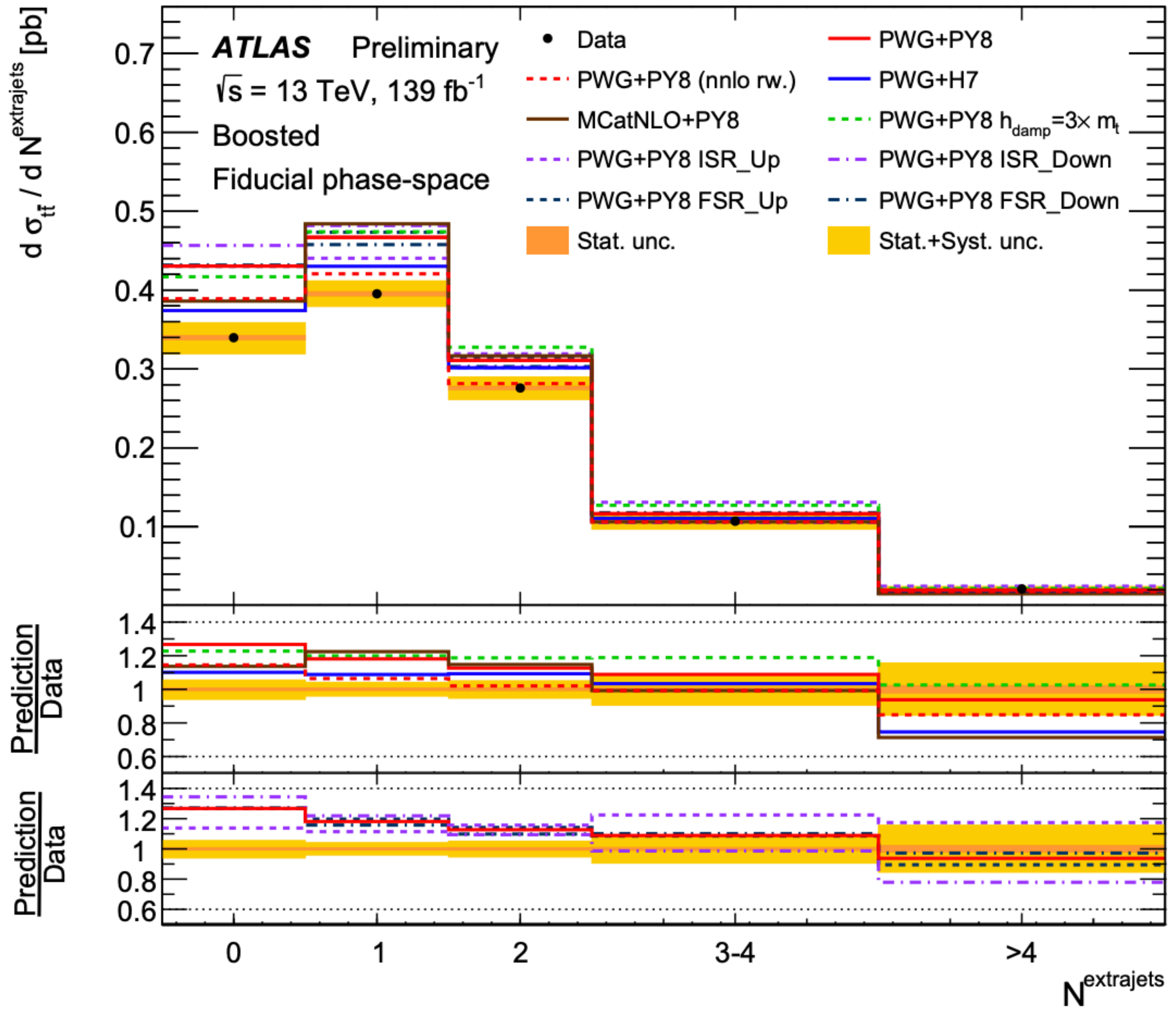


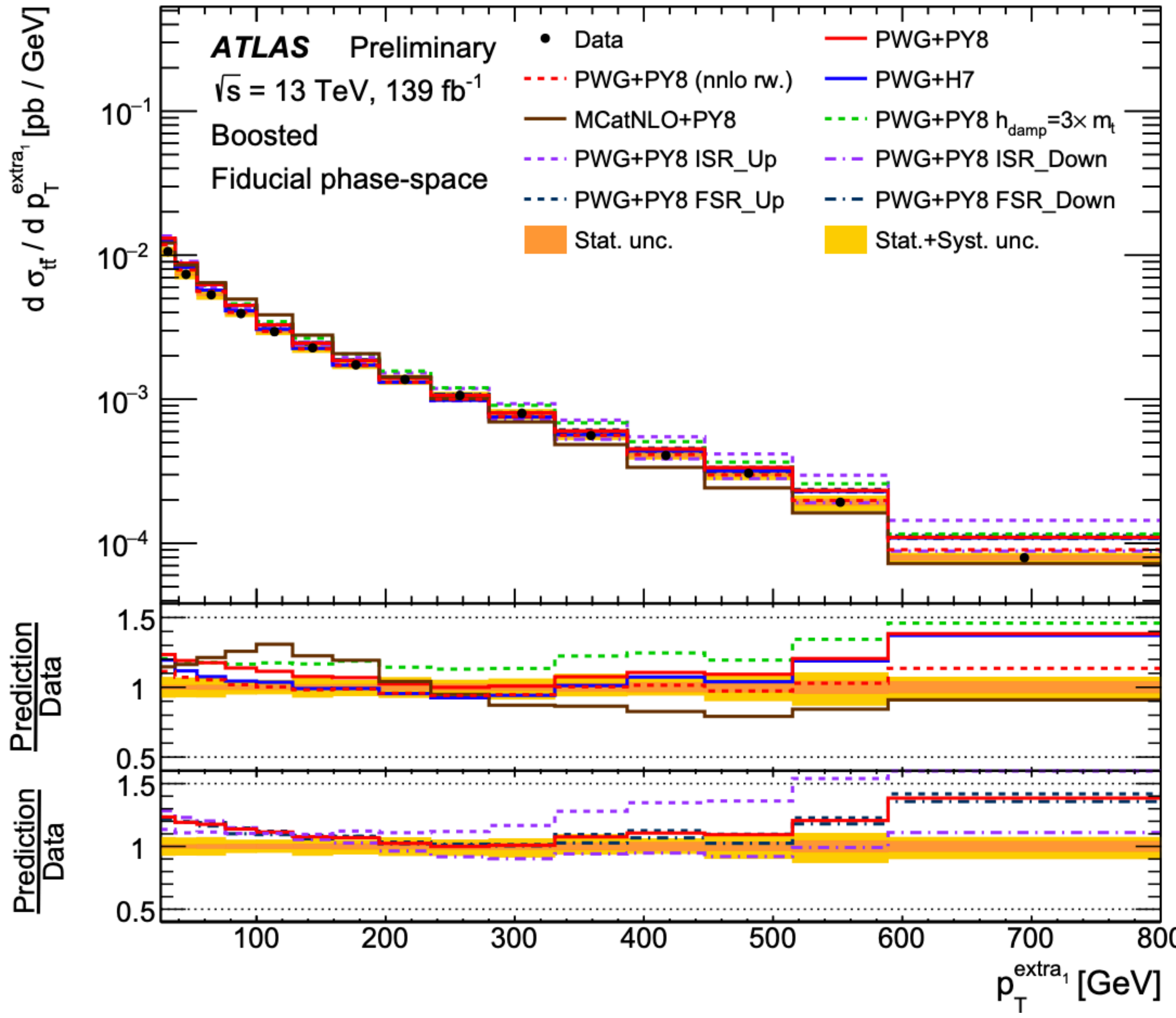
Fit	Observed (expected) significances [σ]	$\mu(WWW)$
$e^{\pm}e^{\pm}$	2.3 (1.4)	1.69 ± 0.79
$e^{\pm}\mu^{\pm}$	4.6 (3.1)	1.57 ± 0.40
$\mu^{\pm}\mu^{\pm}$	5.6 (2.8)	2.13 ± 0.47
2ℓ	6.9 (4.1)	1.80 ± 0.33
3ℓ	4.8 (3.7)	1.33 ± 0.39
Combined	**8.2 (5.4)**	**1.66 ± 0.28**

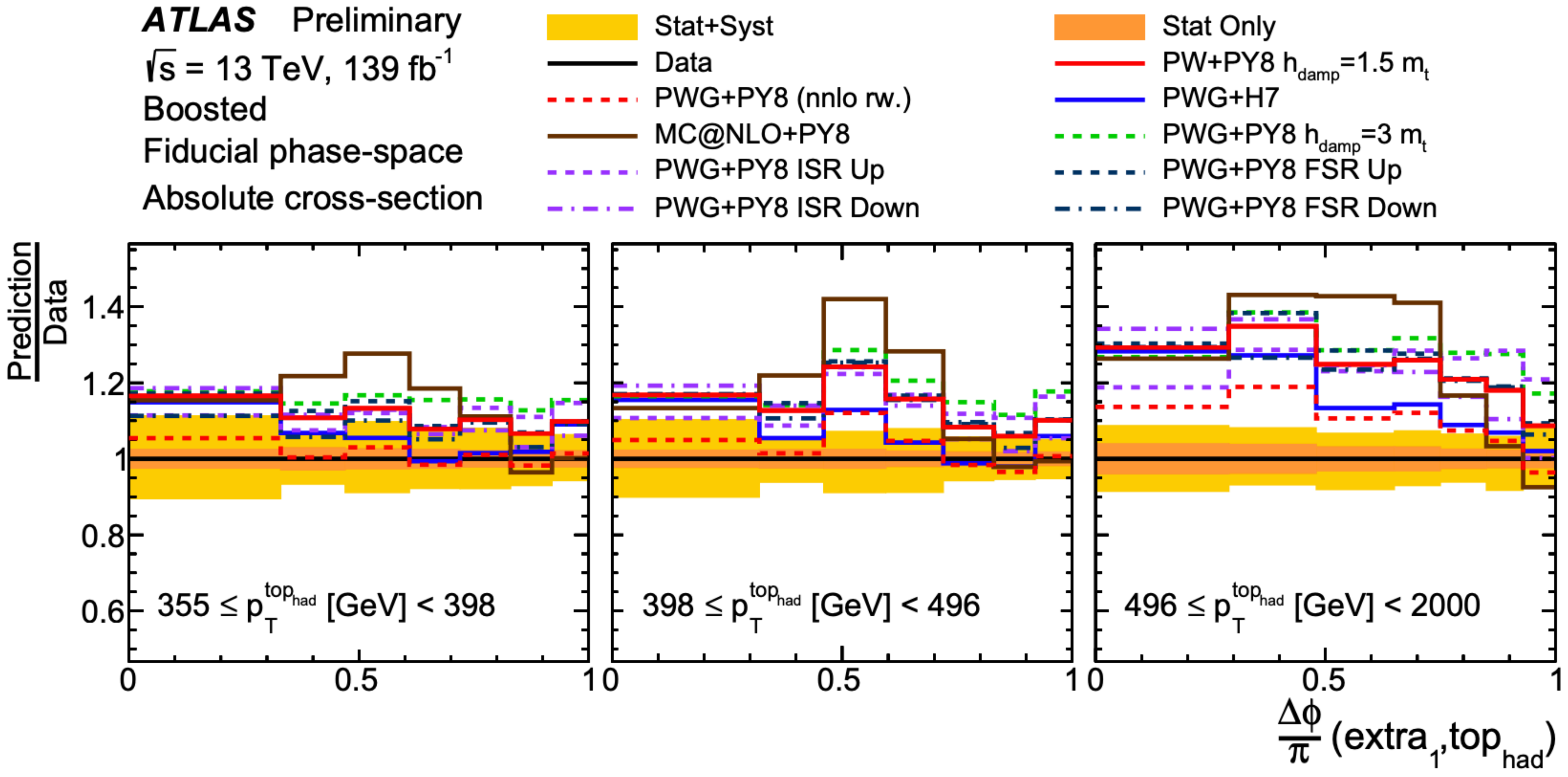
Uncertainty source	$\Delta\sigma/\sigma$ [%]
Data-driven background	5.3
Prompt-lepton-background modeling	3.3
Jets and E_T^{miss}	2.8
MC statistics	2.8
Lepton	2.1
Luminosity	1.9
Signal modeling	1.5
Pile-up modeling	0.9
Total systematic uncertainty	9.5
Data statistics	11.2
WZ normalizations	3.3
Total statistical uncertainty	11.6

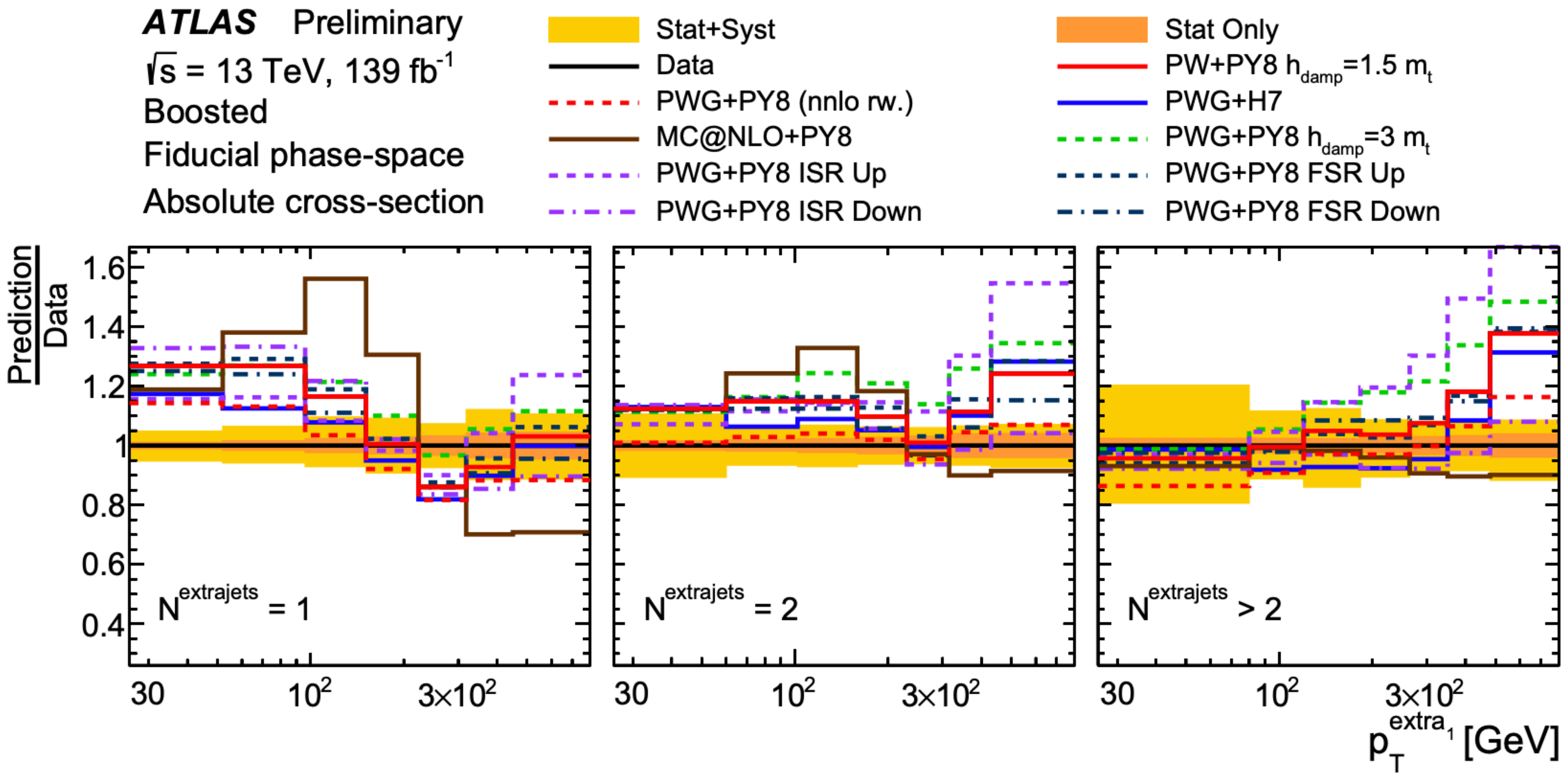
Top-quark production

- Measurements of $t\bar{t}$ system + additional jets
  - Difficulties in modeling of additional radiation in events with high-pT top quarks —> test of parton shower



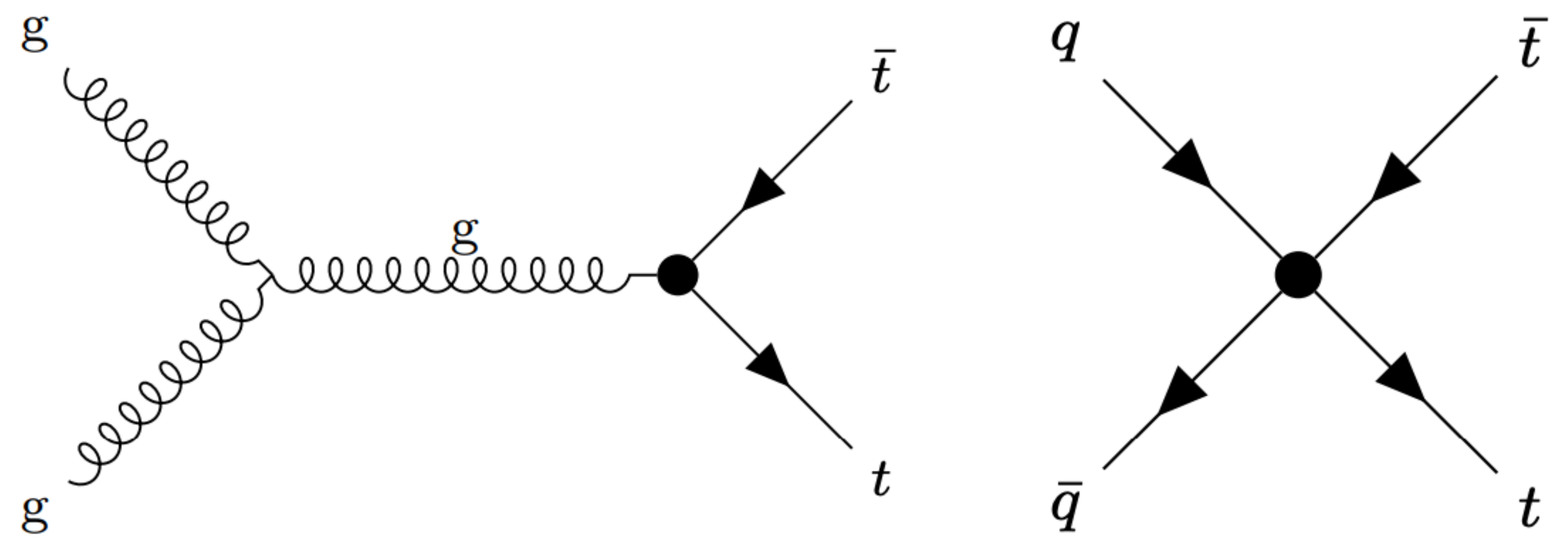


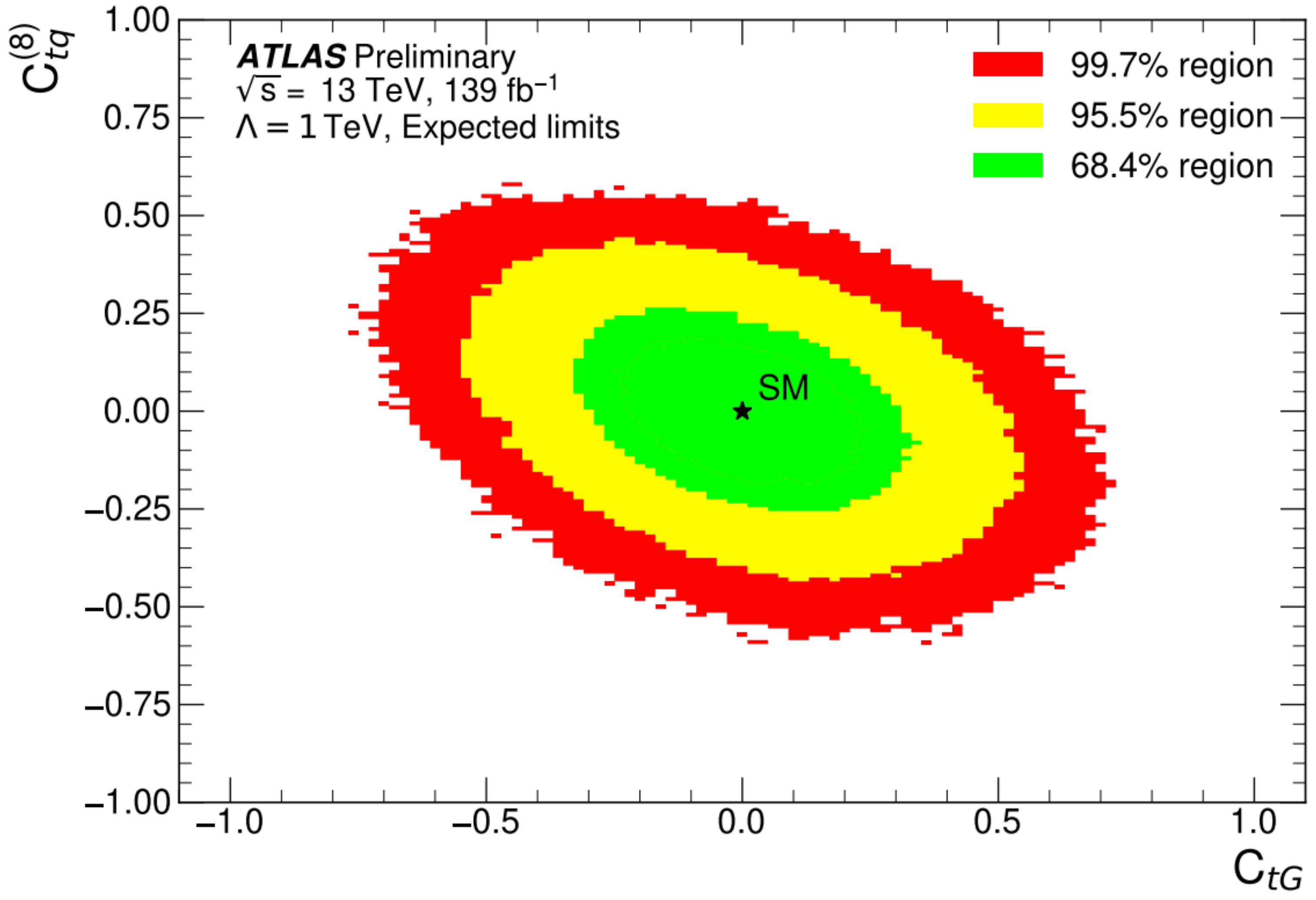


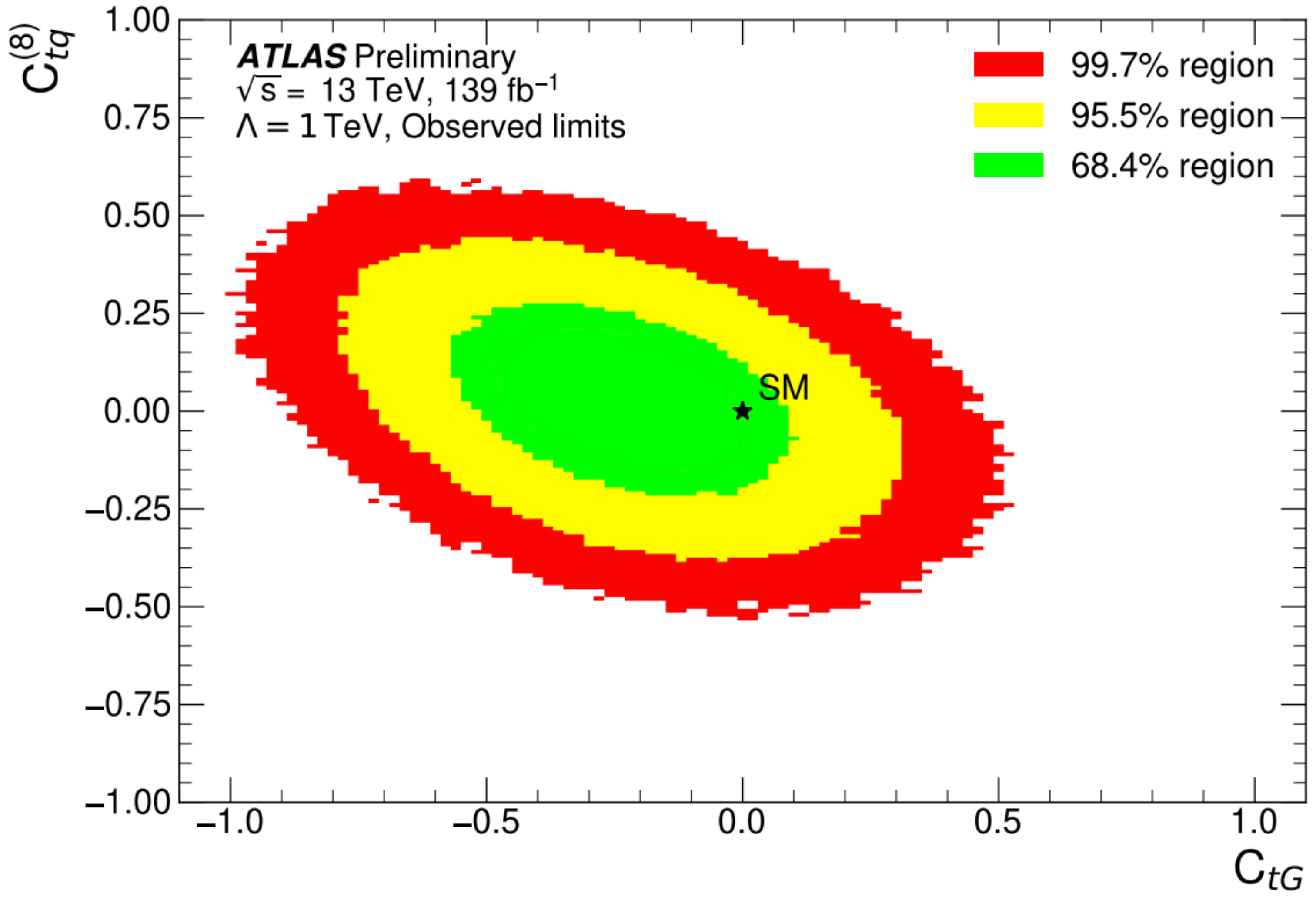


Top-quark EFT constraints

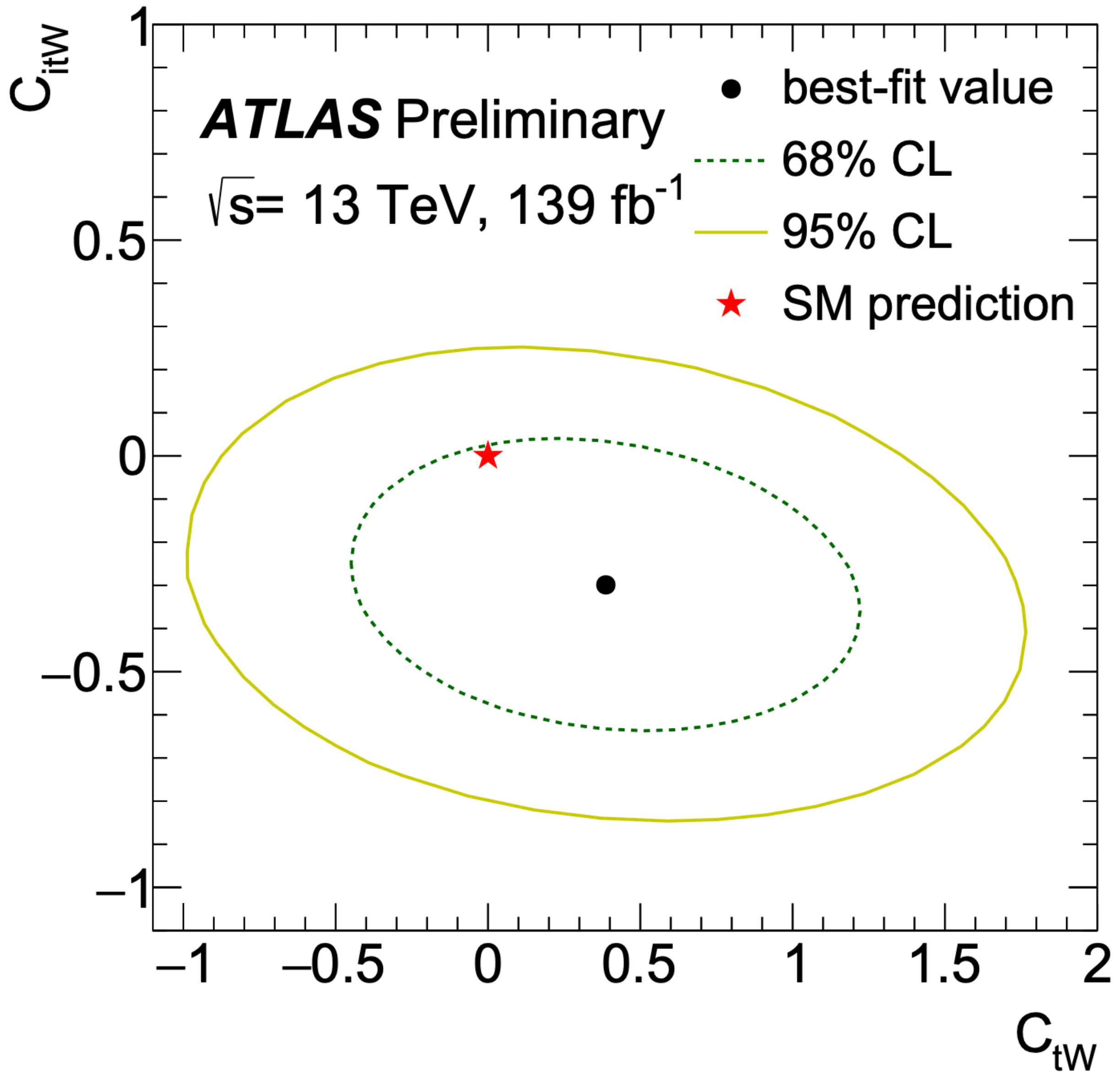
- EFT constraints from $t\bar{t}$ production







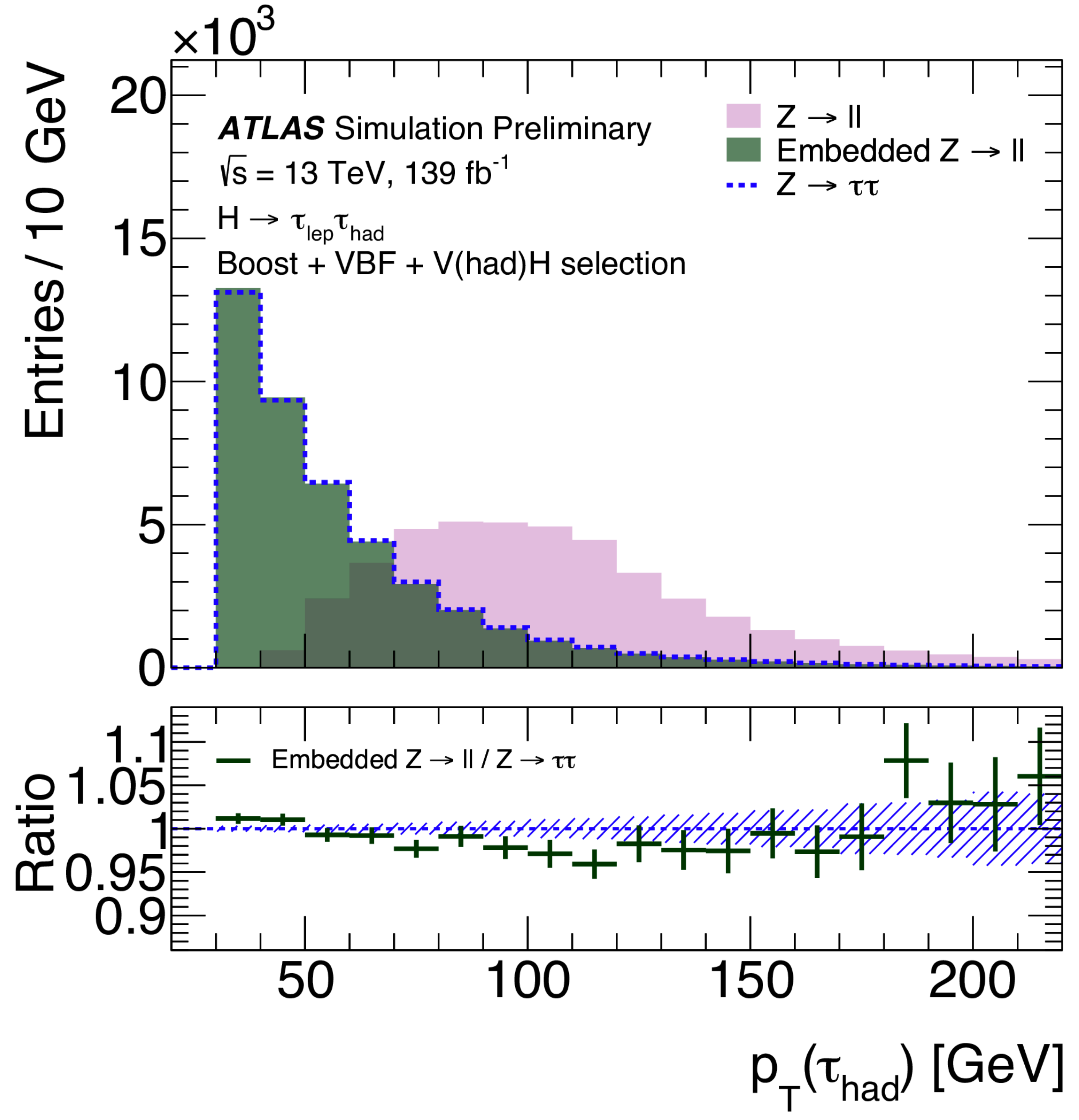
- EFT constraints from single-top polarization



Higgs couplings to τ leptons

- Uncertainties

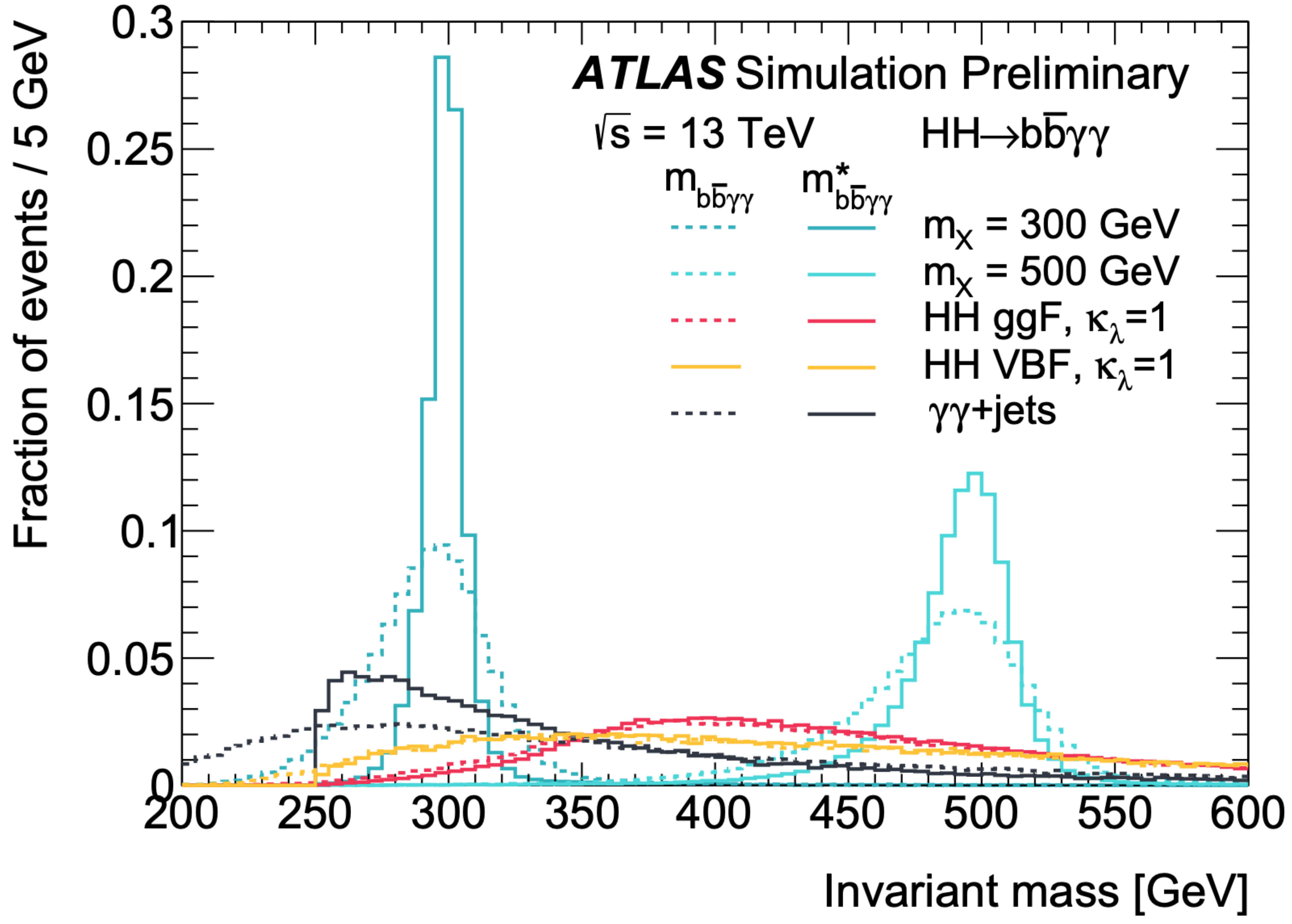
- Kinematic embedding MC closure test

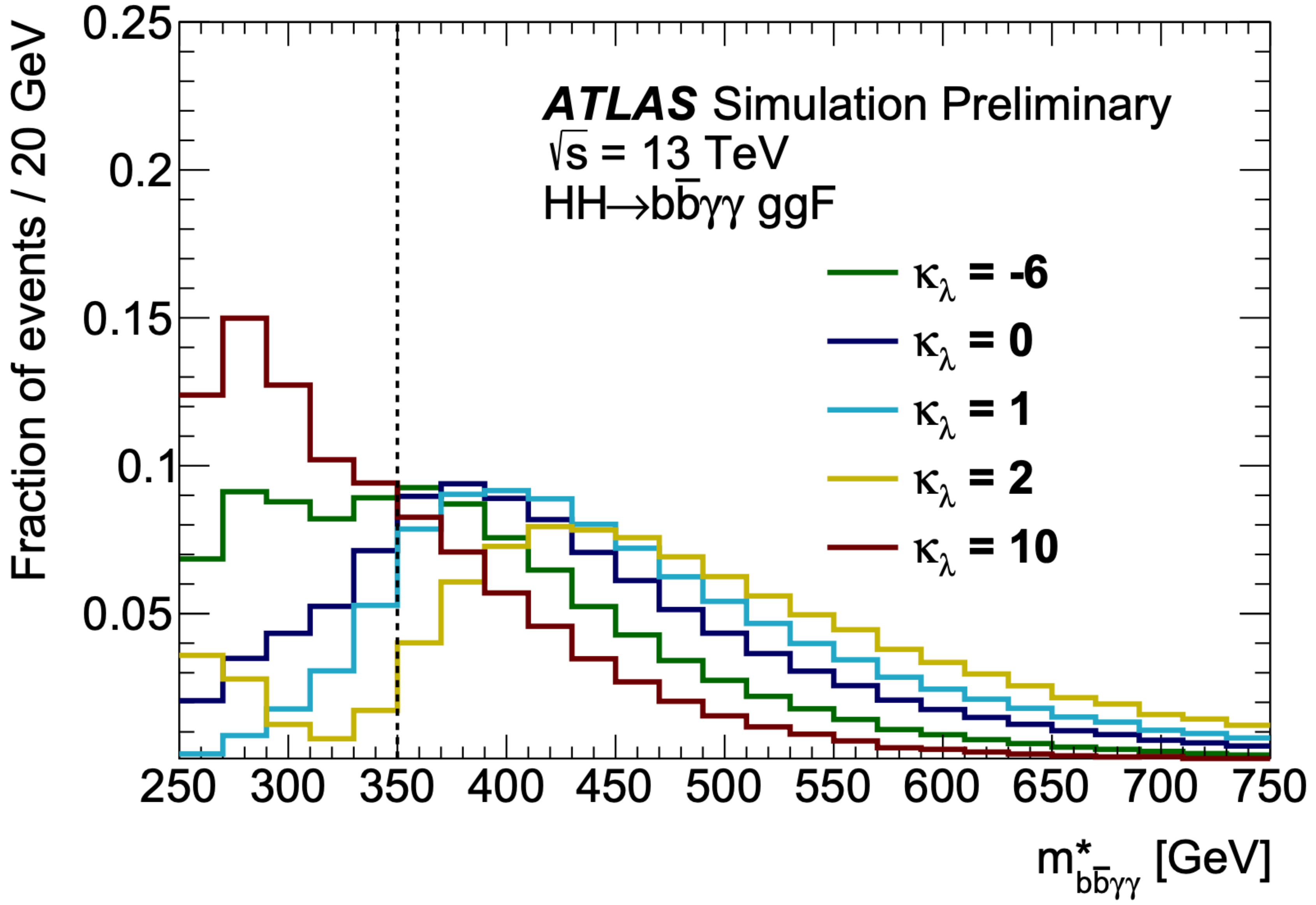


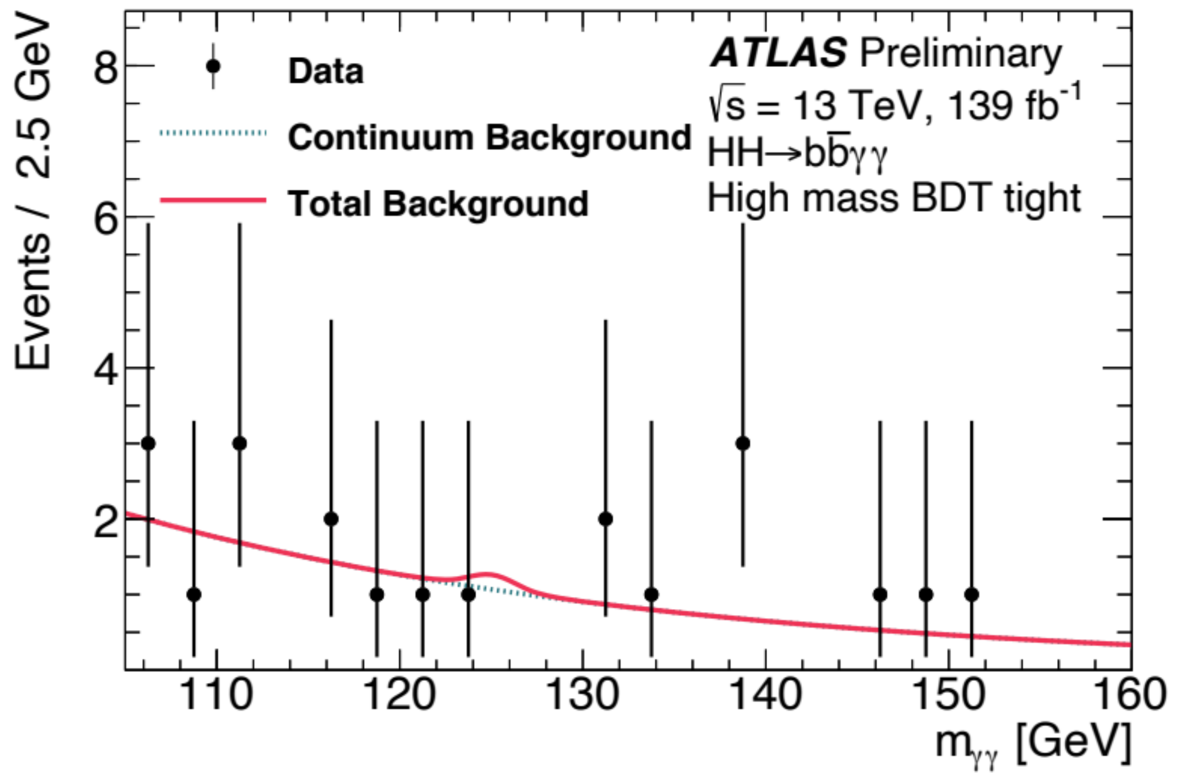
Source of uncertainty	Impact on $\Delta\sigma/\sigma(pp \to H \to \tau\tau)$ [%] Observed	Expected
Theoretical uncertainty in signal	8.1	8.6
Jet and $\vec{E}_T^{miss}$	4.2	4.1
Background sample size	3.7	3.4
Hadronic τ decays	2.0	2.1
Misidentified τ	1.9	1.8
Luminosity	1.7	1.8
Theoretical uncertainty in Top processes	1.4	1.2
Theoretical uncertainty in Z+jets processes	1.1	1.1
Flavor tagging	0.5	0.5
Electrons and muons	0.4	0.3
Total systematic uncertainty	11.1	11.0
Data sample size	6.6	6.3
Total	12.8	12.5

Di-Higgs production

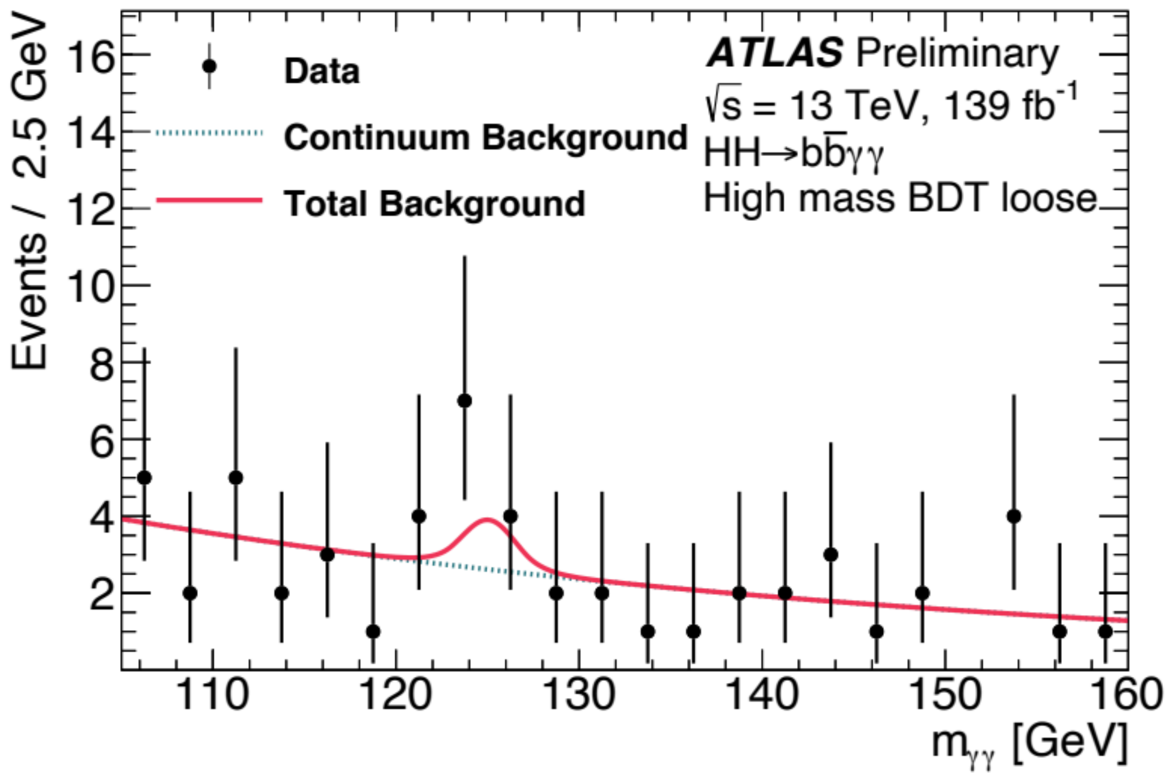
- HH —> bb γγ



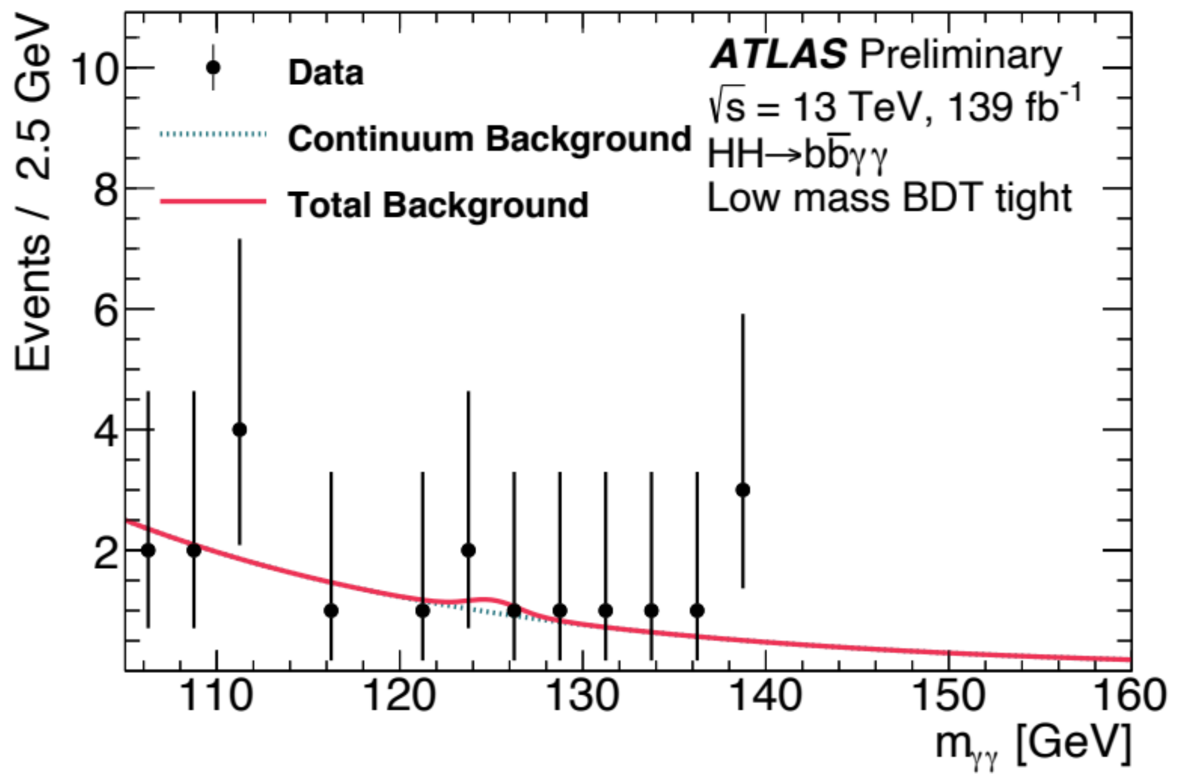




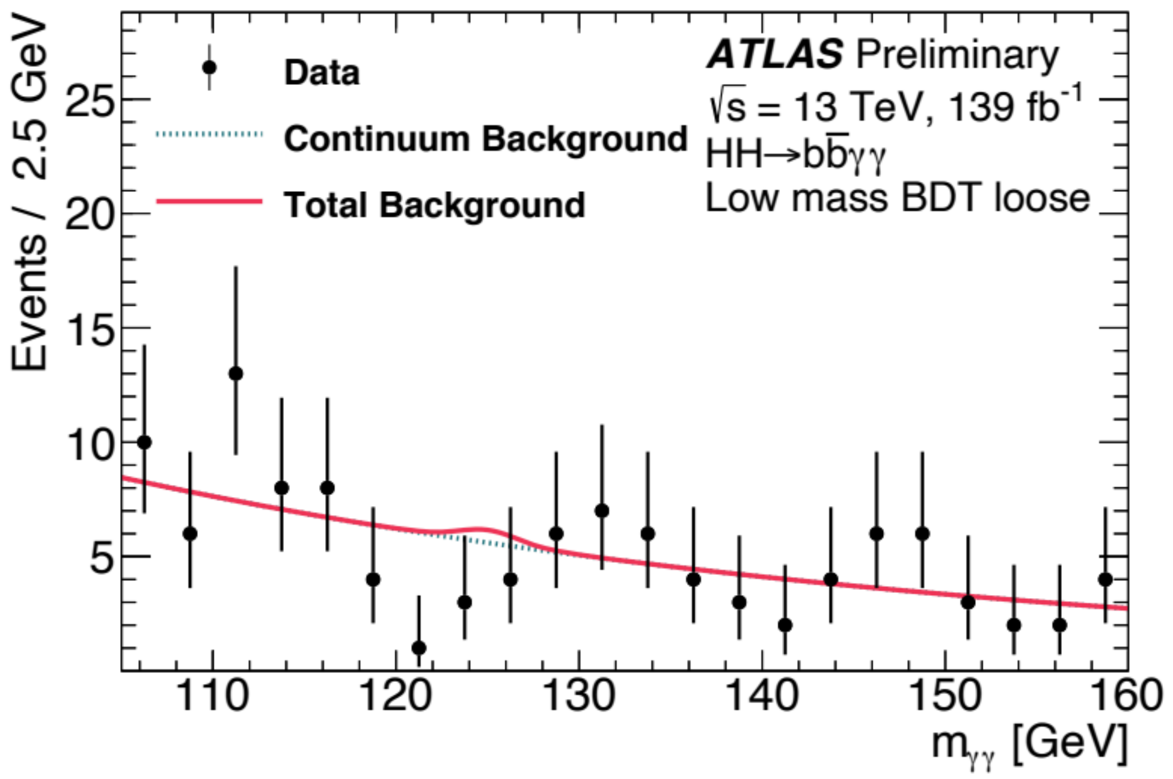
(a) High mass BDT tight



(b) High mass BDT loose



(c) Low mass BDT tight



(d) Low mass BDT loose

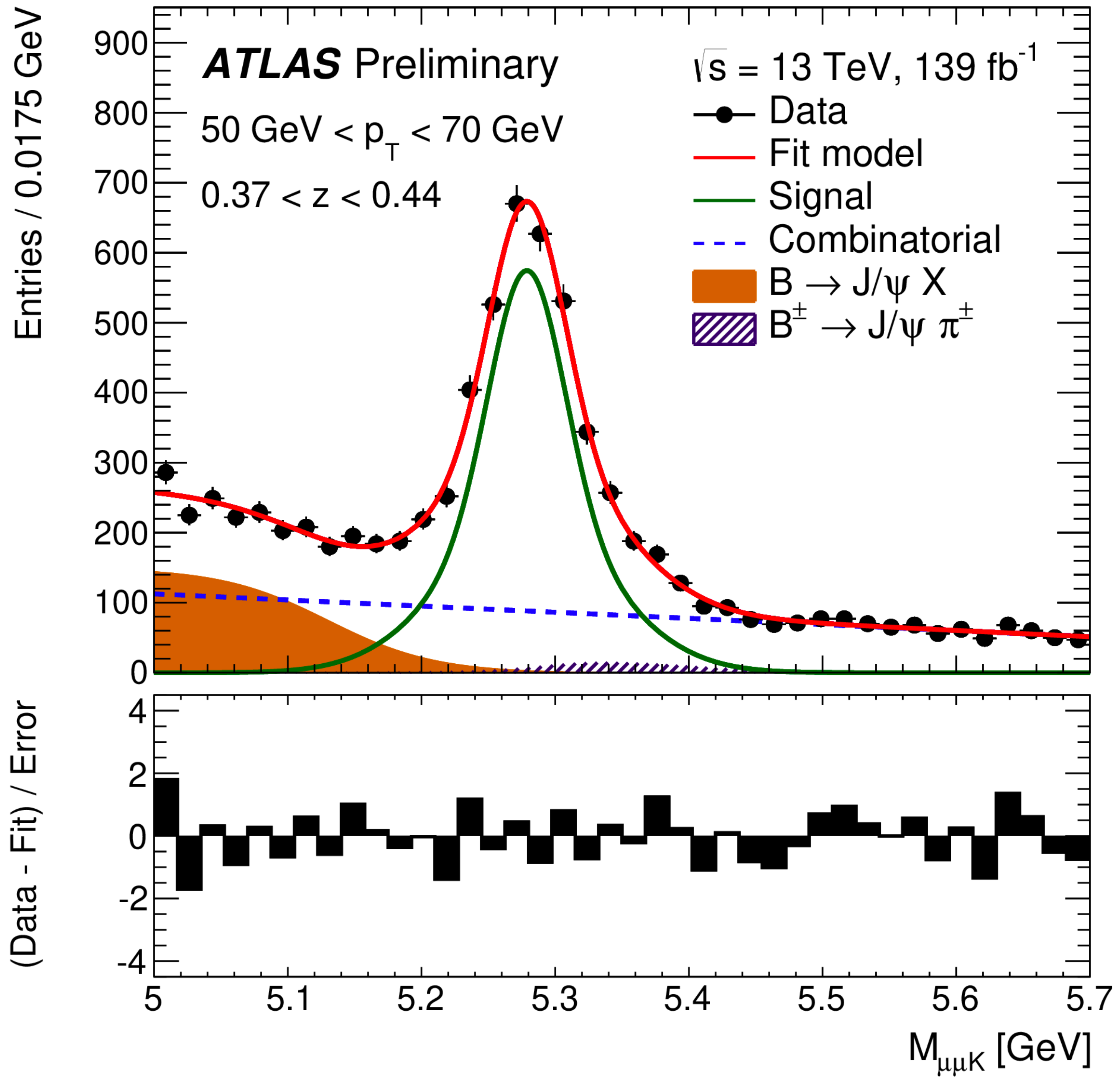
b-quark fragmentation

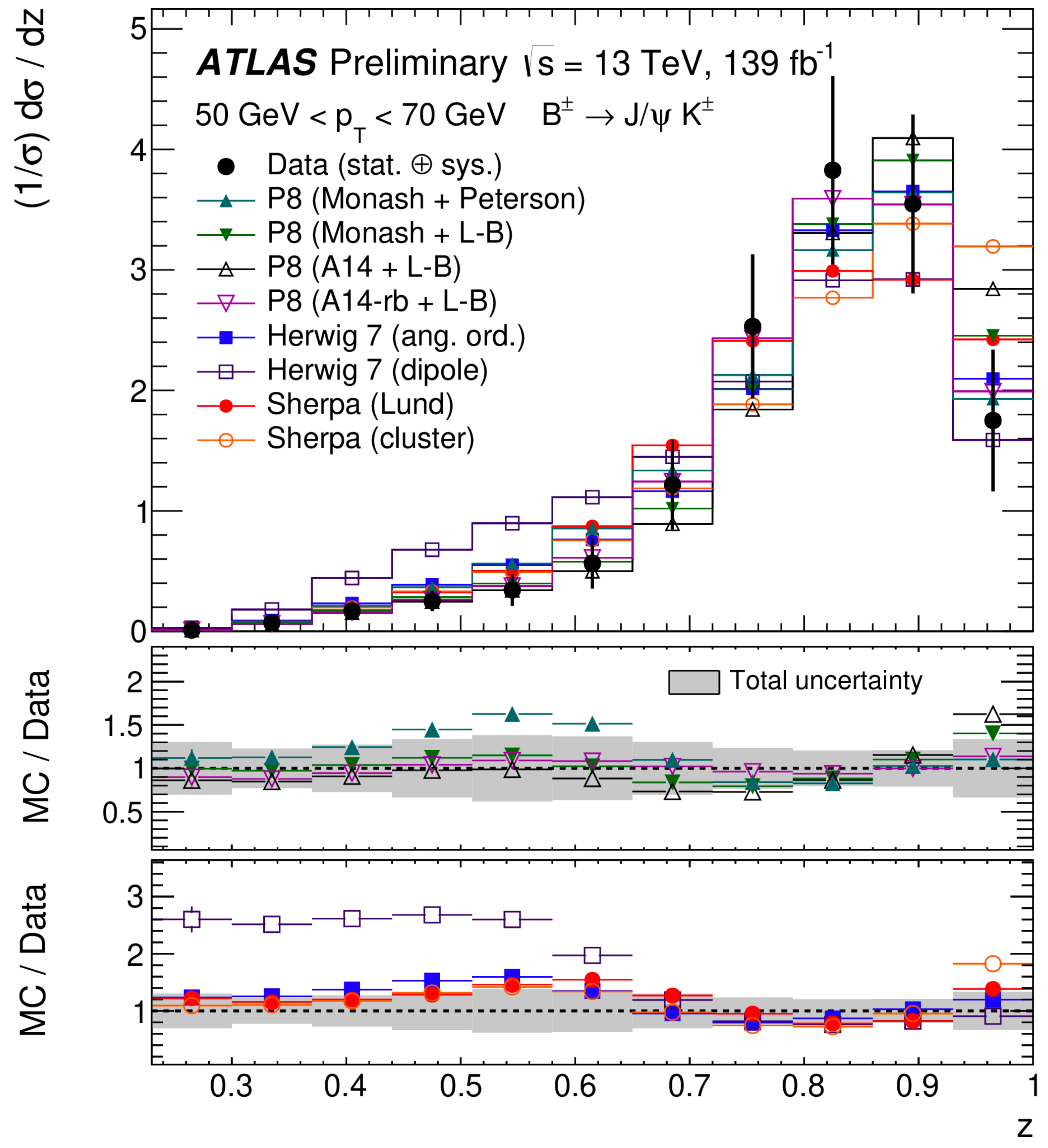
New

CERN-EP-2021-123

- Fragmentation of b-quarks important in key measurements and searches (e.g. top-quark mass or $H \to b\bar{b}$)

- Test fragmentation models derived from measurements at e^+e^- colliders in context of pp collisions at LHC (different $\sqrt{s}$ or color flow)
  —> use jets including $B^\pm \to J/\psi K^\pm \to \mu^+\mu^- K^\pm$ decays

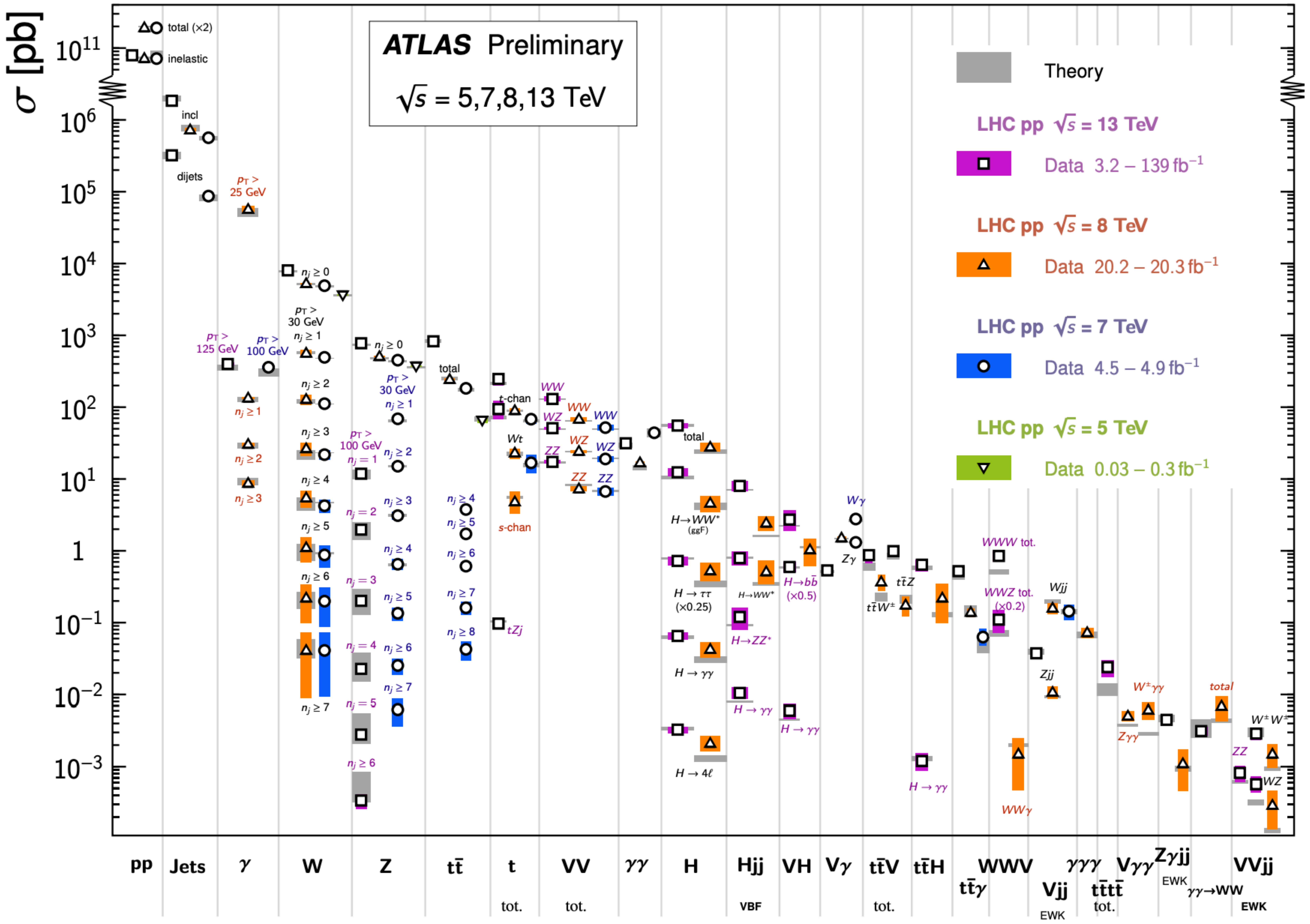


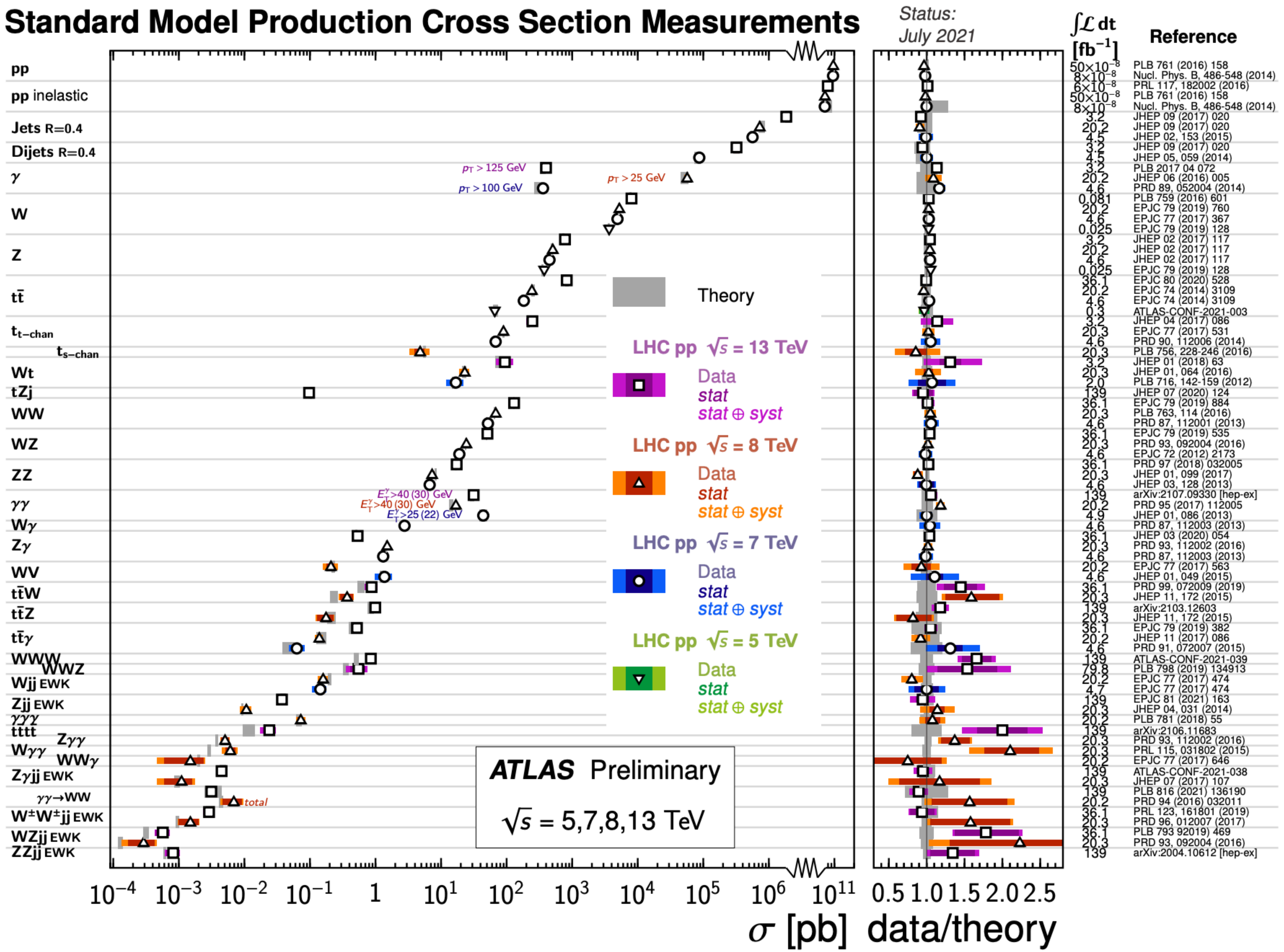


- Fraction of jet momentum carried by b-hadron:
  $$z = \frac{\vec{p}_B \cdot \vec{p}_j}{|\vec{p}_j|^2}$$
- z distribution also sensitive to rate of gluon splitting to $b\bar{b}$
- Pythia8 and SHERPA generally model data well

Standard Model Production Cross Section Measurements

Status: July 2021





Standard Model Production Cross Section Measurements
Status: July 2021
$\int\mathcal{L}\,dt$ [fb^{-1}]
Reference
pp
pp inelastic
Jets R=0.4
Dijets R=0.4
γ
W
Z
tt̄
t_{t-chan}
t_{s-chan}
Wt
tZj
WW
WZ
ZZ
γγ
Wγ
Zγ
WV
tt̄W
tt̄Z
tt̄γ
WWW
WWZ
Wjj EWK
Zjj EWK
γγγ
tttt
Zγγ
Wγγ
WWγ
Zγjj EWK
γγ→WW
W±W±jj EWK
WZjj EWK
ZZjj EWK
p_T > 125 GeV
p_T > 100 GeV
p_T > 25 GeV
E_T^γ>40 (30) GeV
E_T^γ>40 (30) GeV
E_T^γ>25 (22) GeV
total
Theory
LHC pp √s = 13 TeV
Data
stat
stat ⊕ syst
LHC pp √s = 8 TeV
Data
stat
stat ⊕ syst
LHC pp √s = 7 TeV
Data
stat
stat ⊕ syst
LHC pp √s = 5 TeV
Data
stat
stat ⊕ syst
ATLAS Preliminary
√s = 5,7,8,13 TeV
10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10^{1} 10^{2} 10^{3} 10^{4} 10^{5} 10^{6} 10^{11}
σ [pb]
0.5 1.0 1.5 2.0 2.5
data/theory
50×10^{-8} PLB 761 (2016) 158
8×10^{-8} Nucl. Phys. B, 486-548 (2014)
6×10^{-8} PRL 117, 182002 (2016)
50×10^{-8} PLB 761 (2016) 158
8×10^{-8} Nucl. Phys. B, 486-548 (2014)
3.2 JHEP 09 (2017) 020
20.2 JHEP 09 (2017) 020
4.5 JHEP 02, 153 (2015)
3.2 JHEP 09 (2017) 020
4.5 JHEP 05, 059 (2014)
3.2 PLB 2017 04 072
20.2 JHEP 06 (2016) 005
4.6 PRD 89, 052004 (2014)
0.081 PLB 759 (2016) 601
20.2 EPJC 79 (2019) 760
4.6 EPJC 77 (2017) 367
0.025 EPJC 79 (2019) 128
3.2 JHEP 02 (2017) 117
20.2 JHEP 02 (2017) 117
4.6 JHEP 02 (2017) 117
0.025 EPJC 79 (2019) 128
36.1 EPJC 80 (2020) 528
20.2 EPJC 74 (2014) 3109
4.6 EPJC 74 (2014) 3109
0.3 ATLAS-CONF-2021-003
3.2 JHEP 04 (2017) 086
20.3 EPJC 77 (2017) 531
4.6 PRD 90, 112006 (2014)
20.3 PLB 756, 228-246 (2016)
3.2 JHEP 01 (2018) 63
20.3 JHEP 01, 064 (2016)
2.0 PLB 716, 142-159 (2012)
139 JHEP 07 (2020) 124
36.1 EPJC 79 (2019) 884
20.3 PLB 763, 114 (2016)
4.6 PRD 87, 112001 (2013)
36.1 EPJC 79 (2019) 535
20.3 PRD 93, 092004 (2016)
4.6 EPJC 72 (2012) 2173
36.1 PRD 97 (2018) 032005
20.3 JHEP 01, 099 (2017)
4.6 JHEP 03, 128 (2013)
139 arXiv:2107.09330 [hep-ex]
20.2 PRD 95 (2017) 112005
4.9 JHEP 01, 086 (2013)
4.6 PRD 87, 112003 (2013)
36.1 JHEP 03 (2020) 054
20.3 PRD 93, 112002 (2016)
4.6 PRD 87, 112003 (2013)
20.2 EPJC 77 (2017) 563
4.6 JHEP 01, 049 (2015)
36.1 PRD 99, 072009 (2019)
20.3 JHEP 11, 172 (2015)
139 arXiv:2103.12603
20.3 JHEP 11, 172 (2015)
36.1 EPJC 79 (2019) 382
20.2 JHEP 11 (2017) 086
4.6 PRD 91, 072007 (2015)
139 ATLAS-CONF-2021-039
79.8 PLB 798 (2019) 134913
20.2 EPJC 77 (2017) 474
4.7 EPJC 77 (2017) 474
139 EPJC 81 (2021) 163
20.3 JHEP 04, 031 (2014)
20.2 PLB 781 (2018) 55
139 arXiv:2106.11683
20.3 PRD 93, 112002 (2016)
20.3 PRL 115, 031802 (2015)
20.2 EPJC 77 (2017) 646
139 ATLAS-CONF-2021-038
20.3 JHEP 07 (2017) 107
139 PLB 816 (2021) 136190
20.2 PRD 94 (2016) 032011
36.1 PRL 123, 161801 (2019)
20.3 PRD 96, 012007 (2017)
36.1 PLB 793 92019) 469
20.3 PRD 93, 092004 (2016)
139 arXiv:2004.10612 [hep-ex]

ATLAS Heavy Particle Searches* - 95% CL Upper Exclusion Limits

Status: July 2021

ATLAS Preliminary

$\int \mathcal{L}\, dt = (3.6 - 139)\ \mathrm{fb}^{-1}$ $\sqrt{s} = 8, 13$ TeV

	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\, dt[\mathrm{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	0 e, μ, τ, γ	1 – 4 j	Yes	139	M_D 11.2 TeV	$n = 2$	2102.10874
	ADD non-resonant $\gamma\gamma$	2 γ	–	–	36.7	M_S 8.6 TeV	$n = 3$ HLZ NLO	1707.04147
	ADD QBH	–	2 j	–	37.0	M_{th} 8.9 TeV	$n = 6$	1703.09127
	ADD BH multijet	–	≥3 j	–	3.6	M_{th} 9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \to \gamma\gamma$	2 γ	–	–	139	G_{KK} mass 4.5 TeV	$k/\overline{M}_{Pl} = 0.1$	2102.13405
	Bulk RS $G_{KK} \to WW/ZZ$	multi-channel			36.1	G_{KK} mass 2.3 TeV	$k/\overline{M}_{Pl} = 1.0$	1808.02380
	Bulk RS $G_{KK} \to WW \to \ell\nu qq$	1 e, μ	2 j / 1 J	Yes	139	G_{KK} mass 2.0 TeV	$k/\overline{M}_{Pl} = 1.0$	2004.14636
	Bulk RS $g_{KK} \to tt$	1 e, μ	≥1 b, ≥1J/2j	Yes	36.1	g_{KK} mass 3.8 TeV	$\Gamma/m = 15\%$	1804.10823
	2UED / RPP	1 e, μ	≥2 b, ≥3 j	Yes	36.1	KK mass 1.8 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)} \to tt) = 1$	1803.09678
Gauge bosons	SSM $Z' \to \ell\ell$	2 e, μ	–	–	139	Z' mass 5.1 TeV		1903.06248
	SSM $Z' \to \tau\tau$	2 τ	–	–	36.1	Z' mass 2.42 TeV		1709.07242
	Leptophobic $Z' \to bb$	–	2 b	–	36.1	Z' mass 2.1 TeV		1805.09299
	Leptophobic $Z' \to tt$	0 e, μ	≥1 b, ≥2 J	Yes	139	Z' mass 4.1 TeV	$\Gamma/m = 1.2\%$	2005.05138
	SSM $W' \to \ell\nu$	1 e, μ	–	Yes	139	W' mass 6.0 TeV		1906.05609
	SSM $W' \to \tau\nu$	1 τ	–	Yes	139	W' mass 5.0 TeV		ATLAS-CONF-2021-025
	SSM $W' \to tb$	–	≥1 b, ≥1 J	–	139	W' mass 4.4 TeV		ATLAS-CONF-2021-043
	HVT $W' \to WZ \to \ell\nu qq$ model B	1 e, μ	2 j / 1 J	Yes	139	W' mass 4.3 TeV	$g_V = 3$	2004.14636
	HVT $Z' \to ZH$ model B	0-2 e, μ	1-2 b	Yes	139	Z' mass 3.2 TeV	$g_V = 3$	ATLAS-CONF-2020-043
	HVT $W' \to WH$ model B	0 e, μ	≥1 b, ≥2 J		139	W' mass 3.2 TeV	$g_V = 3$	2007.05293
	LRSM $W_R \to \mu N_R$	2 μ	1 J	–	80	W_R mass 5.0 TeV	$m(N_R) = 0.5$ TeV, $g_L = g_R$	1904.12679
CI	CI $qqqq$	–	2 j	–	37.0	Λ 21.8 TeV η_{LL}^{-}		1703.09127
	CI $\ell\ell qq$	2 e, μ	–	–	139	Λ 35.8 TeV	η_{LL}^{-}	2006.12946
	CI $eebs$	2 e	1 b	–	139	Λ 1.8 TeV	$g_* = 1$	2105.13847
	CI $\mu\mu bs$	2 μ	1 b	–	139	Λ 2.0 TeV	$g_* = 1$	2105.13847
	CI $tttt$	≥1 e,μ	≥1 b, ≥1 j	Yes	36.1	Λ 2.57 TeV	$\lvert C_{4t} \rvert = 4\pi$	1811.02305
DM	Axial-vector med. (Dirac DM)	0 e, μ, τ, γ	1 – 4 j	Yes	139	m_{med} 2.1 TeV	g_q=0.25, g_χ=1, $m(\chi)$=1 GeV	2102.10874
	Pseudo-scalar med. (Dirac DM)	0 e, μ, τ, γ	1 – 4 j	Yes	139	m_{med} 376 GeV	g_q=1, g_χ=1, $m(\chi)$=1 GeV	2102.10874
	Vector med. Z'-2HDM (Dirac DM)	0 e, μ	2 b	Yes	139	m_{med} 3.1 TeV	$\tan\beta$=1, g_Z=0.8, $m(\chi)$=100 GeV	ATLAS-CONF-2021-006
	Pseudo-scalar med. 2HDM+a	multi-channel			139	m_{med} 560 GeV	$\tan\beta$=1, g_χ=1, $m(\chi)$=10 GeV	ATLAS-CONF-2021-036
	Scalar reson. $\phi \to t\chi$ (Dirac DM)	0-1 e, μ	1 b, 0-1 J	Yes	36.1	m_ϕ 3.4 TeV	y=0.4, λ=0.2, $m(\chi)$=10 GeV	1812.09743
LQ	Scalar LQ 1st gen	2 e	≥2 j	Yes	139	LQ mass 1.8 TeV	$\beta = 1$	2006.05872
	Scalar LQ 2nd gen	2 μ	≥2 j	Yes	139	LQ mass 1.7 TeV	$\beta = 1$	2006.05872
	Scalar LQ 3rd gen	1 τ	2 b	Yes	139	LQ_3^u mass 1.2 TeV	$\mathcal{B}(LQ_3^u \to b\tau) = 1$	ATLAS-CONF-2021-008
	Scalar LQ 3rd gen	0 e, μ	≥2 j, ≥2 b	Yes	139	LQ_3^u mass 1.24 TeV	$\mathcal{B}(LQ_3^u \to t\nu) = 1$	2004.14060
	Scalar LQ 3rd gen	≥2 e, μ, ≥1 τ	≥1 j, ≥1 b	–	139	LQ_3^d mass 1.43 TeV	$\mathcal{B}(LQ_3^d \to t\tau) = 1$	2101.11582
	Scalar LQ 3rd gen	0 e, μ, ≥1 τ	0 – 2 j, 2 b	Yes	139	LQ_3^d mass 1.26 TeV	$\mathcal{B}(LQ_3^d \to b\nu) = 1$	2101.12527
Heavy quarks	VLQ $TT \to Zt + X$	2e/2μ/≥3e,μ	≥1 b, ≥1 j	–	139	T mass 1.4 TeV	SU(2) doublet	ATLAS-CONF-2021-024
	VLQ $BB \to Wt/Zb + X$	multi-channel			36.1	B mass 1.34 TeV	SU(2) doublet	1808.02343
	VLQ $T_{5/3} T_{5/3} \lvert T_{5/3} \to Wt + X$	2(SS)/≥3 e,μ	≥1 b, ≥1 j	Yes	36.1	$T_{5/3}$ mass 1.64 TeV	$\mathcal{B}(T_{5/3} \to Wt) = 1$, $c(T_{5/3} Wt) = 1$	1807.11883
	VLQ $T \to Ht/Zt$	1 e, μ	≥1 b, ≥3 j	Yes	139	T mass 1.8 TeV	SU(2) singlet, $\kappa_T = 0.5$	ATLAS-CONF-2021-040
	VLQ $Y \to Wb$	1 e, μ	≥1 b, ≥1 j	Yes	36.1	Y mass 1.85 TeV	$\mathcal{B}(Y \to Wb) = 1$, $c_R(Wb) = 1$	1812.07343
	VLQ $B \to Hb$	0 e,μ	≥2b, ≥1j, ≥1J	–	139	B mass 2.0 TeV	SU(2) doublet, $\kappa_B = 0.3$	ATLAS-CONF-2021-018
Excited fermions	Excited quark $q^* \to qg$	–	2 j	–	139	q^* mass 6.7 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1910.08447
	Excited quark $q^* \to q\gamma$	1 γ	1 j	–	36.7	q^* mass 5.3 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1709.10440
	Excited quark $b^* \to bg$	–	1 b, 1 j	–	36.1	b^* mass 2.6 TeV		1805.09299
	Excited lepton ℓ^*	3 e, μ	–	–	20.3	ℓ^* mass 3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	3 e, μ, τ	–	–	20.3	ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	Type III Seesaw	2,3,4 e, μ	≥2 j	Yes	139	N^0 mass 910 GeV		ATLAS-CONF-2021-023
	LRSM Majorana ν	2 μ	2 j	–	36.1	N_R mass 3.2 TeV	$m(W_R) = 4.1$ TeV, $g_L = g_R$	1809.11105
	Higgs triplet $H^{\pm\pm} \to W^\pm W^\pm$	2,3,4 e, μ (SS)	various	Yes	139	$H^{\pm\pm}$ mass 350 GeV	DY production	2101.11961
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	2,3,4 e, μ (SS)	–	–	36.1	$H^{\pm\pm}$ mass 870 GeV	DY production	1710.09748
	Higgs triplet $H^{\pm\pm} \to \ell\tau$	3 e, μ, τ	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, $\mathcal{B}(H_L^{\pm\pm} \to \ell\tau) = 1$	1411.2921
	Multi-charged particles	–	–	–	36.1	multi-charged particle mass 1.22 TeV	DY production, $\lvert q \rvert = 5e$	1812.03673
	Magnetic monopoles	–	–	–	34.4	monopole mass 2.37 TeV	DY production, $\lvert g \rvert = 1 g_D$, spin 1/2	1905.10130

$\sqrt{s}$ = 8 TeV | $\sqrt{s}$ = 13 TeV partial data | $\sqrt{s}$ = 13 TeV full data

Mass scale [TeV] (10^{-1}, 1, 10)

*Only a selection of the available mass limits on new states or phenomena is shown.

†Small-radius (large-radius) jets are denoted by the letter j (J).