(Top and) Higgs Physics in ATLAS

Jordy Degens, on behalf of Liverpool ATLAS Group

Liverpool HEP Meeting, 2024-05-23

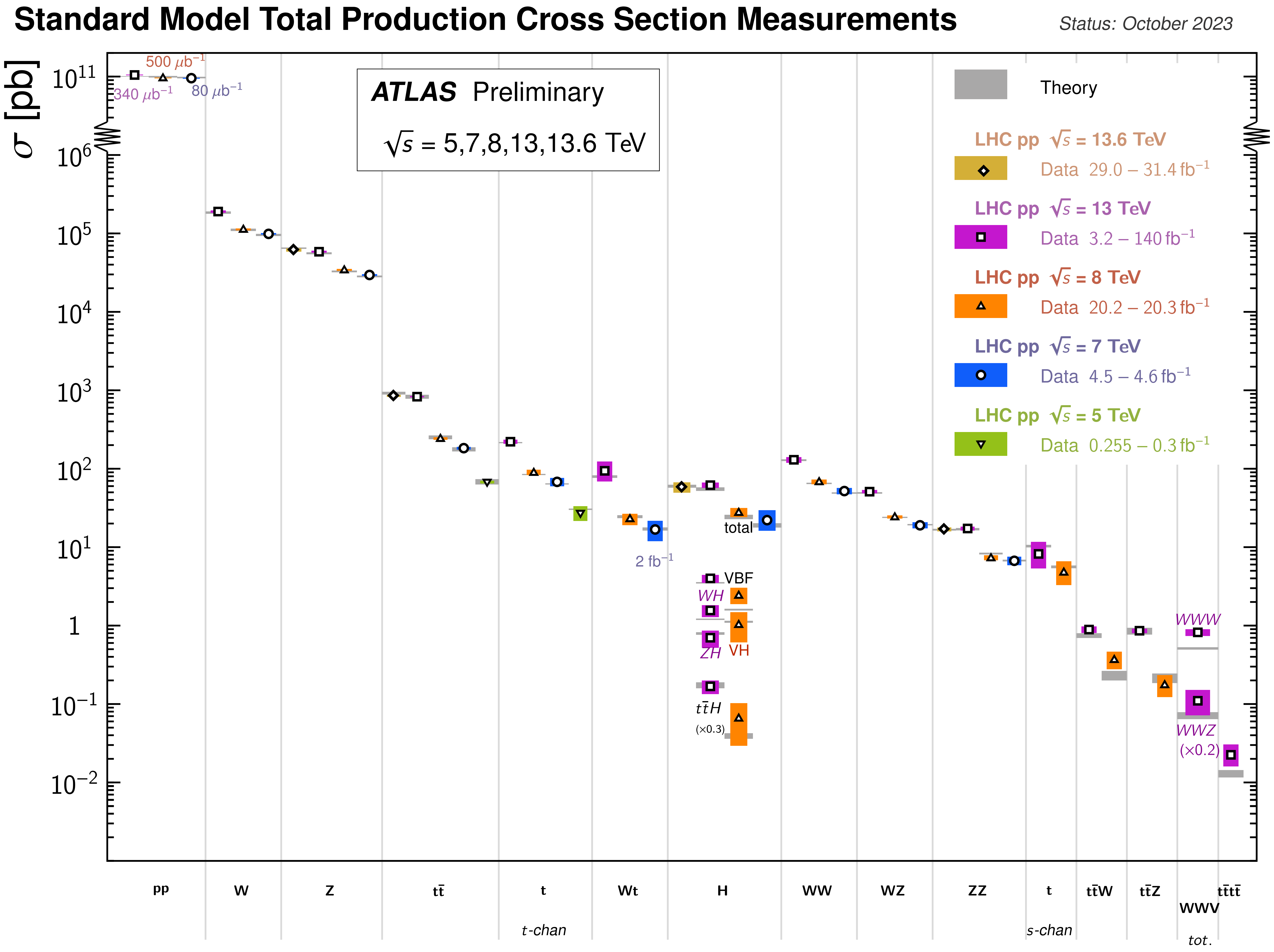
Testing the SM

Top quark

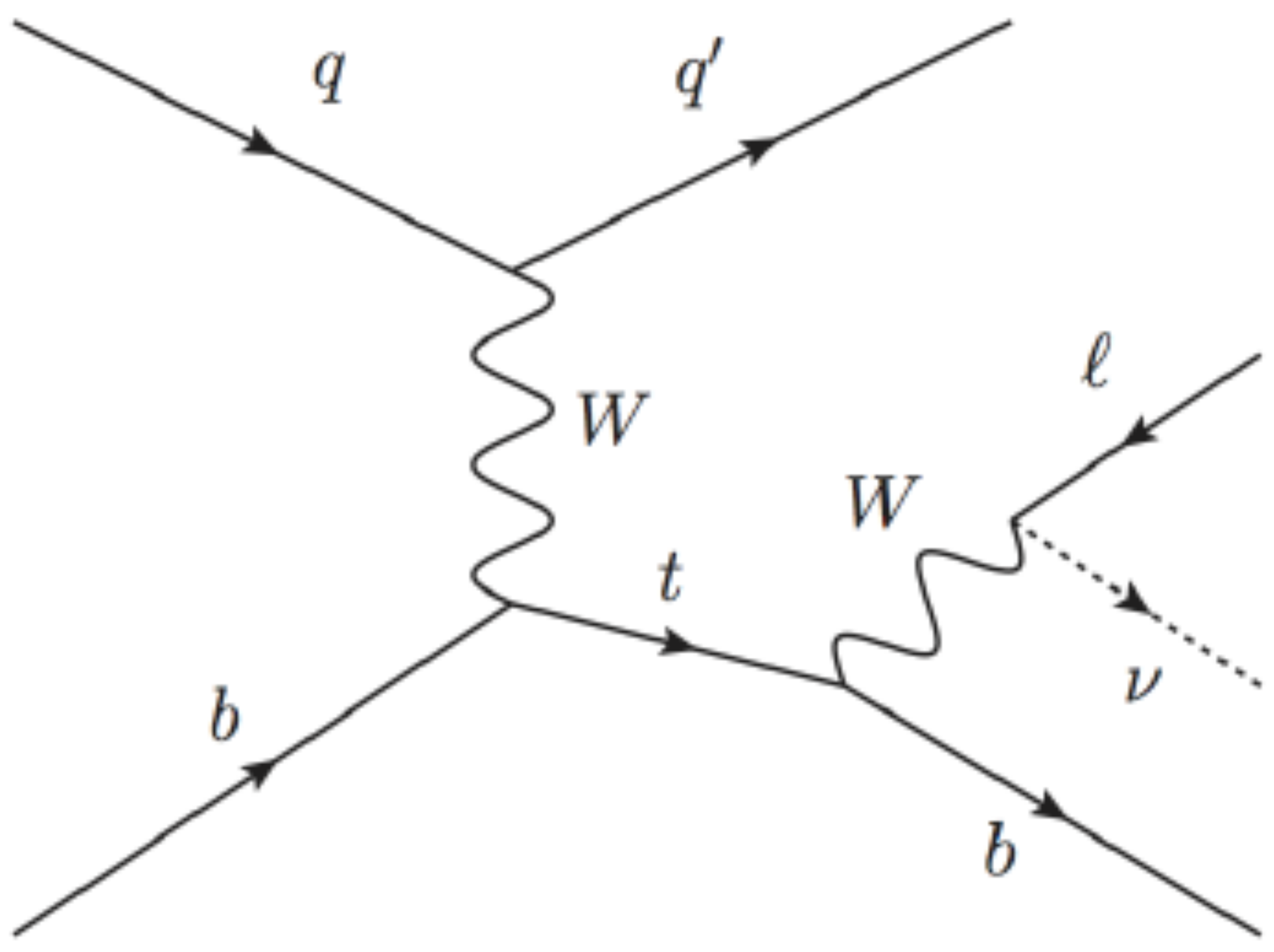
- Heaviest particle in the SM
- Only “bare” quark in the SM
- LHC is a true top factory
- No other running collider able to produce top quarks
- Focus of my PhD thesis

Higgs boson

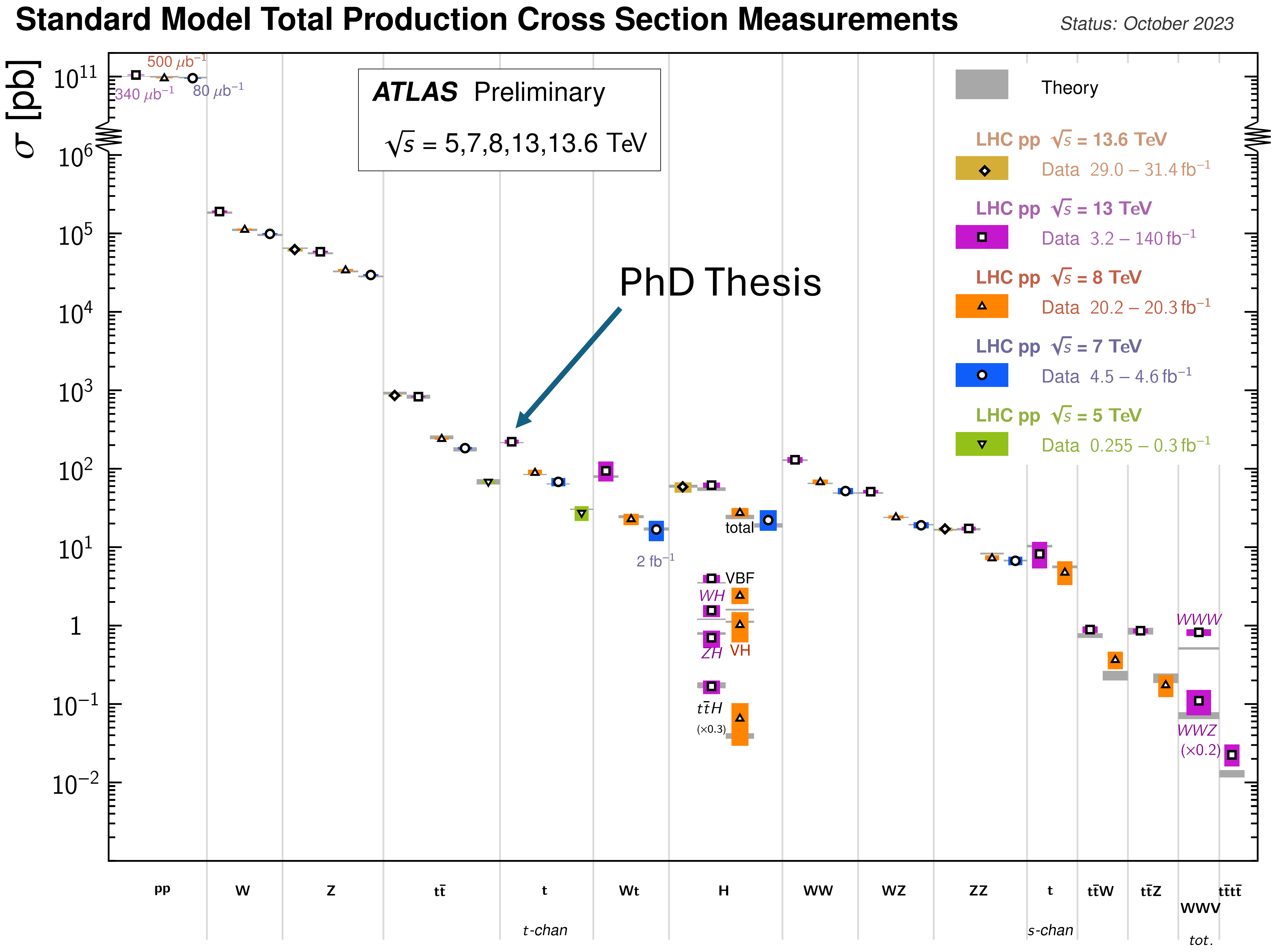
- Discovered in 2012
- Completed the SM
- Focus of my study here in Liverpool since November 2023



t-channel single top :

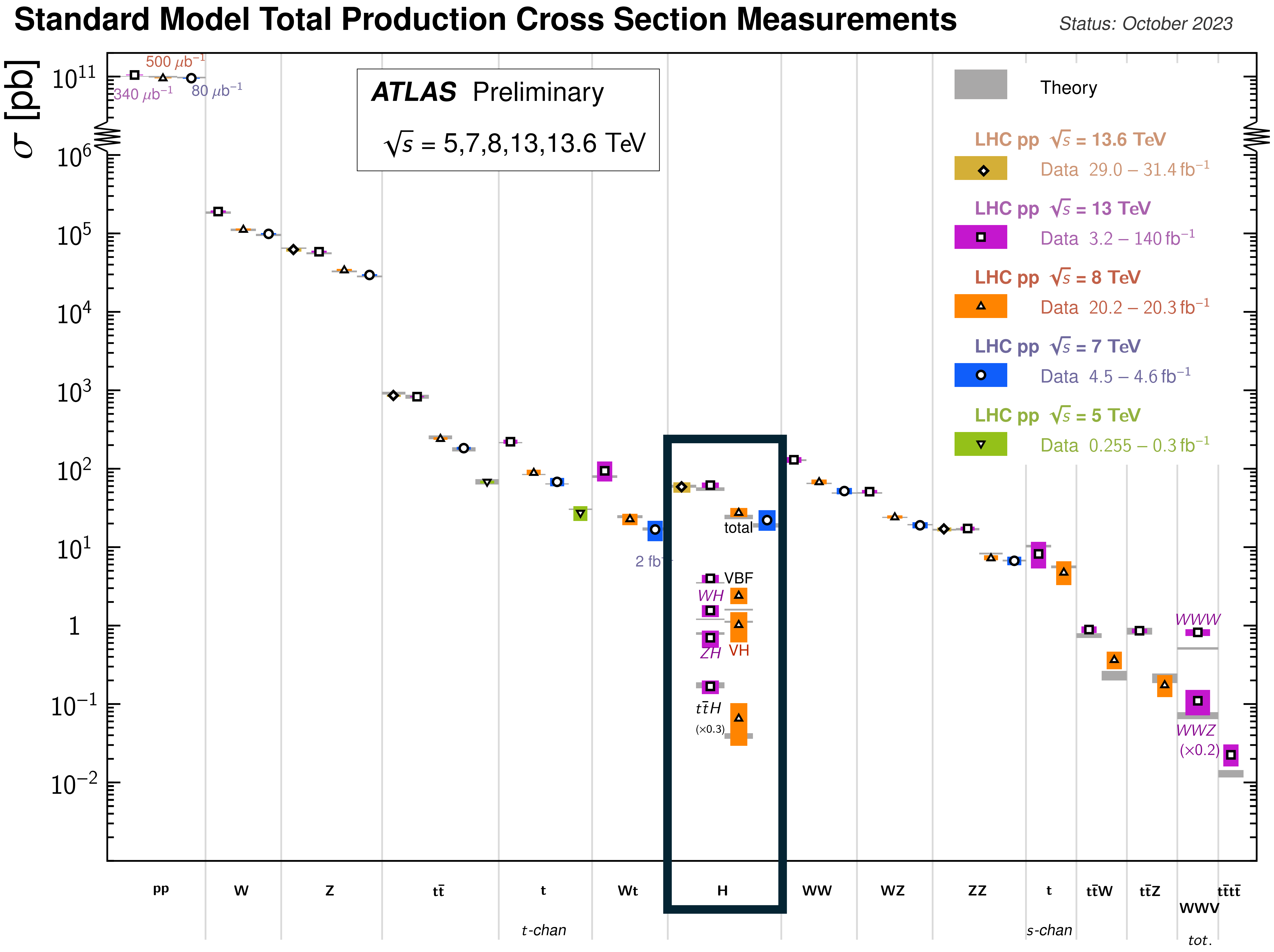


- Ideal probe for tW interactions
- ~30 million t-channel collisions produced at ATLAS in run 2
- Polarised production of tops



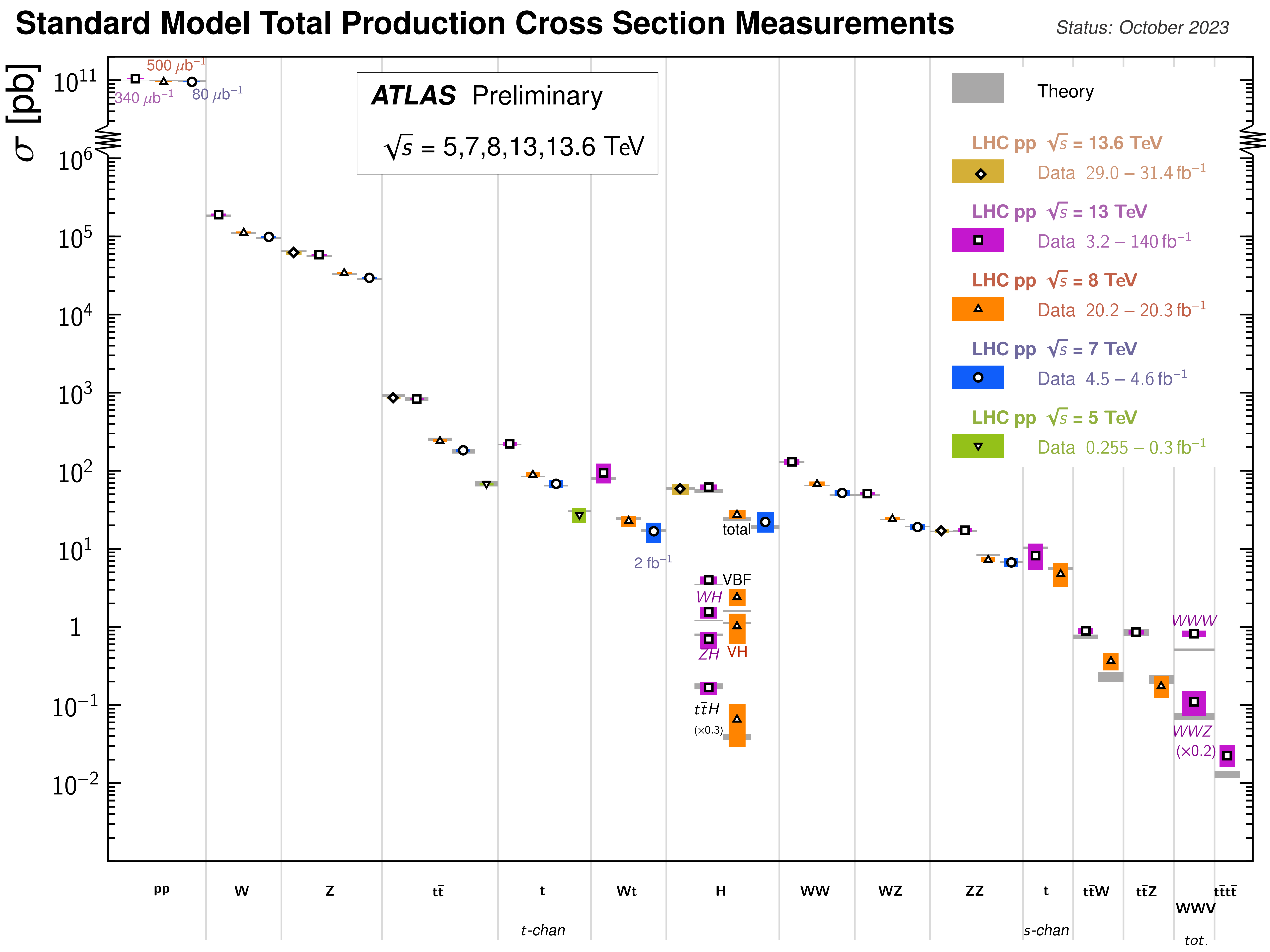
Higgs boson physics:

- Many different production mechanisms
- Many different decay modes
- Allows to study all different couplings of the Higgs boson
- ~9 million Higgs bosons produced at ATLAS in run 2



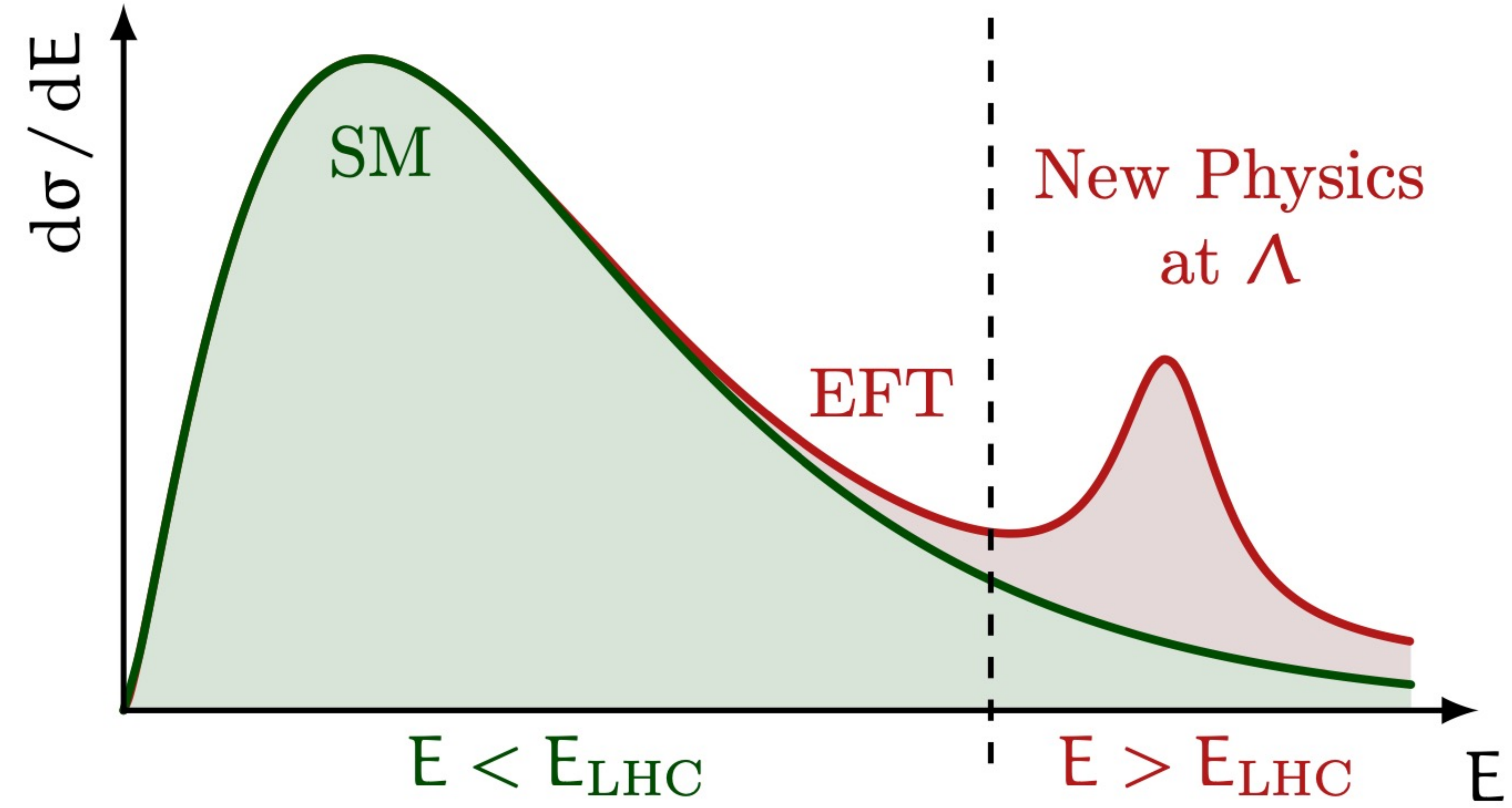
ATLAS physics program:

- Measure each process individually
- Combine individual measurements
- Search for new physics
  - Common way of interpretation is EFT



Effective Field Theory

- New Physics interactions out of reach for LHC energy



- Extend SM Lagrangian with higher order interactions:

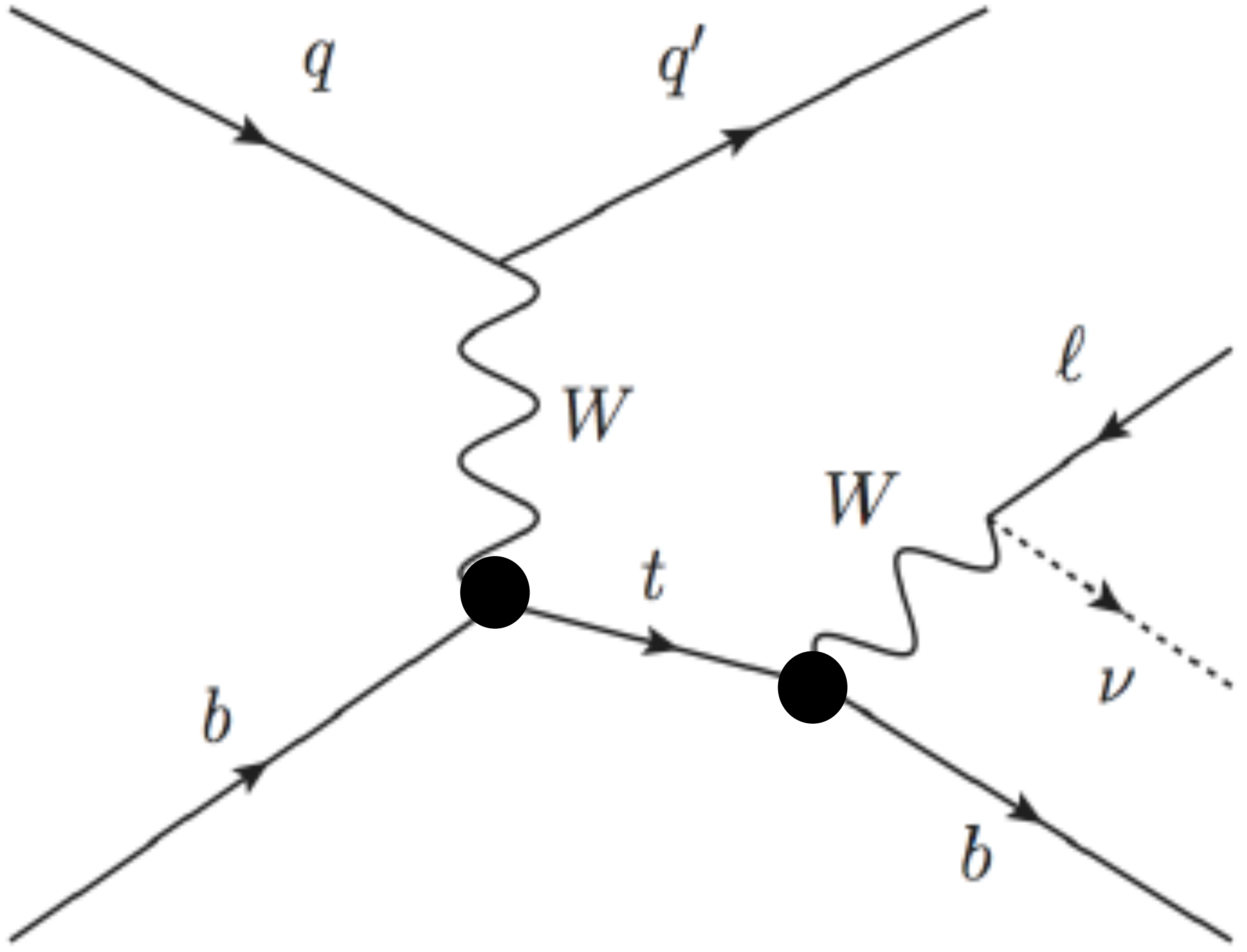
$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \frac{c_i}{\Lambda^2} O_i^6$$

- Due to interference with SM can measure small deviations of SM processes
- Allows to search for new physics across different processes in a systematic way

Effective Field Theory in t-channel

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \frac{c_i}{\Lambda^2} O_i^6$$

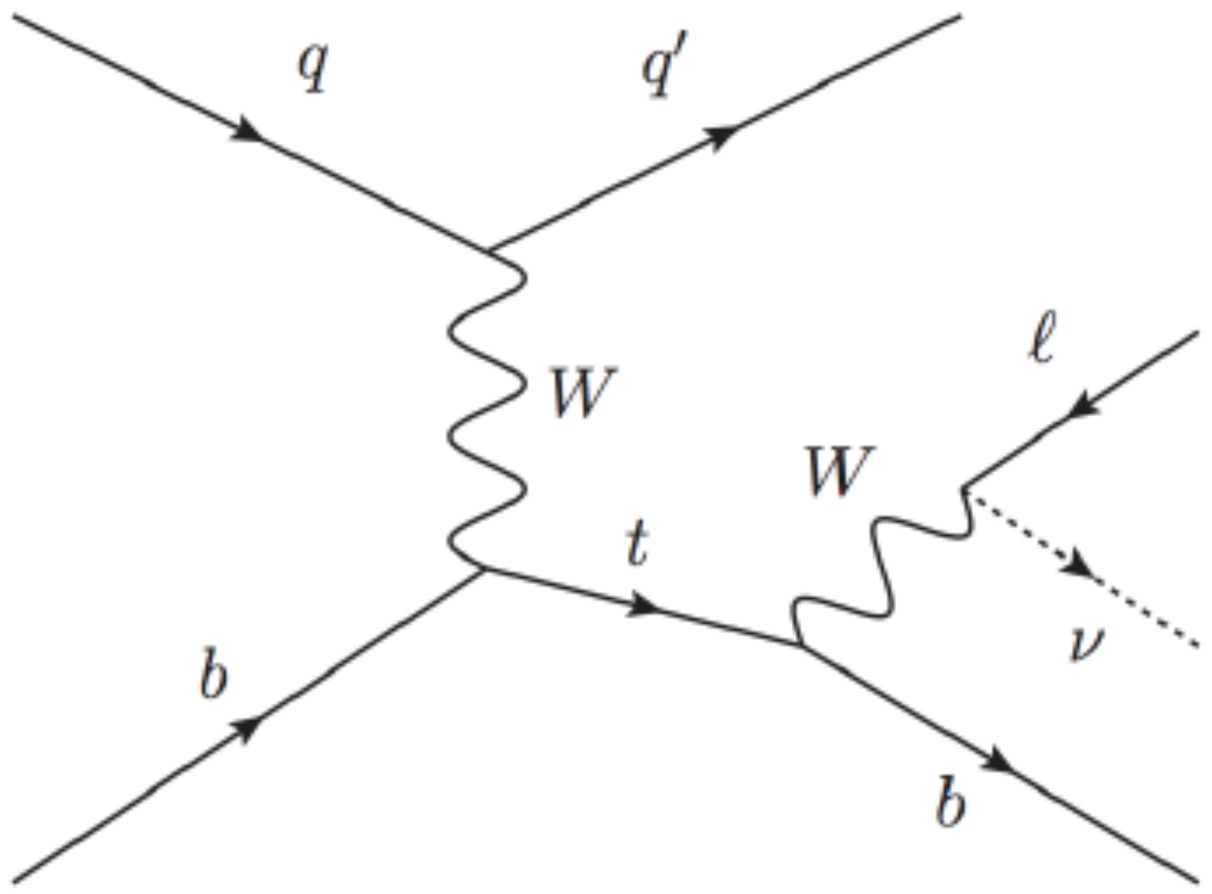
- $\mathcal{O}_{\phi Q}^{3}$ -> cross-section only
- $\mathcal{O}_{qQ}^{3,1}$ **-> p_T - spectrum**
- $\mathcal{O}_{tW}$ **-> angular variables**
  - **Real coefficient (c_{tW})**
    - **New (chiral) right-handed interaction**
  - **Imaginary coefficient (c_{itW})**
    - **Linked to new CP-violating interaction**

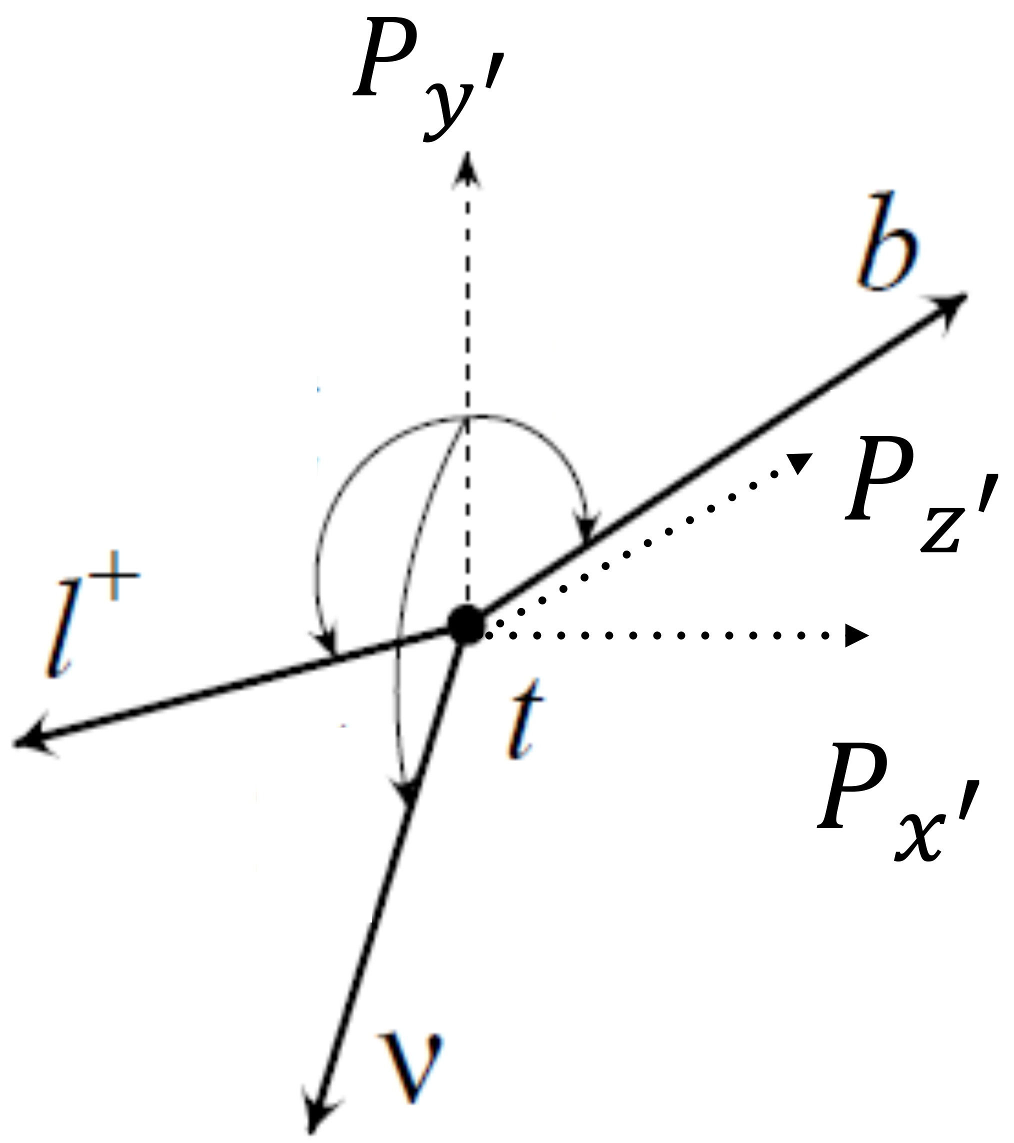


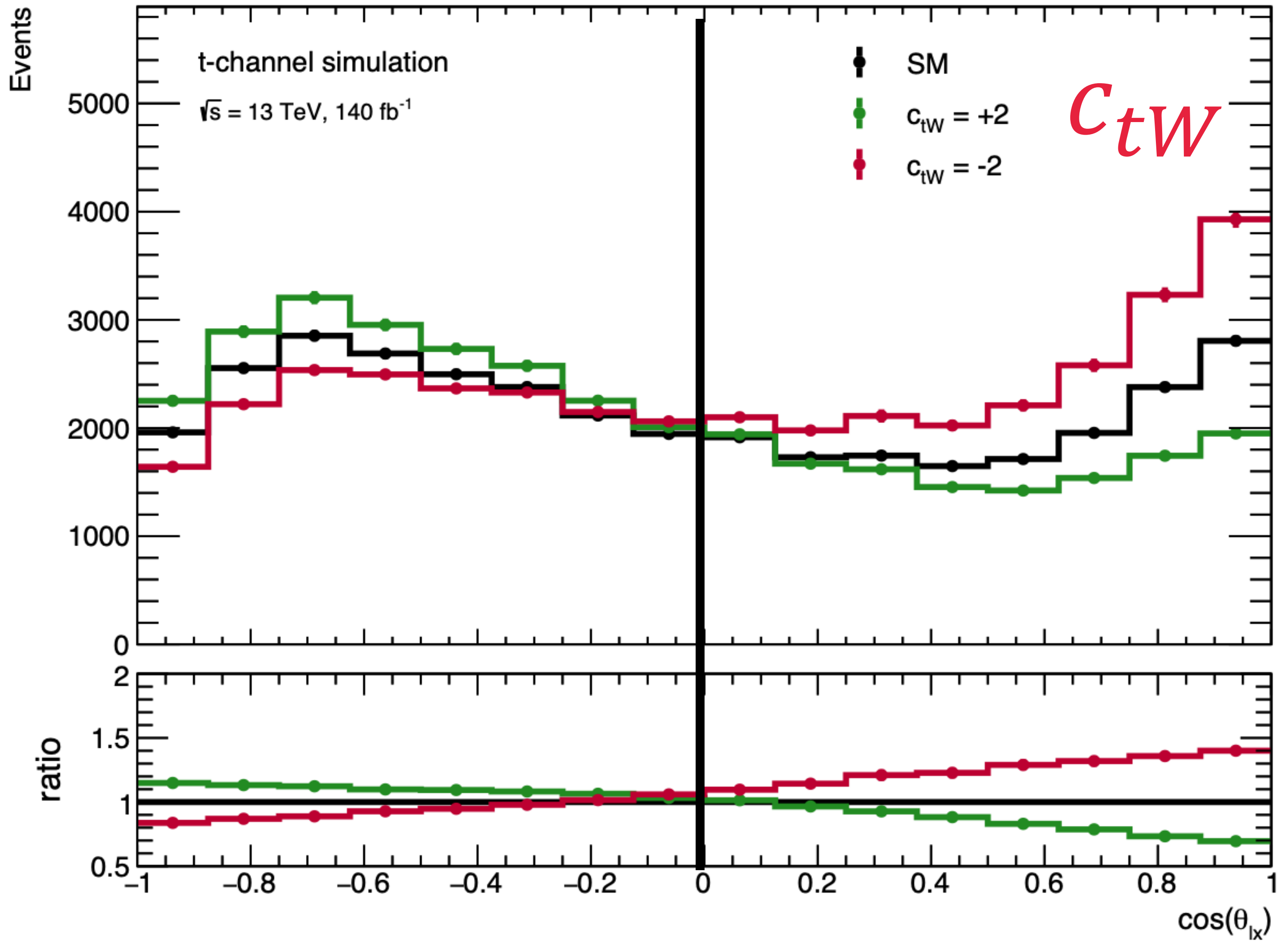
- **Create analysis with focus on measuring EFT parameters after reconstruction**

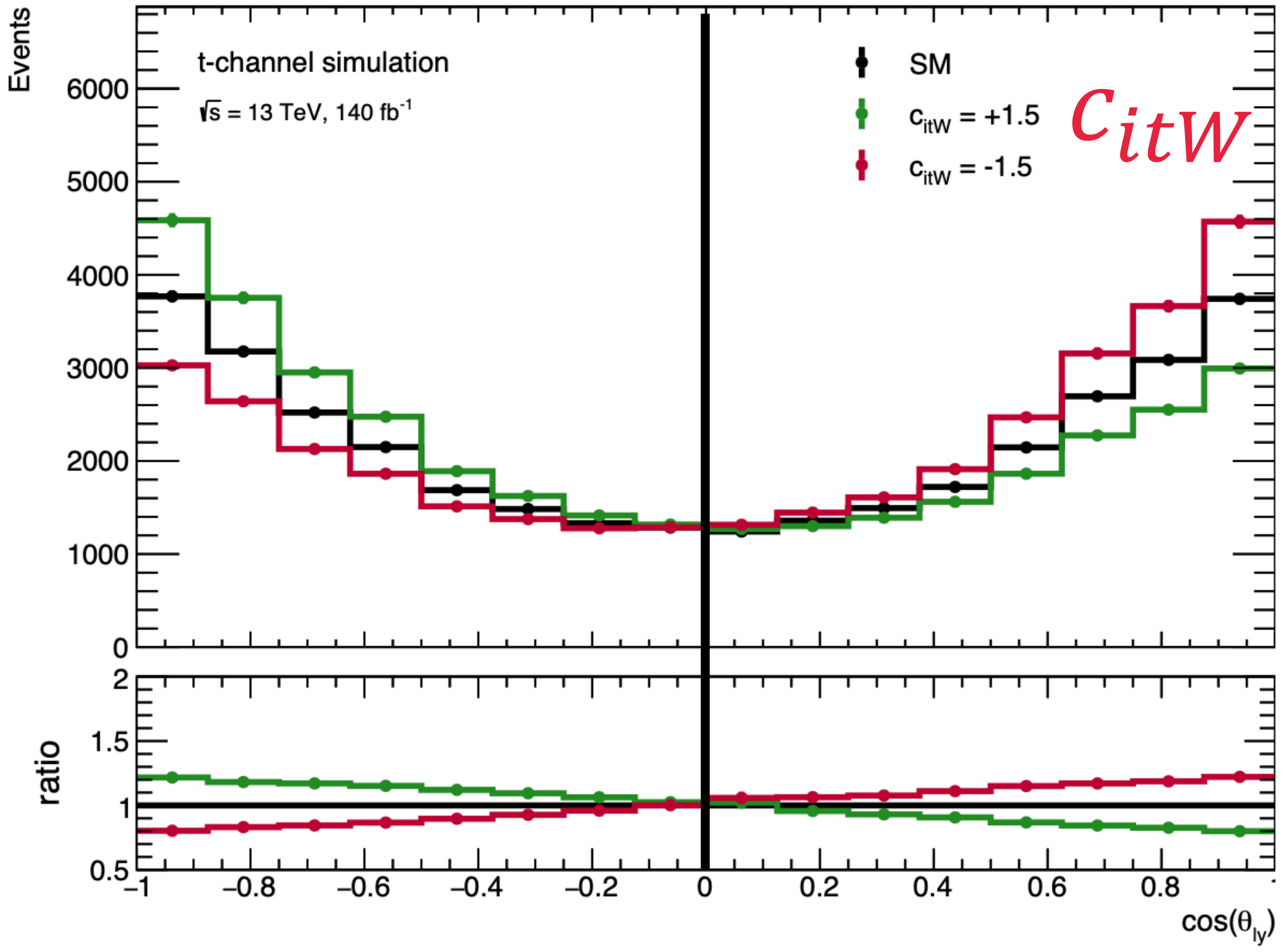
EFT sensitivity

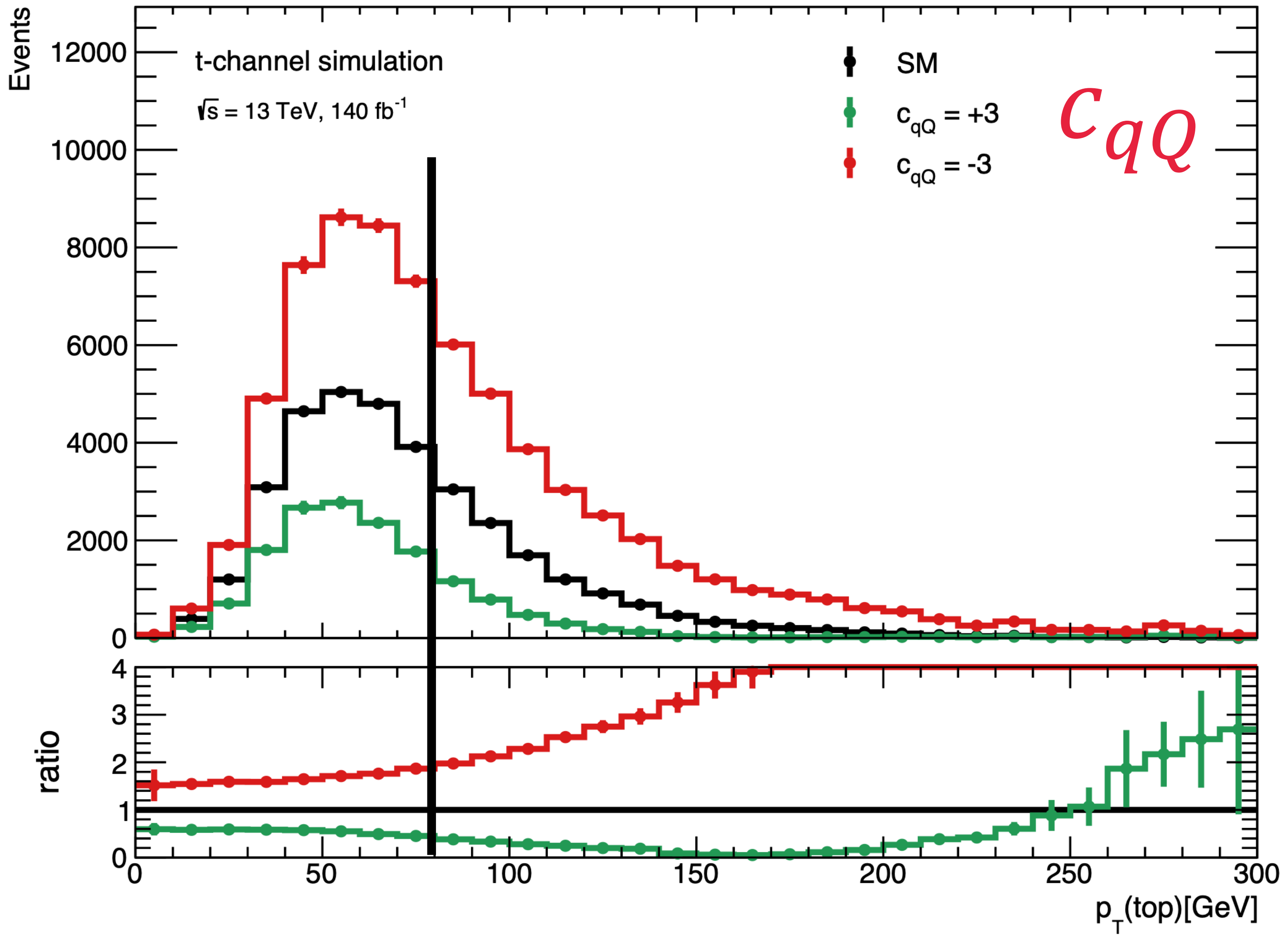
- Use top spin axis to create 3-dimensional coordinate system
- Measure angle of lepton in this coordinate system
- Combine with top momentum measurement





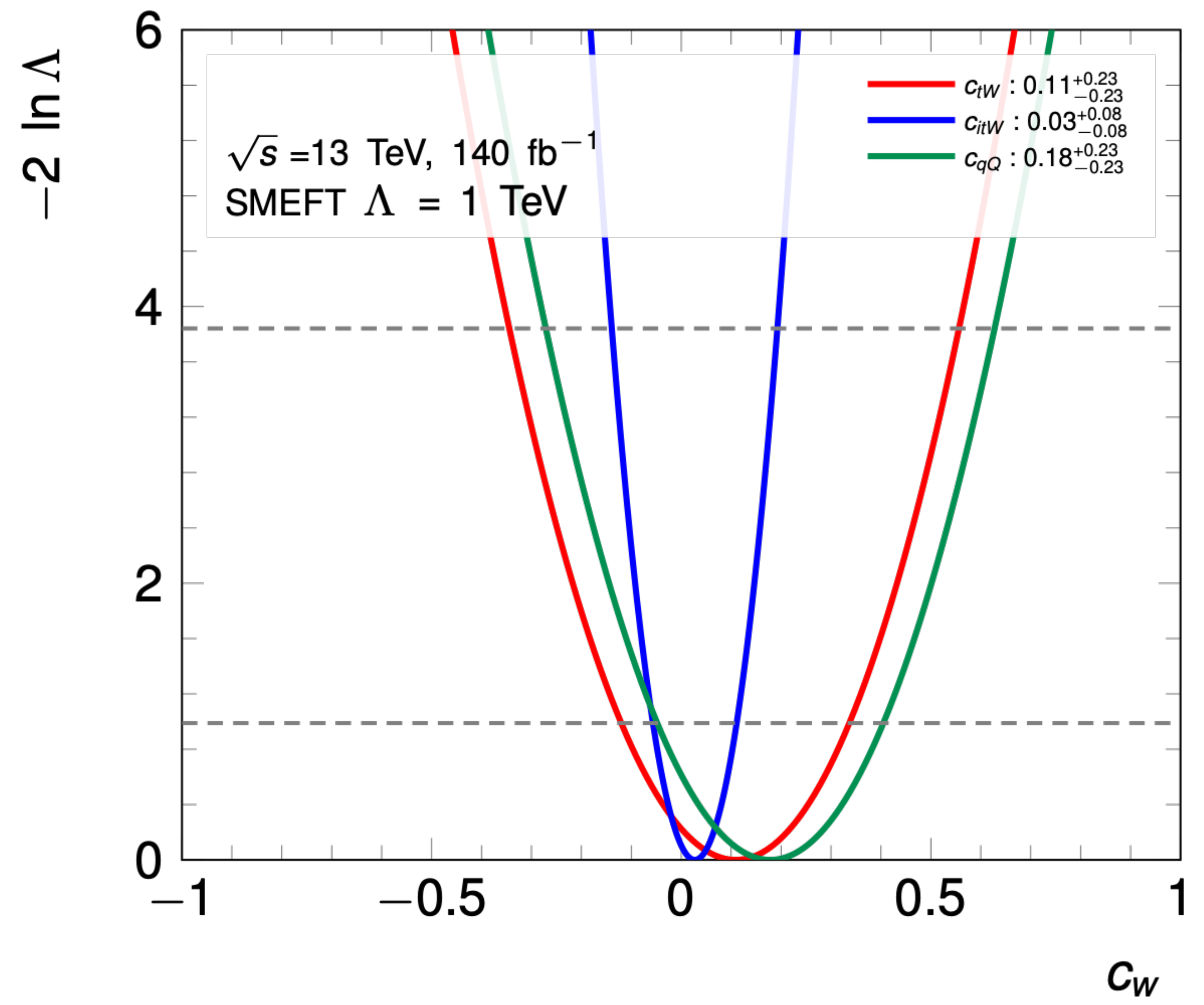


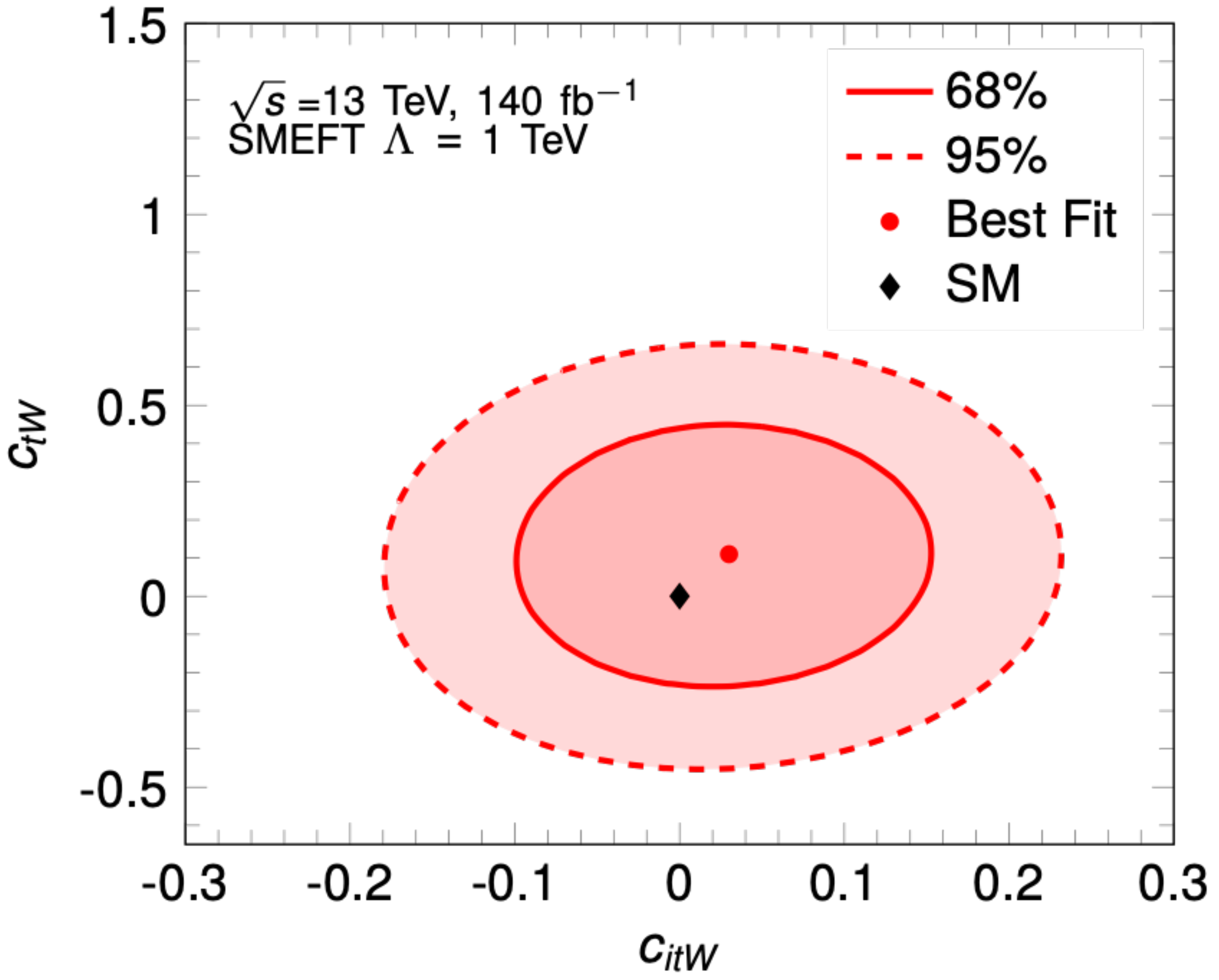


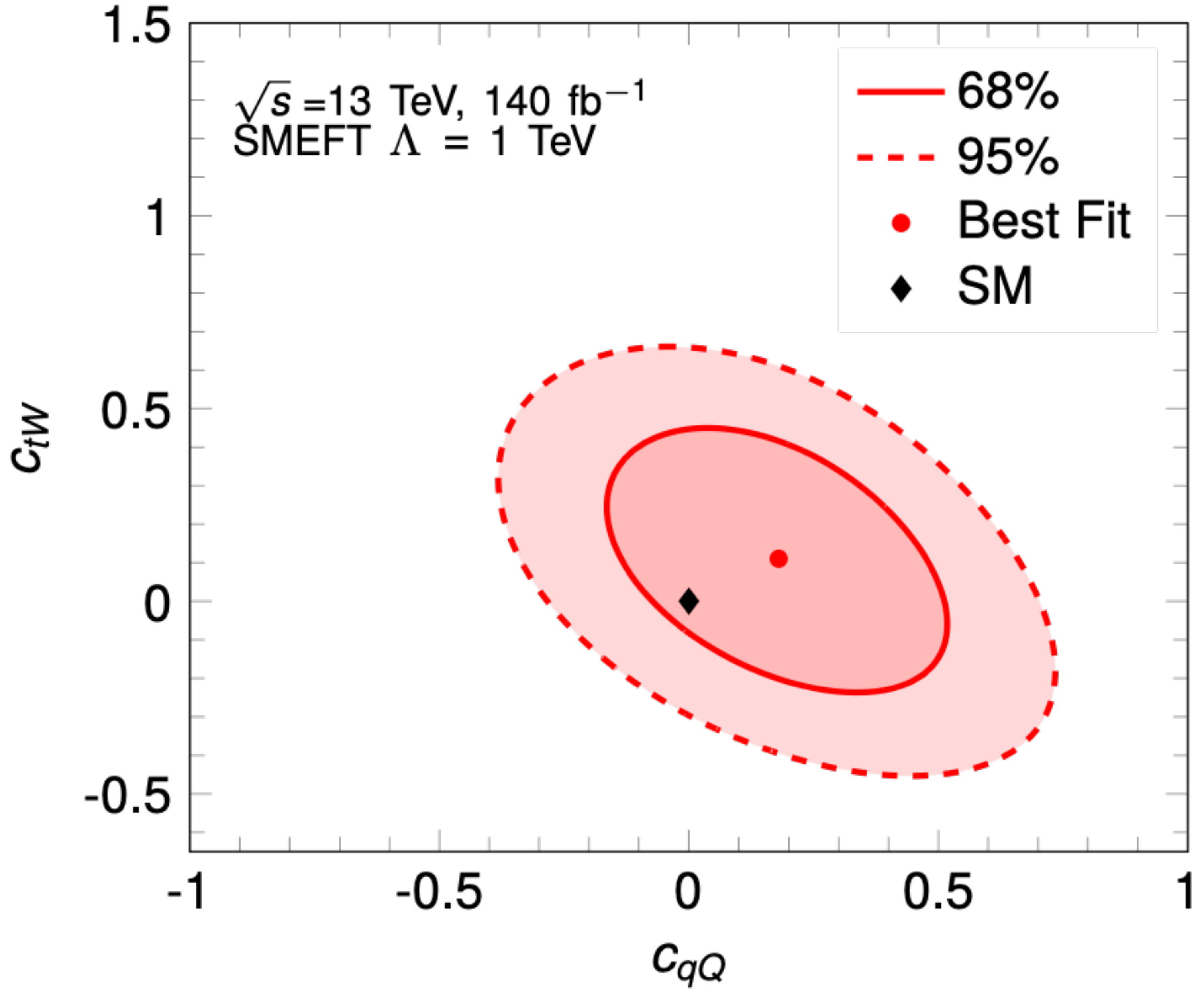


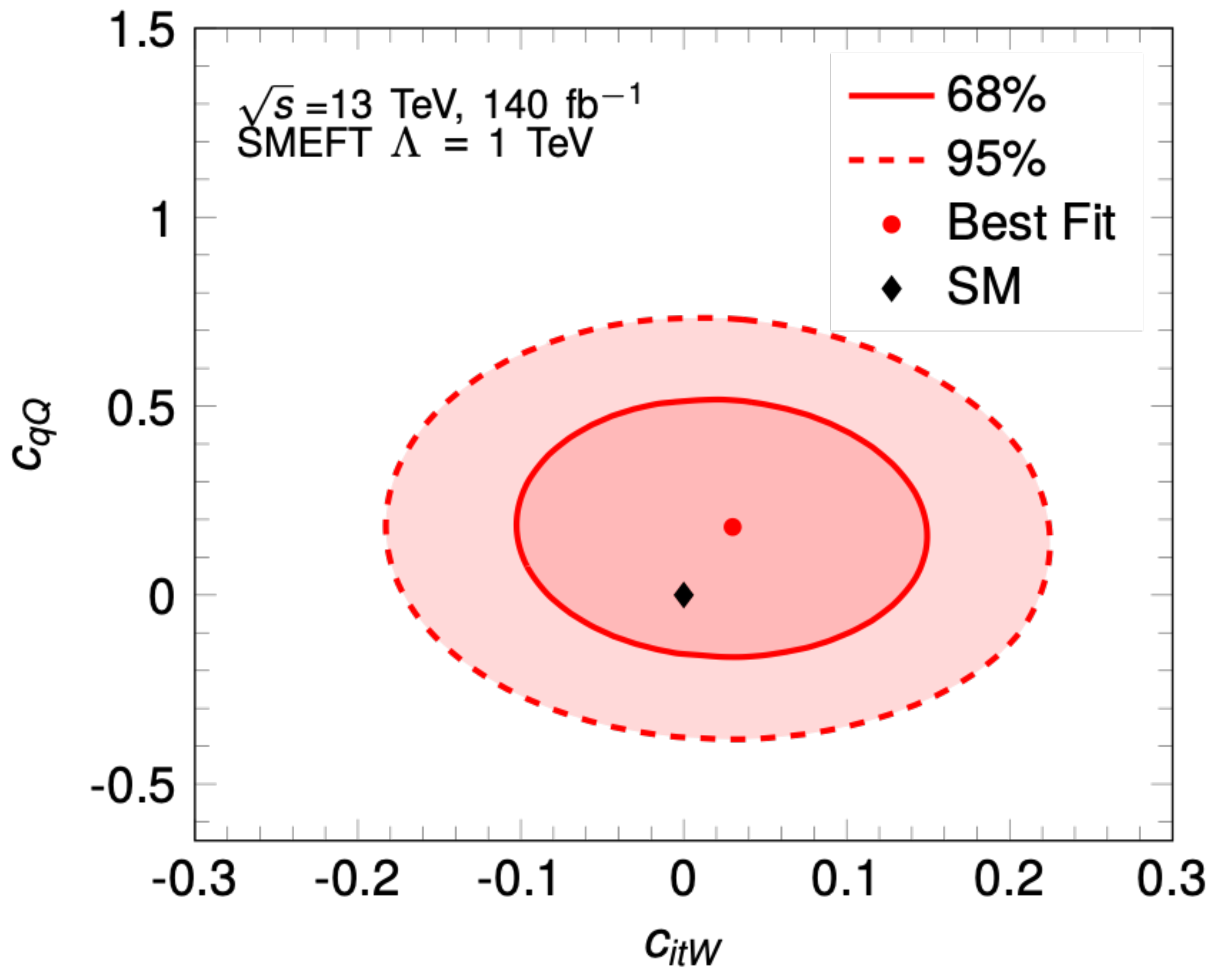
Maximum likelihood Fit

- First simultaneous EFT measurement in t-channel interactions
- Best limit on c_{itW}
- No new (CP-violating) interactions found in top interactions
- Input to a global EFT combination



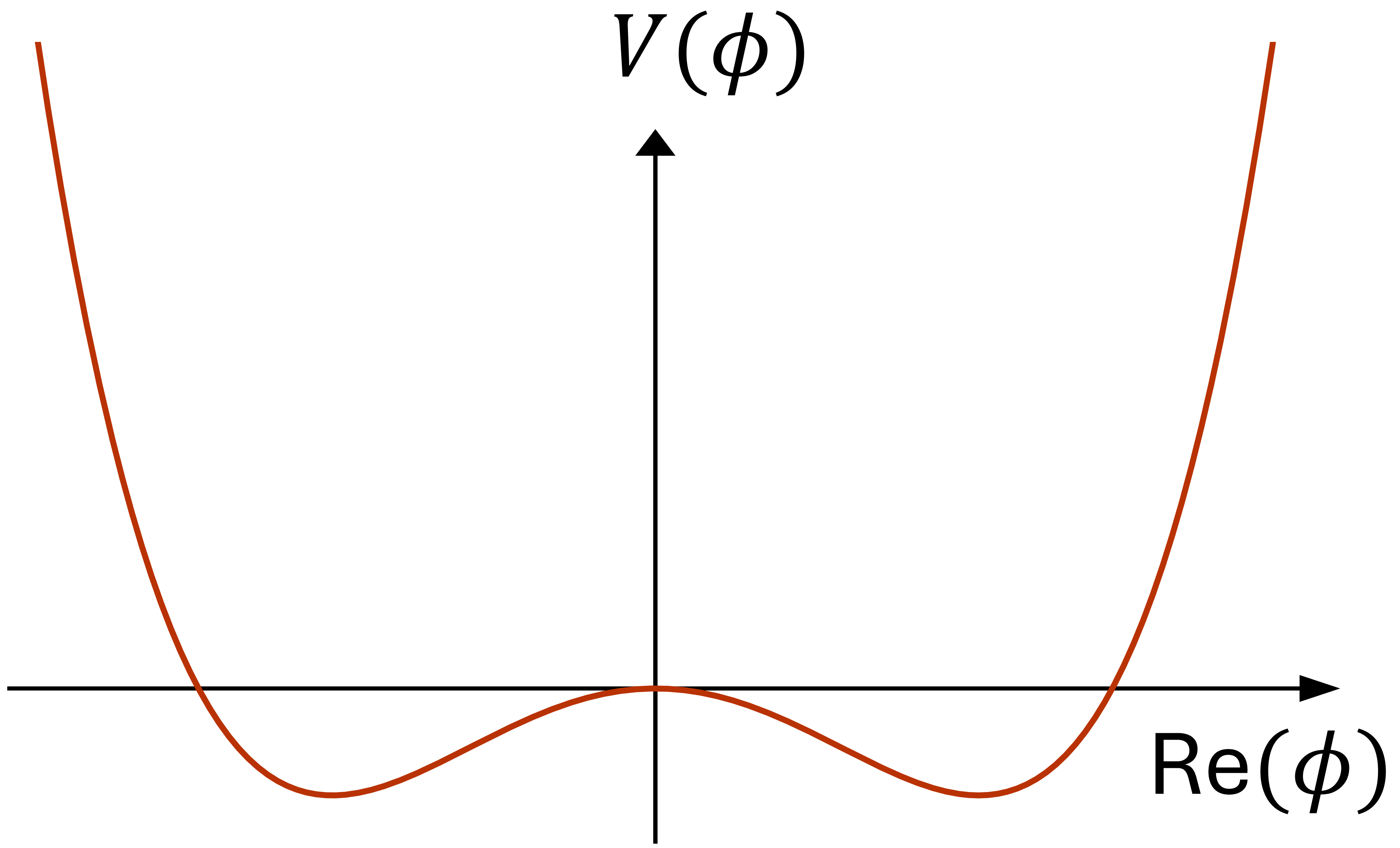






The Higgs boson

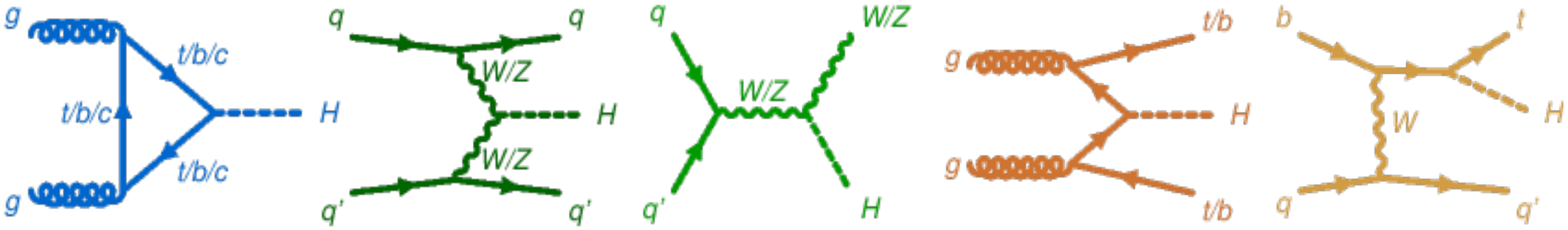
$$\mathcal{L}_{\mathrm{SM}} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu}$$
$$+ i\bar{\psi}\not{D}\psi$$
$$+ |D_\mu\phi|^2 - \mu^2(\phi^\dagger\phi) - \lambda(\phi^\dagger\phi)^2$$
$$+ y_{ij}\psi_i\phi\psi_j + \mathrm{h.c.}$$



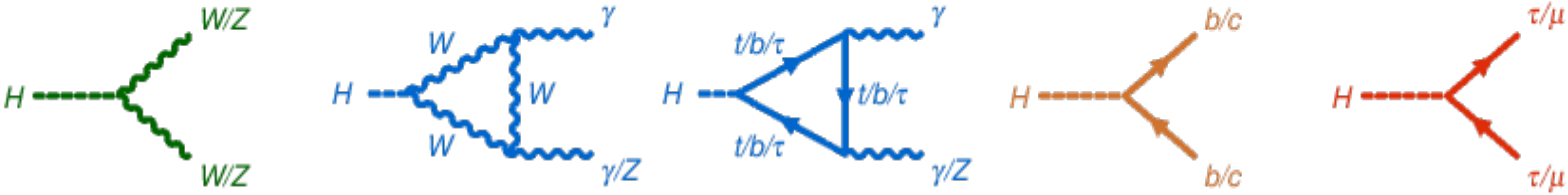
Higgs boson physics

- Many different production and decay modes
- Allows to measure many different Higgs interactions

Production modes:



Decay modes:



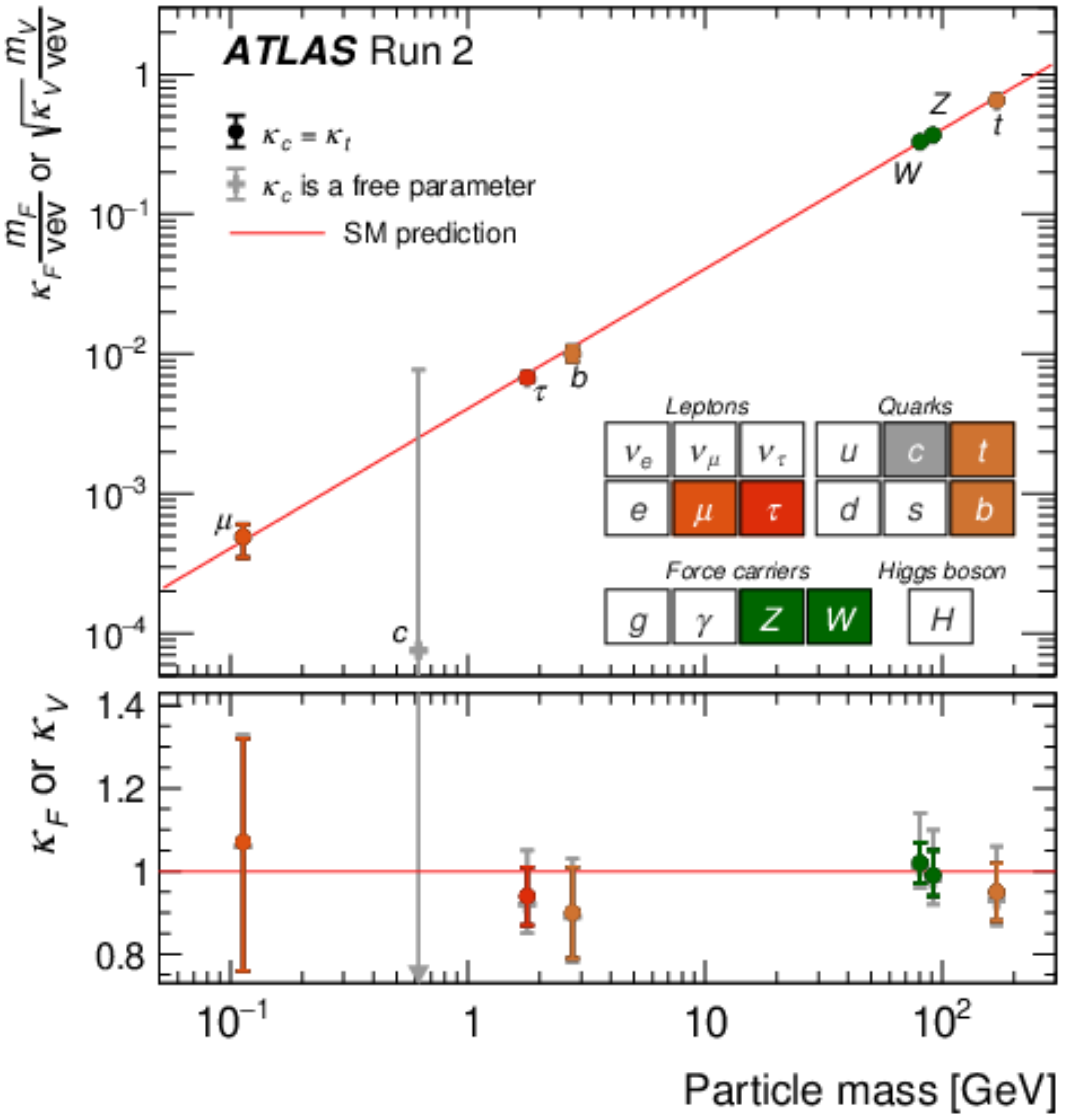
Where do we stand?

Higgs couples to Vector bosons

- W/Z couplings both measured
  - Including differential measurements
    - Number of additional jets
    - Momentum spectra

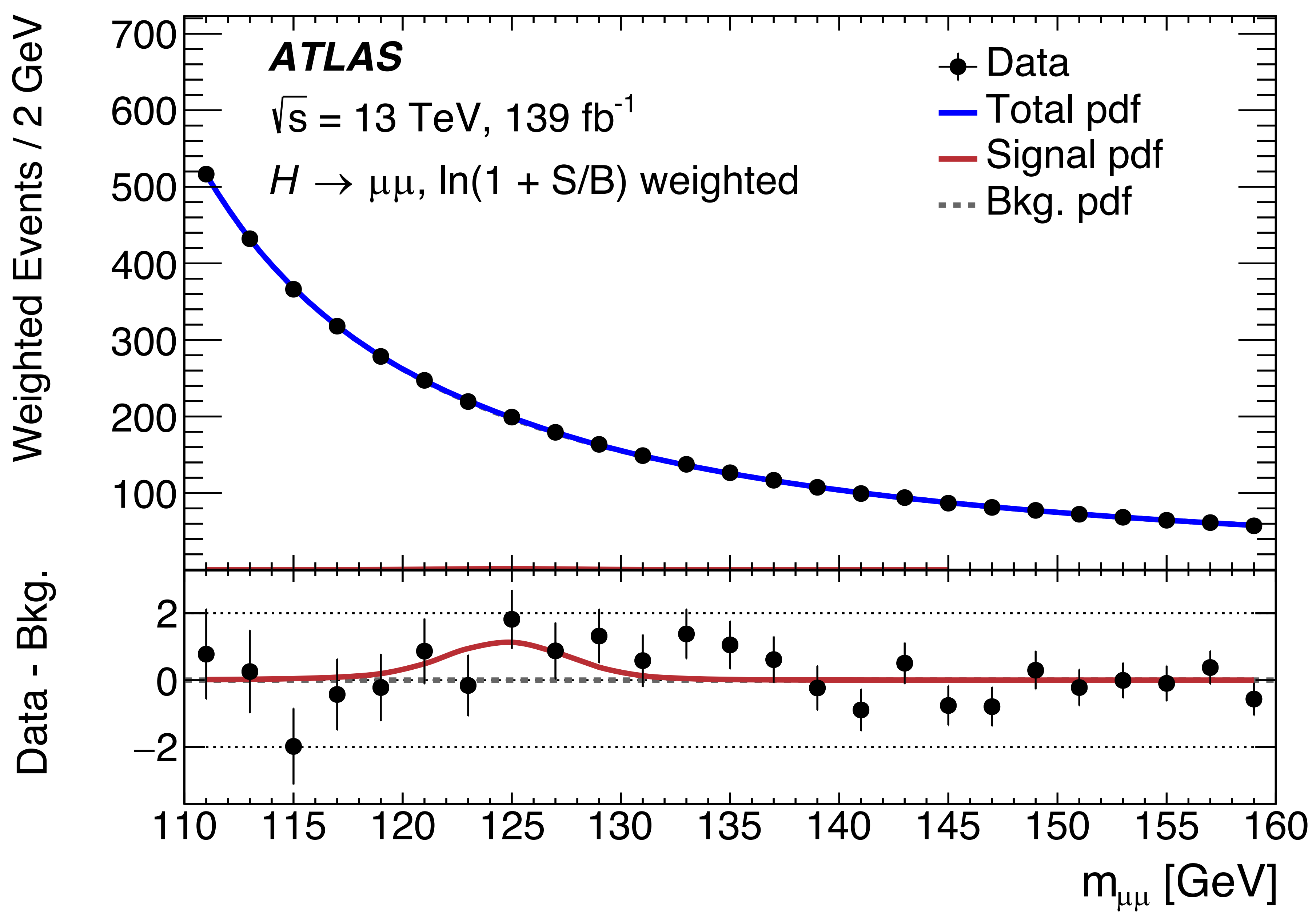
Higgs couples to 3rd generation of fermions

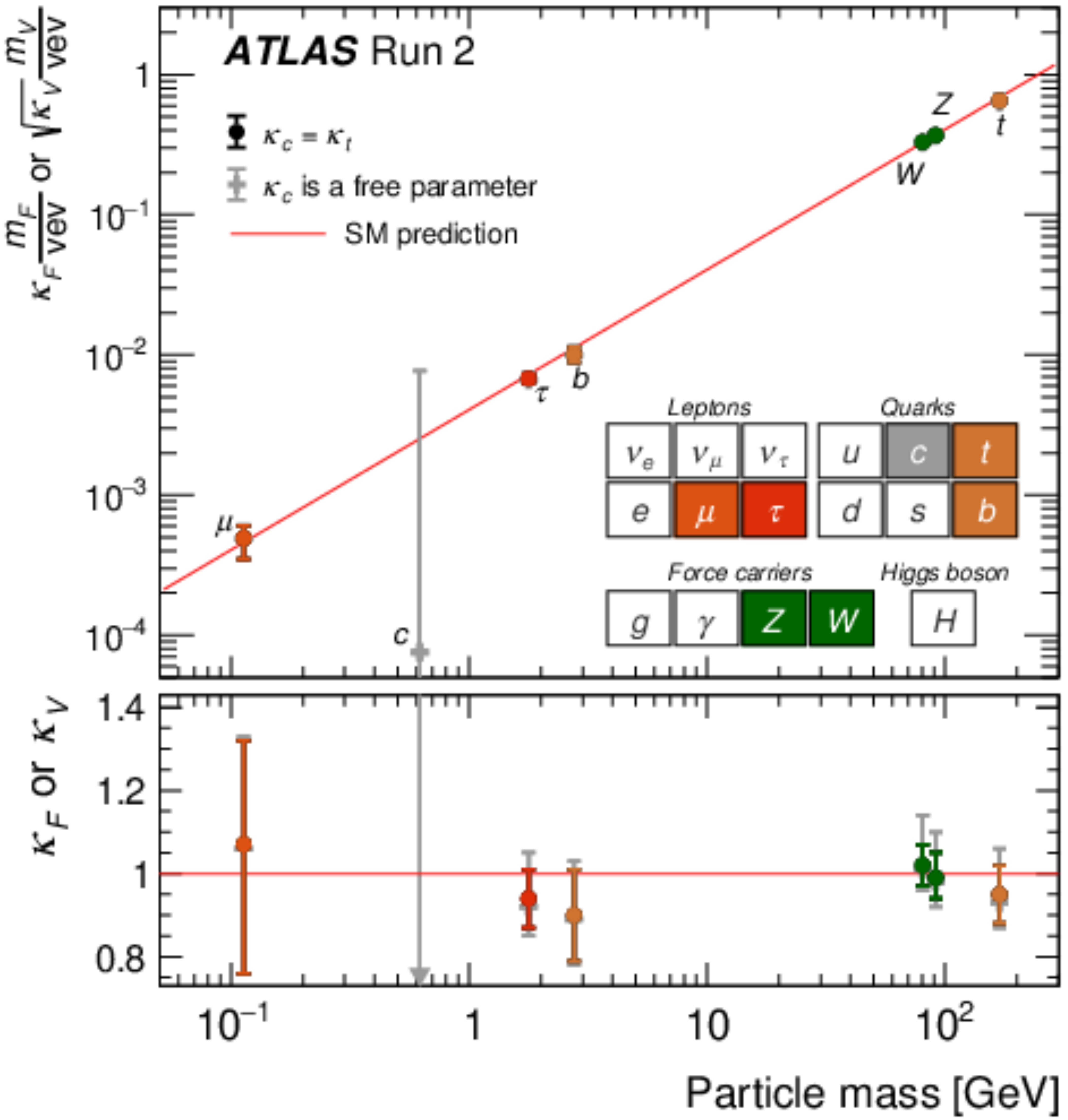
- top/b/τ couplings all measured
  - Including differential measurements
    - Number of additional jets
    - Momentum spectra
  - Long term contributions from Liverpool in H->bb final state (Andy, Carl)



What about other generation?

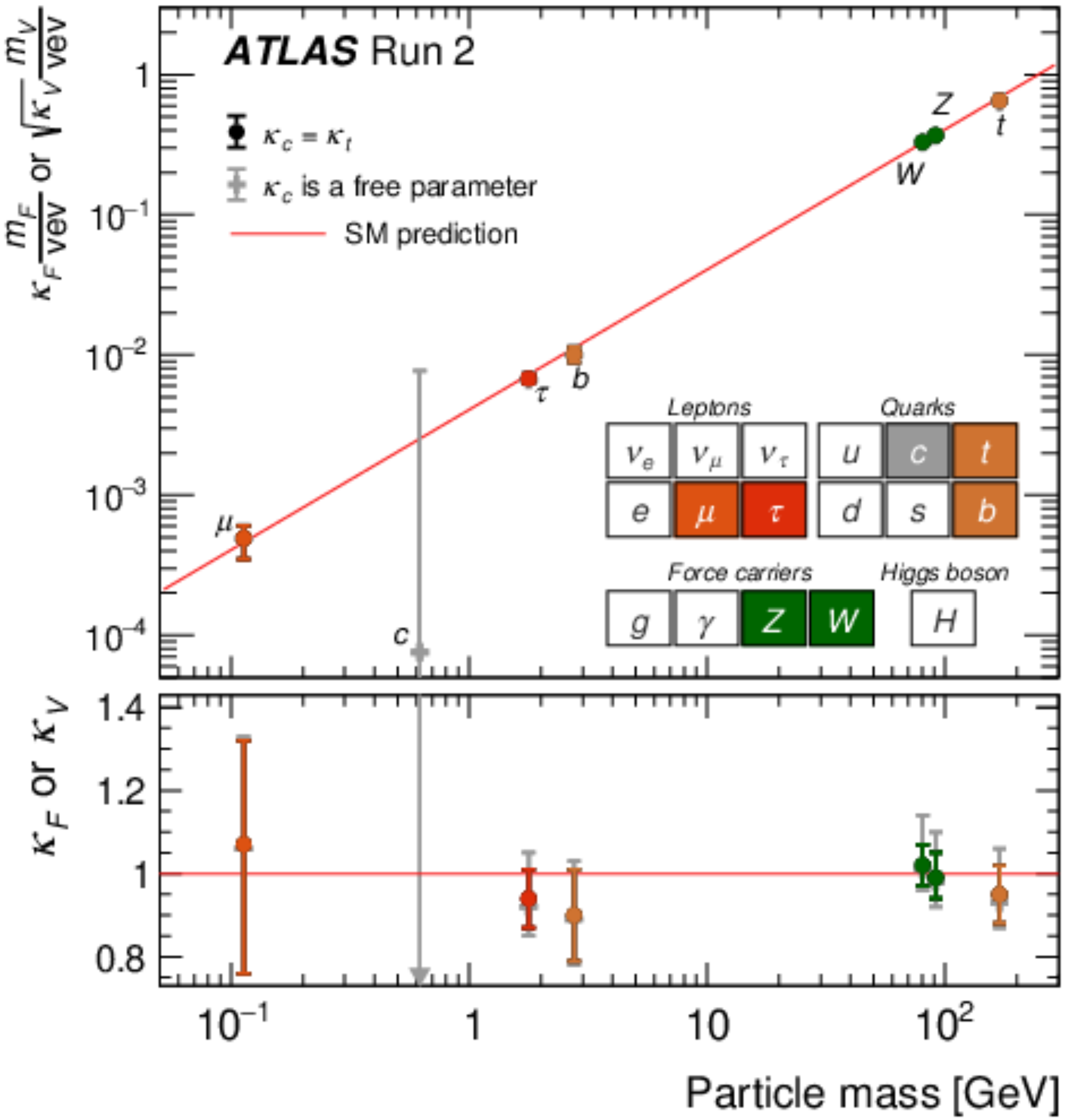
- H->$\mu\mu$ observed with ATLAS at 2 sigma (Jan)
- Run 3 analysis ongoing
  - Challenging with new muon forward detector NSW
  - Aim for 5 sigma observation of combined CMS + ATLAS measurement





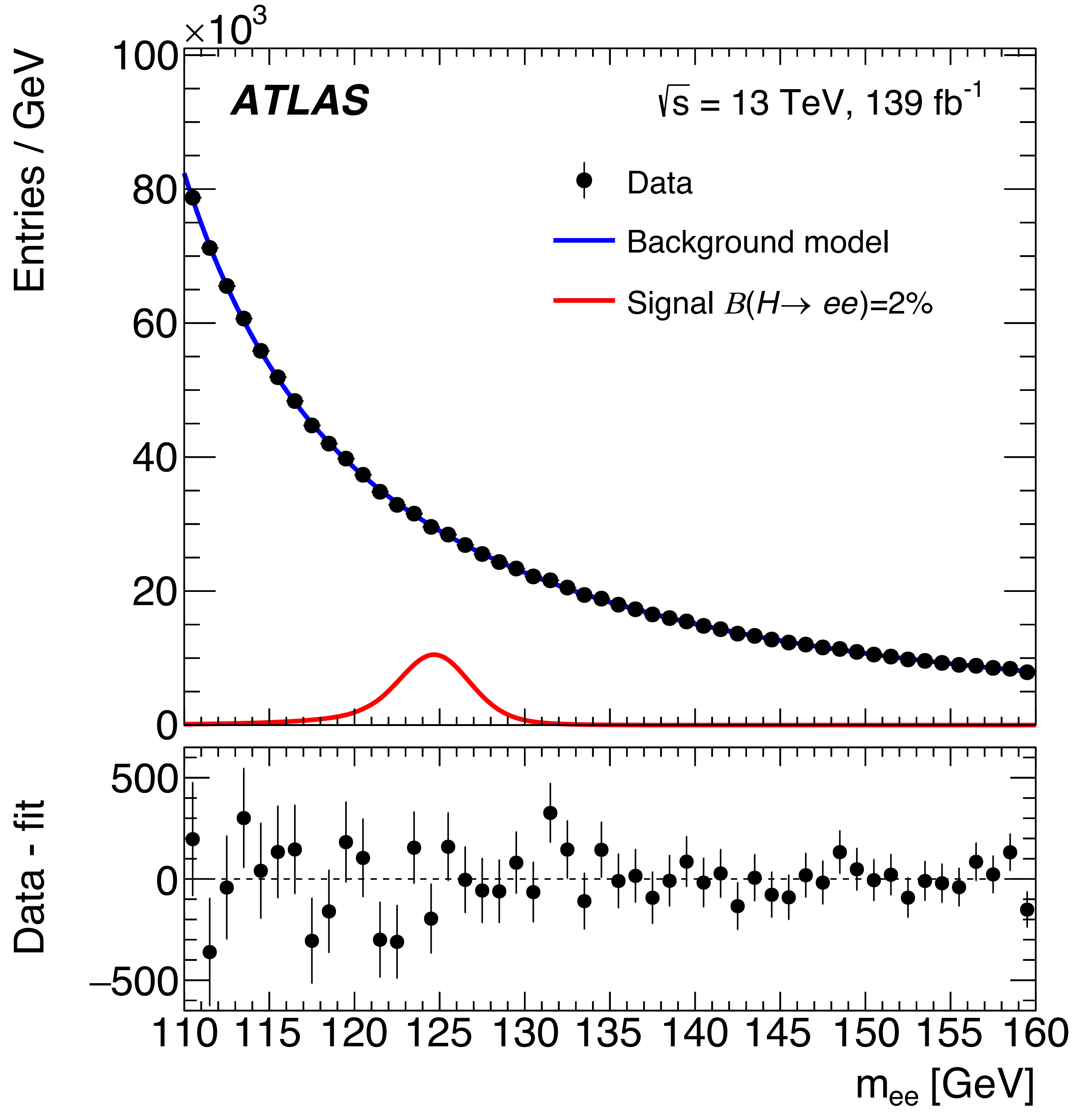
What about other generation?

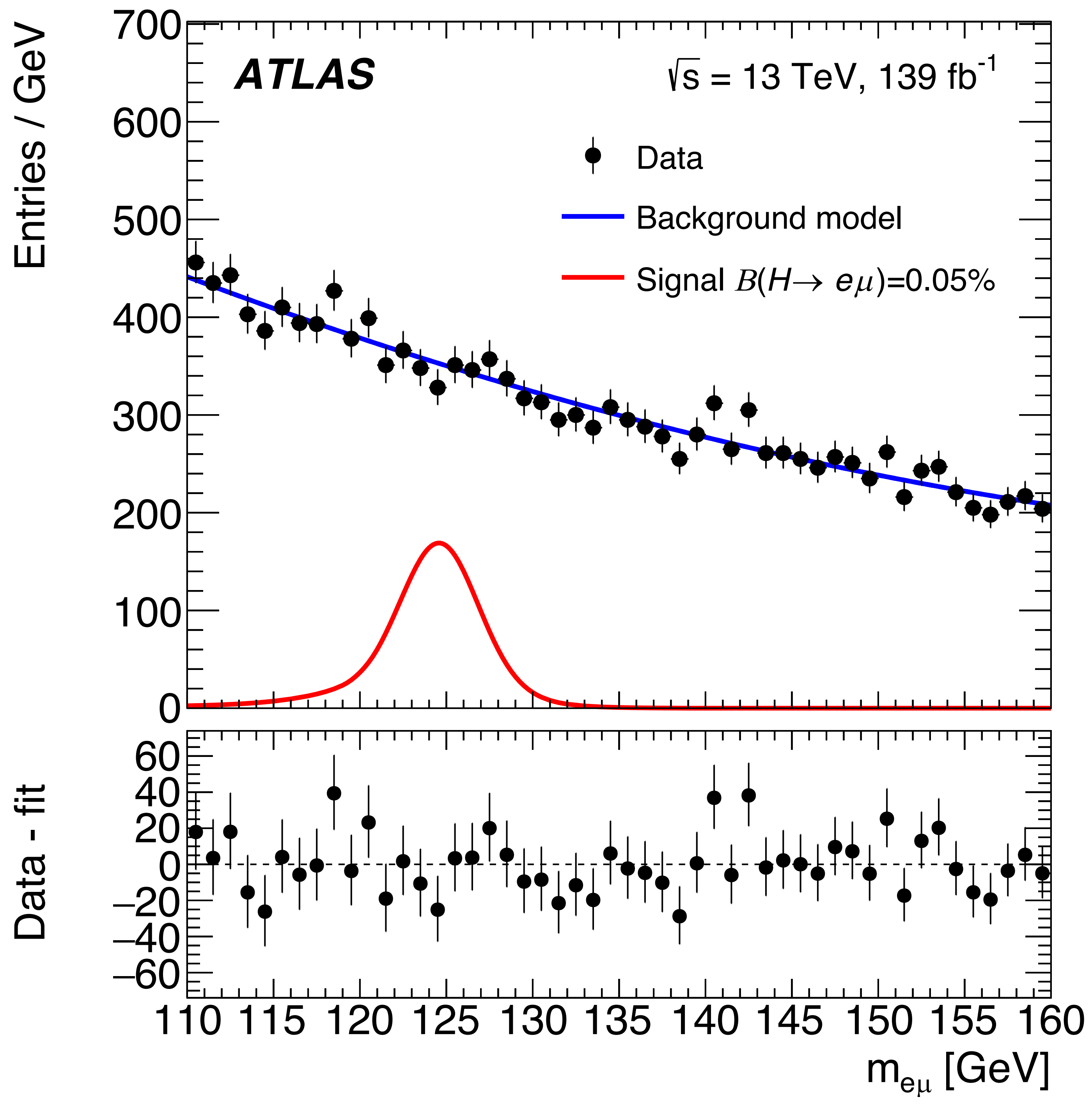
- H->cc observed (expected) limit of $\mu = 26$ (31)
  - Established different H coupling between b and c quarks
- Re-analysis of run 2 (Ting + Andy)
  - Simultaneously measure H->cc and H->bb
  - Improve sensitivity by factor 2-3
  - Aim for paper at ICHEP
  - Poster by Ting
- Start run 3 analysis of h->bb/cc

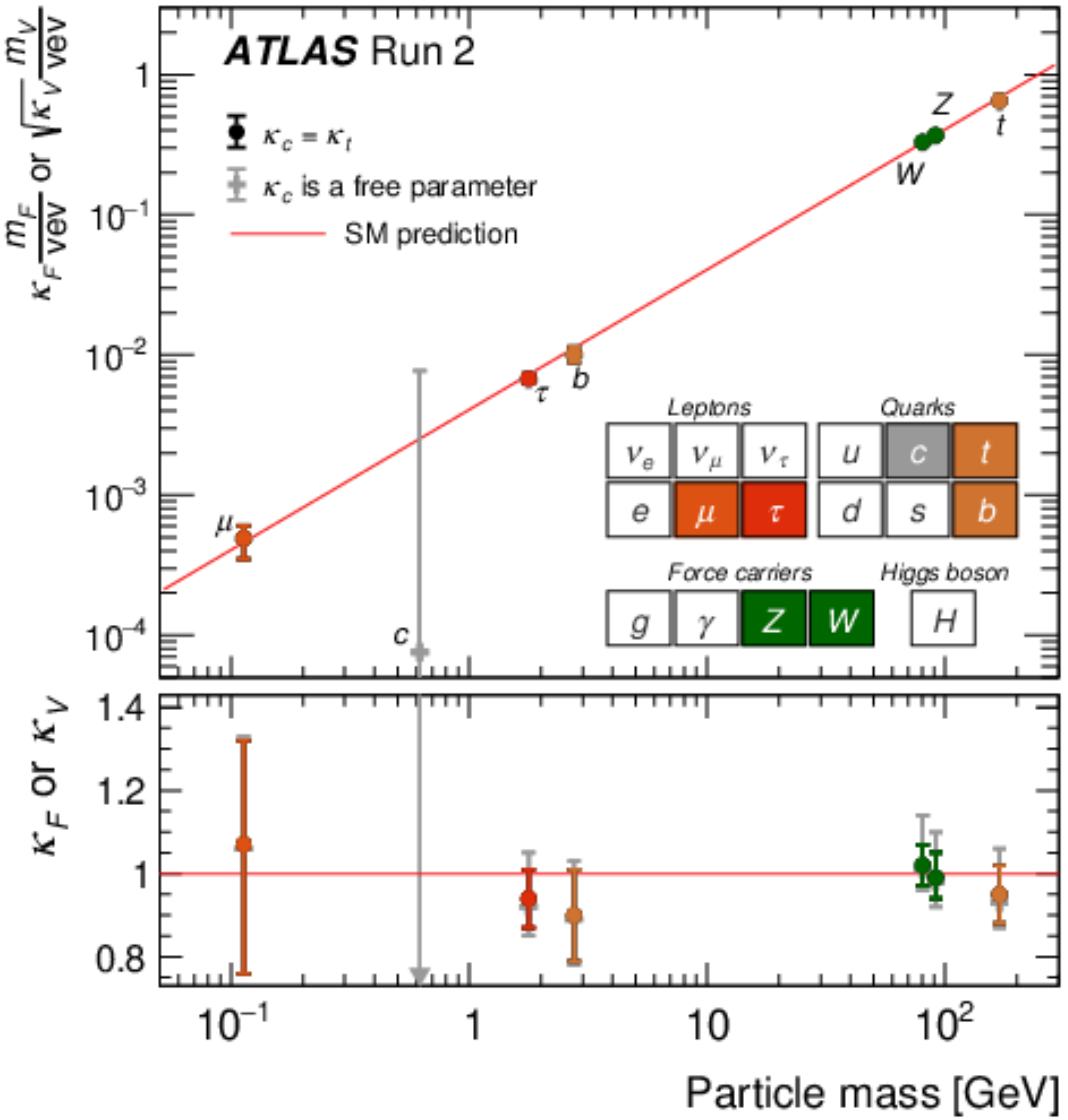


What about other generation?

- 1st generation hard to access (Andy, Jan)
  - 95% CL H->ee branching fraction of $3.6 \cdot 10^{-4}$
  - 95% CL LFV H→eμ branching fraction of: $6.2 \cdot 10^{-5}$
  - Best limits to date





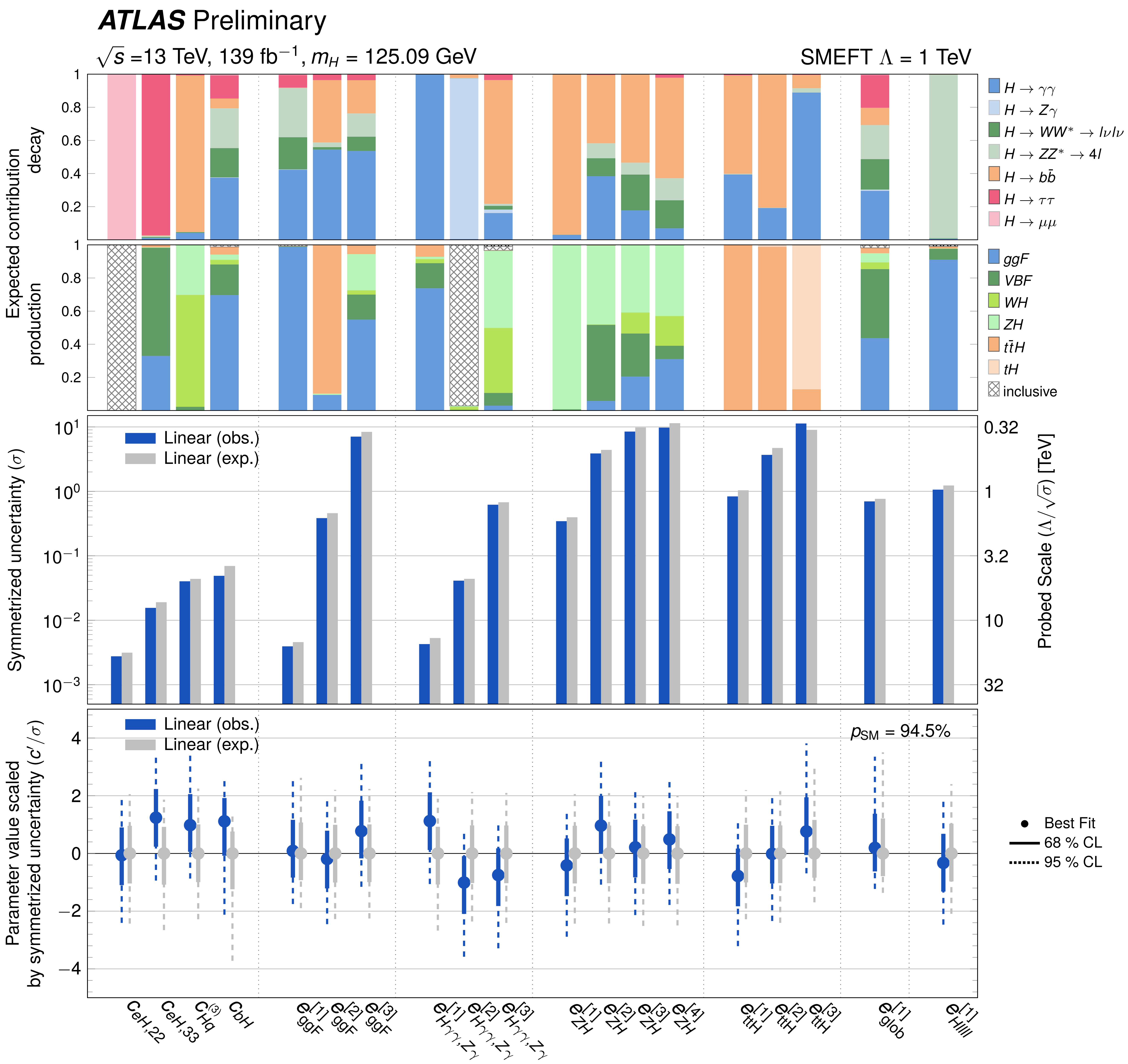


Higgs EFT combination

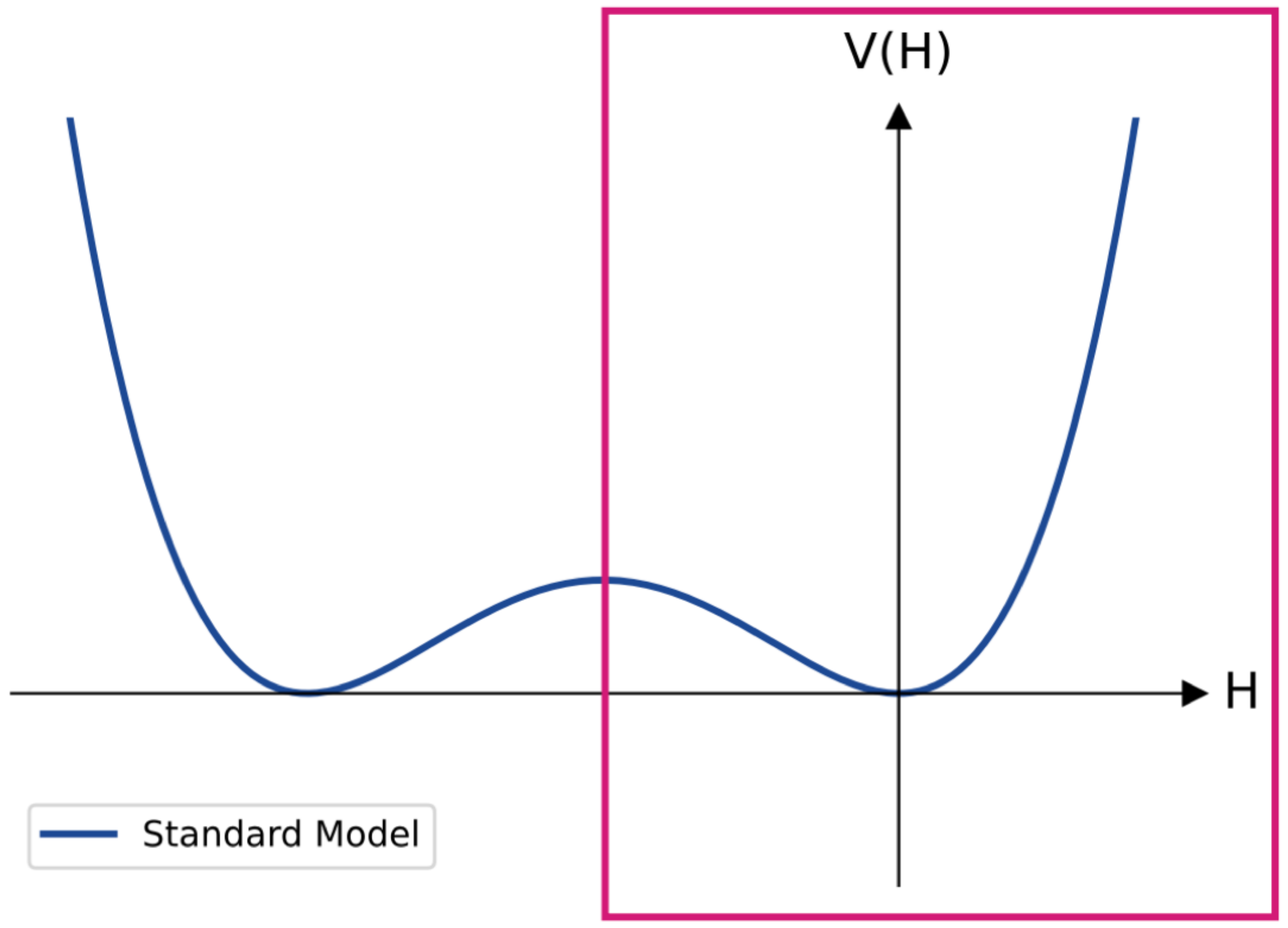
- Reminder:

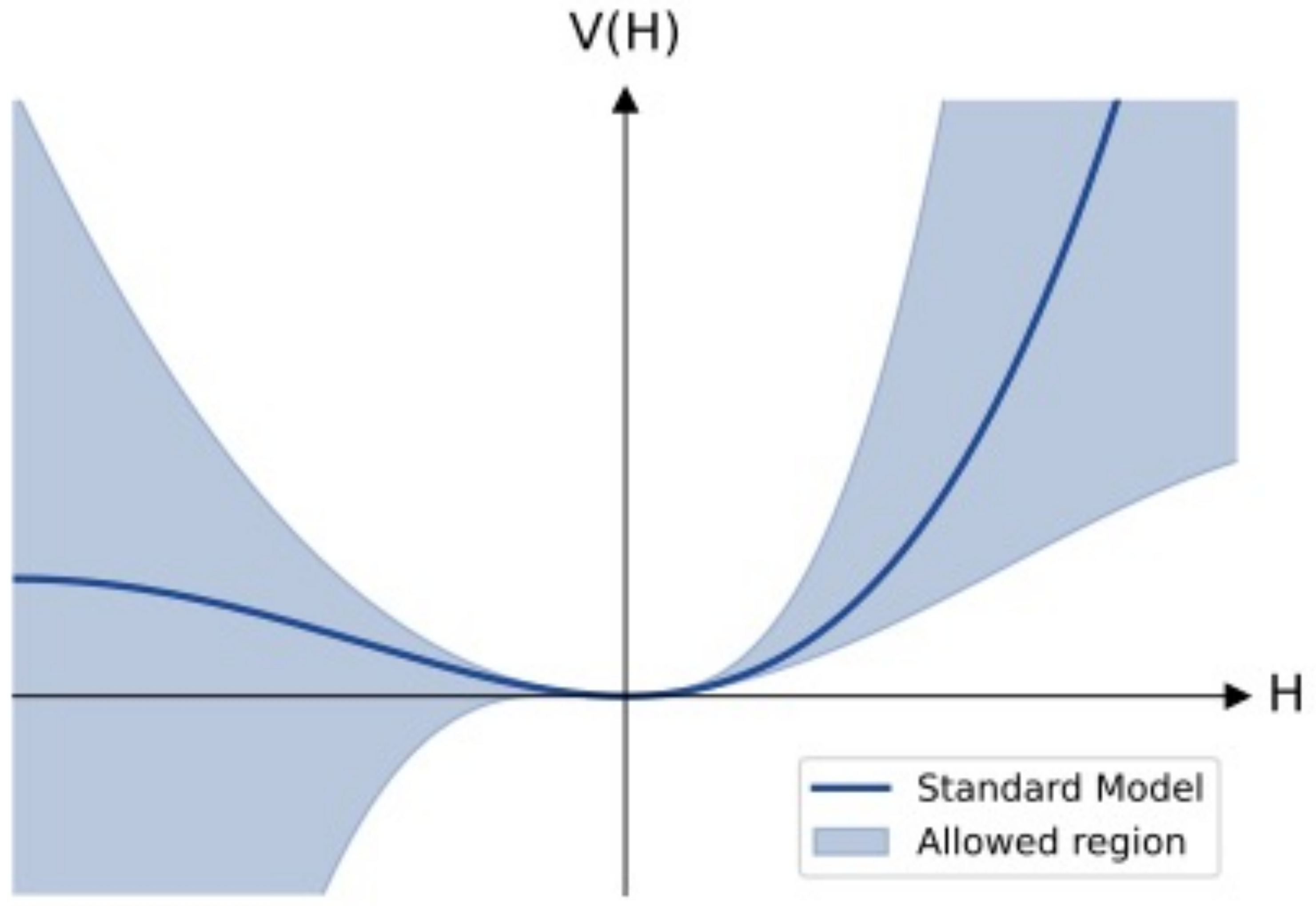
$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \frac{c_i}{\Lambda^2} O_i^6$$

- 24 different (CP-event) operators effecting Higgs boson physics
- Combine all different measurements in 1 EFT analysis
  - No new physics found
- Next steps:
  - Combination with other measurements
    - Top
    - Di-higgs

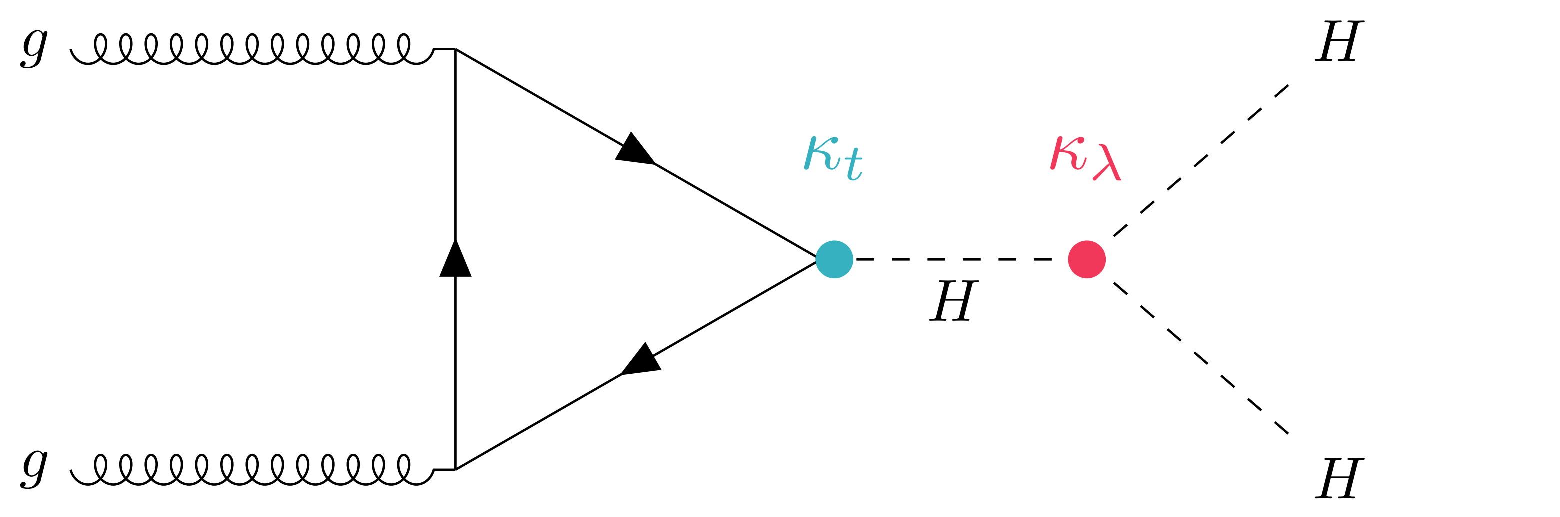


Testing the potential





$$V(H) = \frac{1}{2} m_H^2 \, H^2 + \boxed{\lambda \, vev \, H^3} + \frac{1}{4} \, \lambda \, H^4$$



- Location of minimum well established from single Higgs
- Shape Not explored
  - Is it Mexican hat shaped?
  - Measure Higgs self-coupling modifier $\kappa_\lambda = \lambda / \lambda_{SM}$
    - ~2000 times smaller than single Higgs production
    - ~4000 Higgs pairs produced during run-2

HH Decay

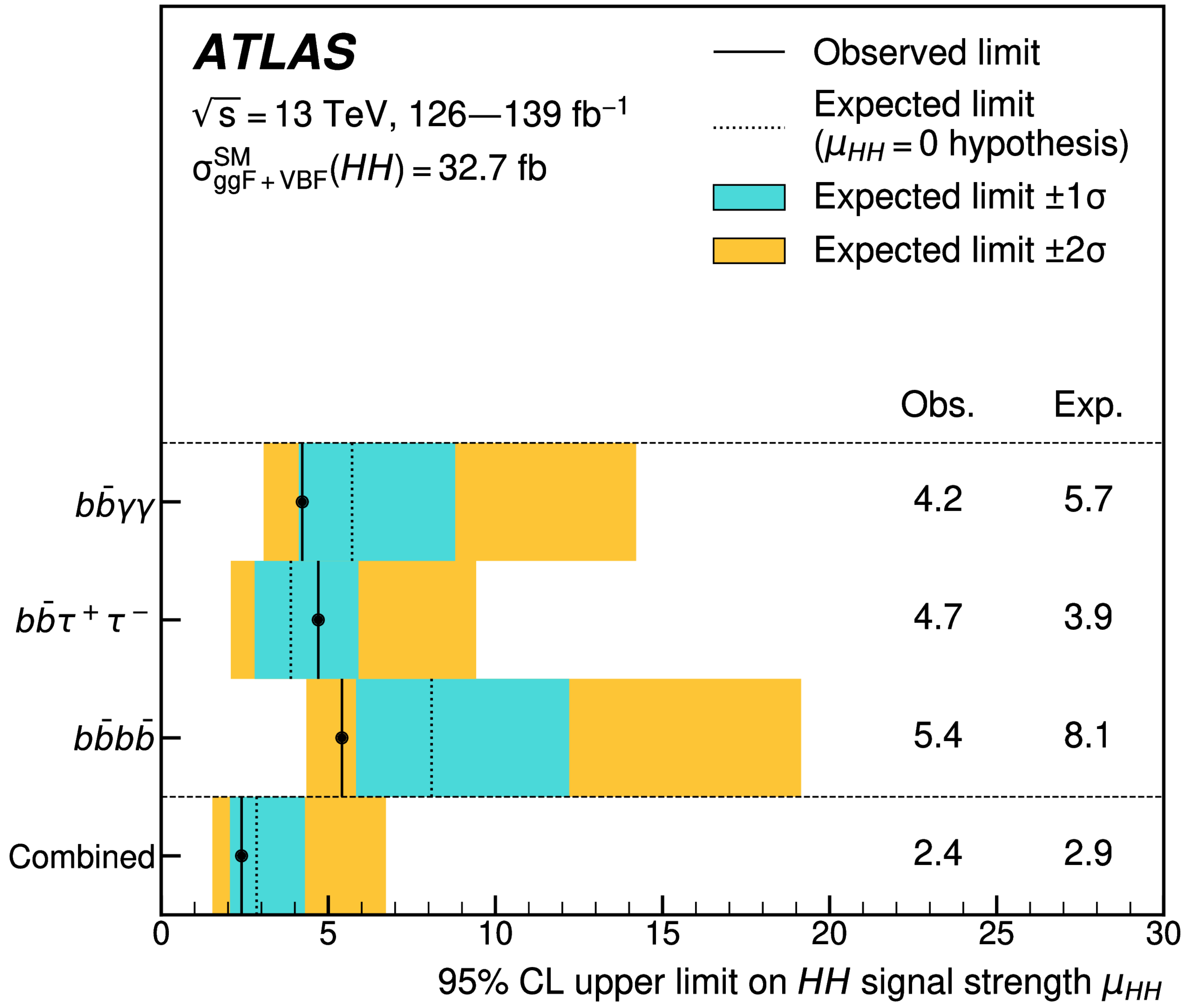
	bb	WW	ττ	ZZ	γγ
bb	34%				
WW	25%	4.6%			
ττ	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.069%	
γγ	0.26%	0.10%	0.028%	0.012%	0.0005%

Many different decay modes

- HH->4b: Large branching ratio but huge background
- HH->bb$\gamma\gamma$: Low branching ratio but very clean
- **HH->bb$\tau\tau$: Moderate branching ratio and relatively clean**
  - **τ can decay hadronically (67%) leptonically (33%)**

First full run 2 result in HH->bb$\tau\tau$ (Carl, Nikos, Jordan, Matt)

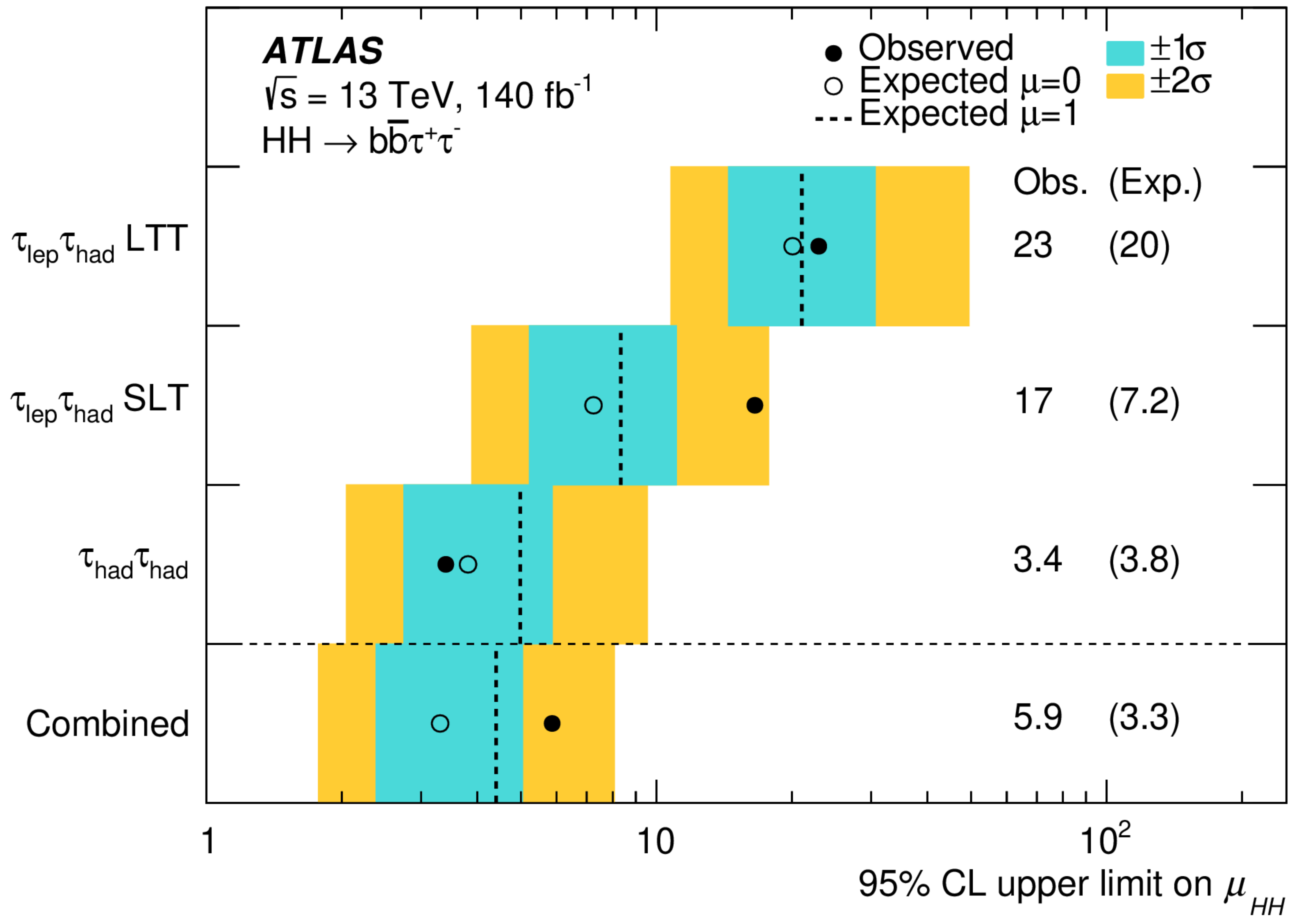
- Main analyzers of the lephad channel
- observed (expected) upper limit from bbtt on $\mu_{HH} = 4.7\ (3.9)$
  - Most sensitive channel in combination
  - Included a search for new heavy resonances
- Contributions to final di-Higgs combination
  - Including combined EFT interpretation

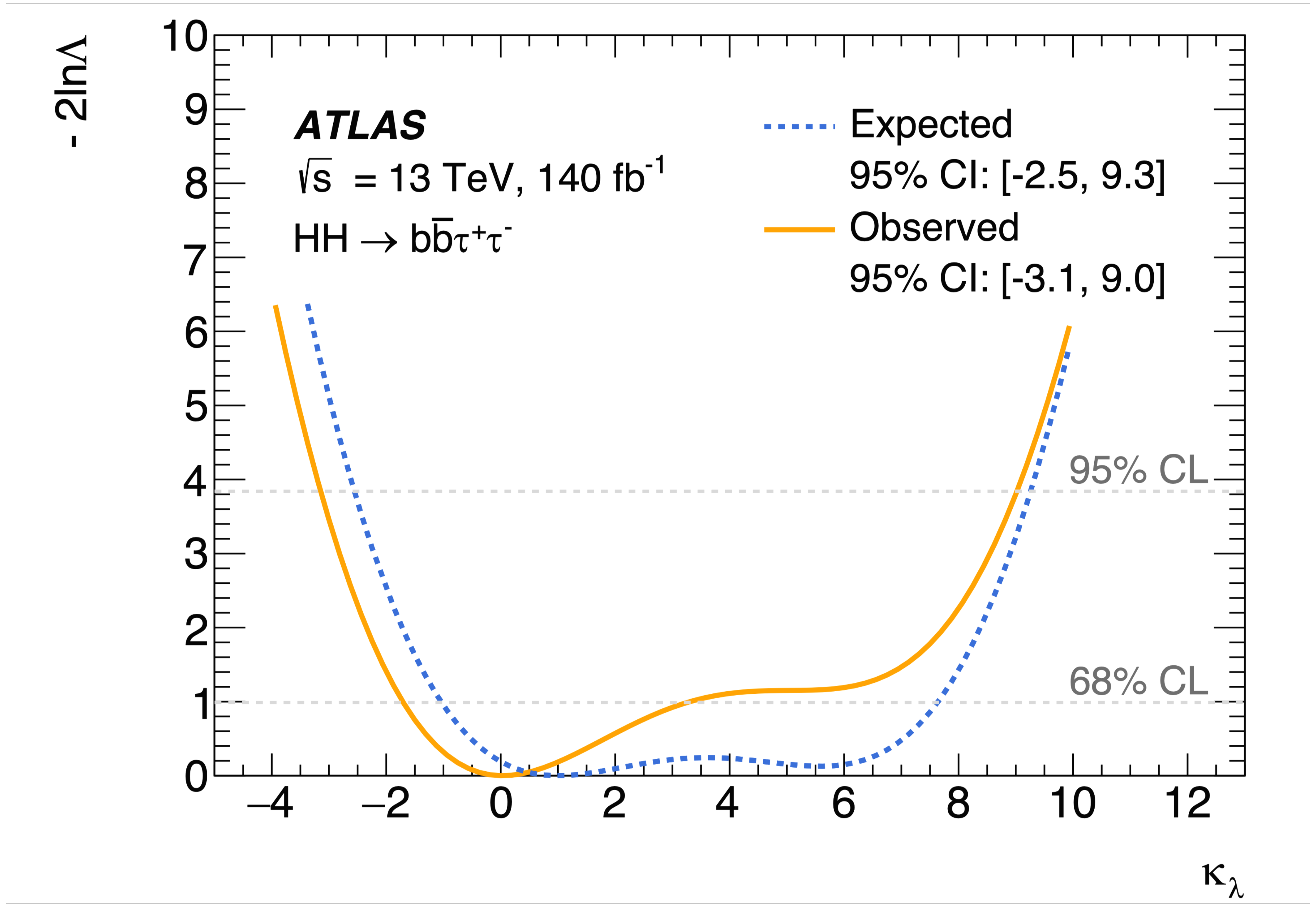


Legacy HH->bb$\tau\tau$ result

ATLAS recently published new HH->bb$\tau\tau$ legacy run 2 result

- Observed (expected) upper limit of $\mu_{HH} = 5.9$ (3.3)
- 20% better limit on κ_λ in HH->bb$\tau\tau$
- New di-Higgs combination ongoing





Run 2 + Run 3 HH->bb$\tau\tau$ measurement

Liverpool contributions (Bhupesh, Carl, Jordy)

- Software coordinator of the new analysis framework
- Focus will be on HadHad channel
- Investigate top modelling (talk Bhupesh)
- Study new MVA strategy

Flavour tagging Improvements

- ~2x better performance compared to previous tagger (DL1d)
- Ongoing calibration of GN2 tagger (Andy + Nikos)

Tau tagging Improvements

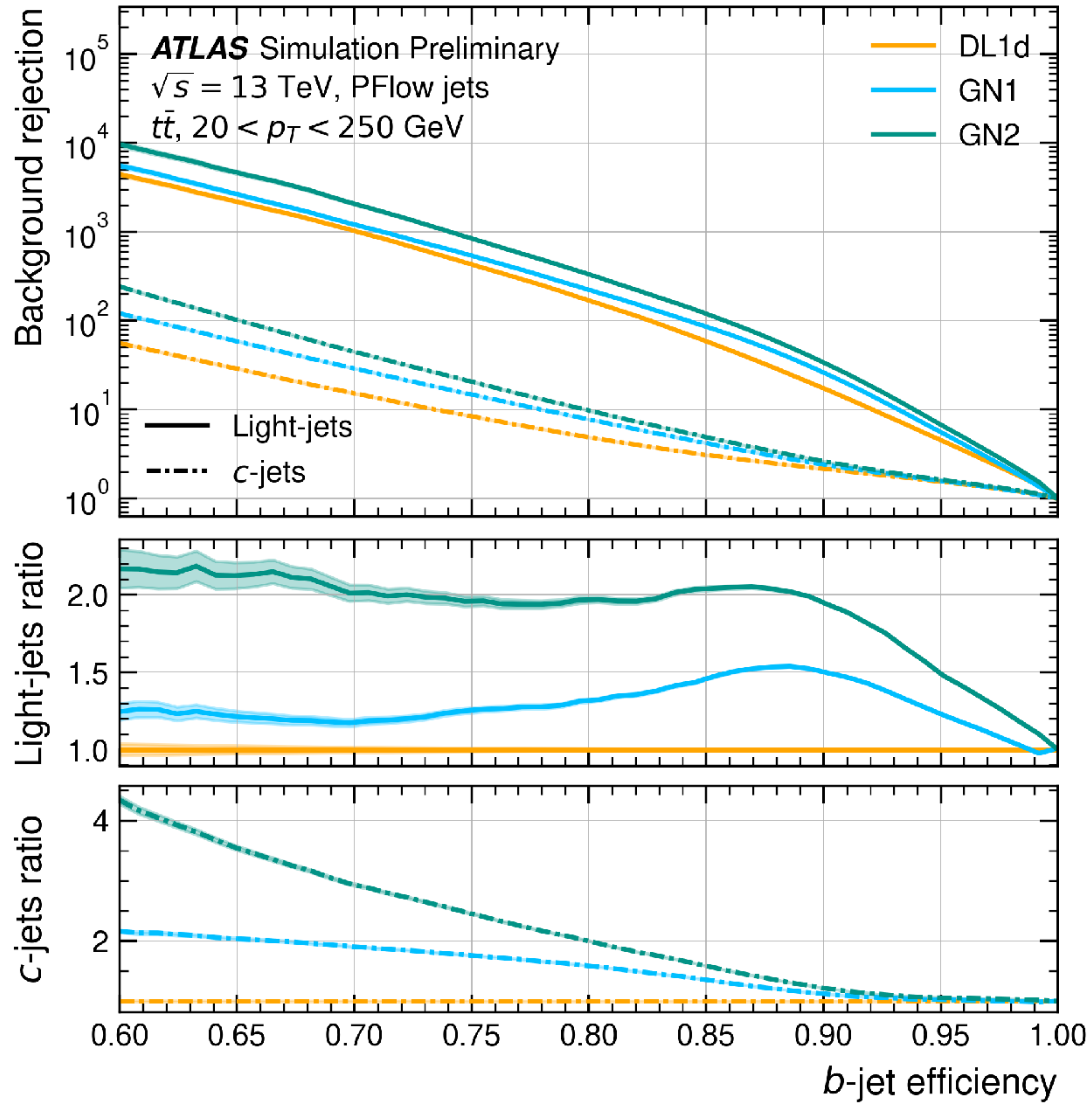
- Training of new tagger also using GNN architecture (Monica, Joe, Nikos, Rob, Mehul, Jordy)
- Similar improvements expected with respect to b-tagging
- More details in Robs 2nd year talk

Estimated sensitivity:

- Combined (CMS+ATLAS) evidence for HH production by end of run 3

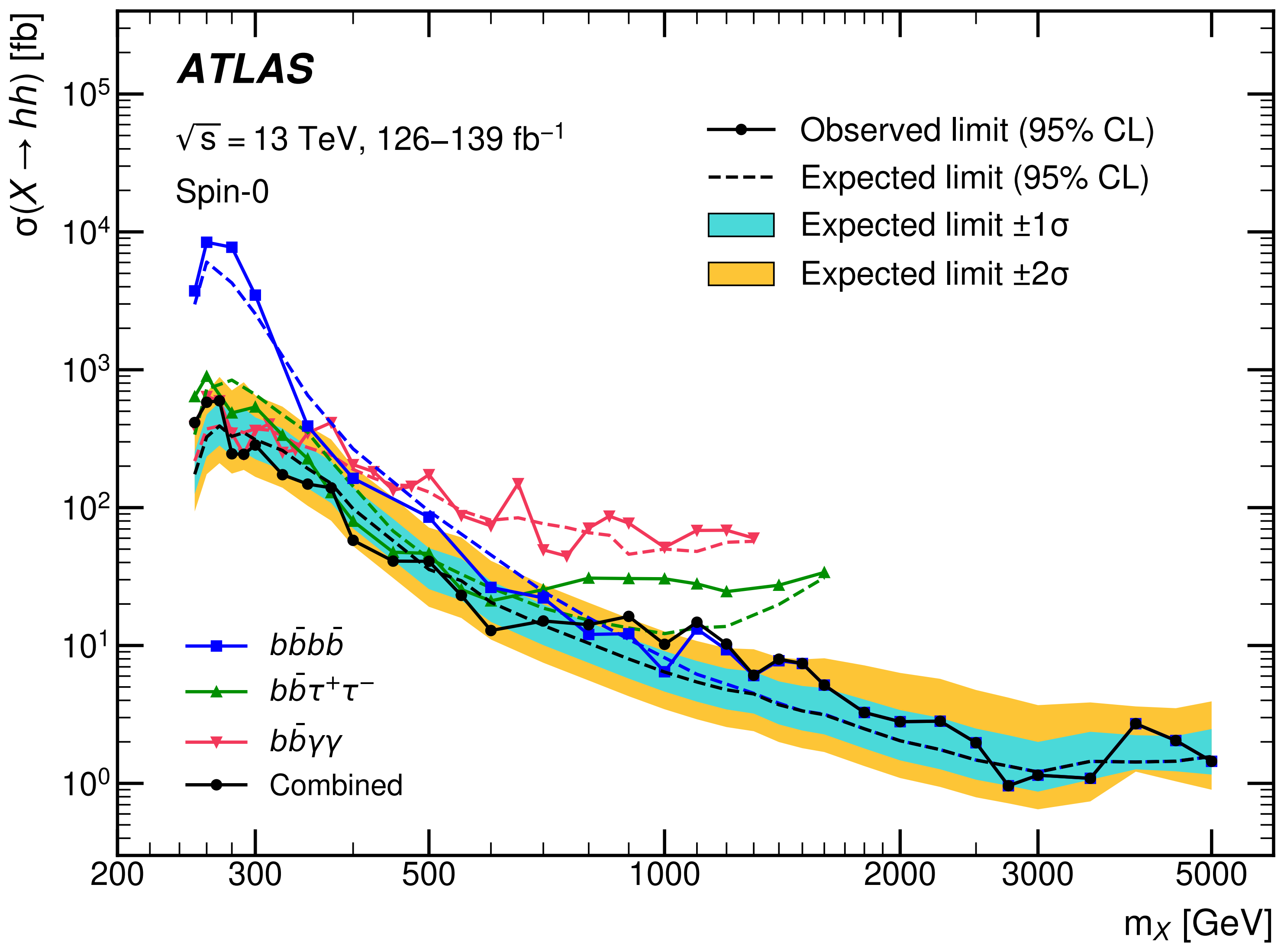
One of main physics results for ATLAS HL-LHC

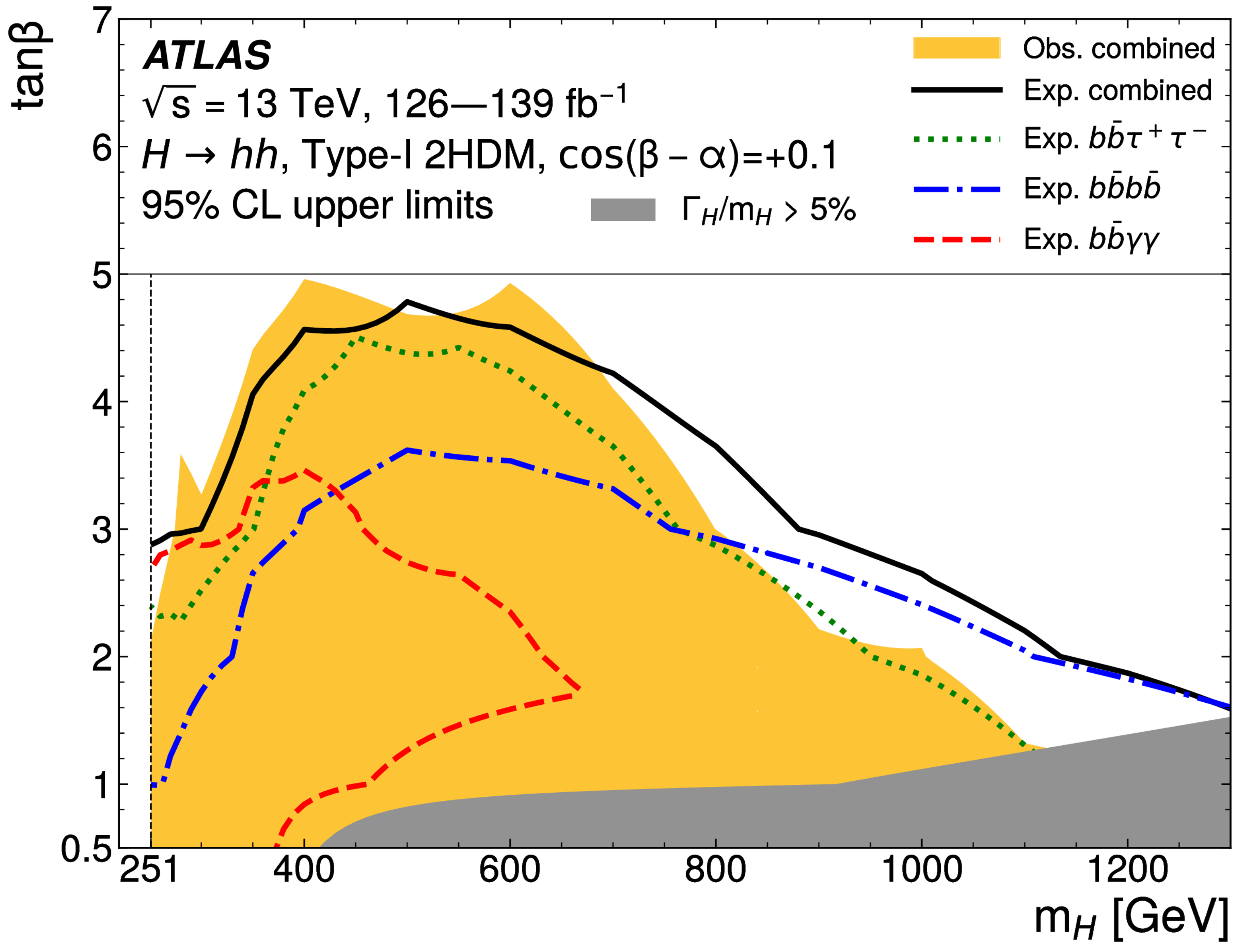
- New tracking detector build in Liverpool: ITk

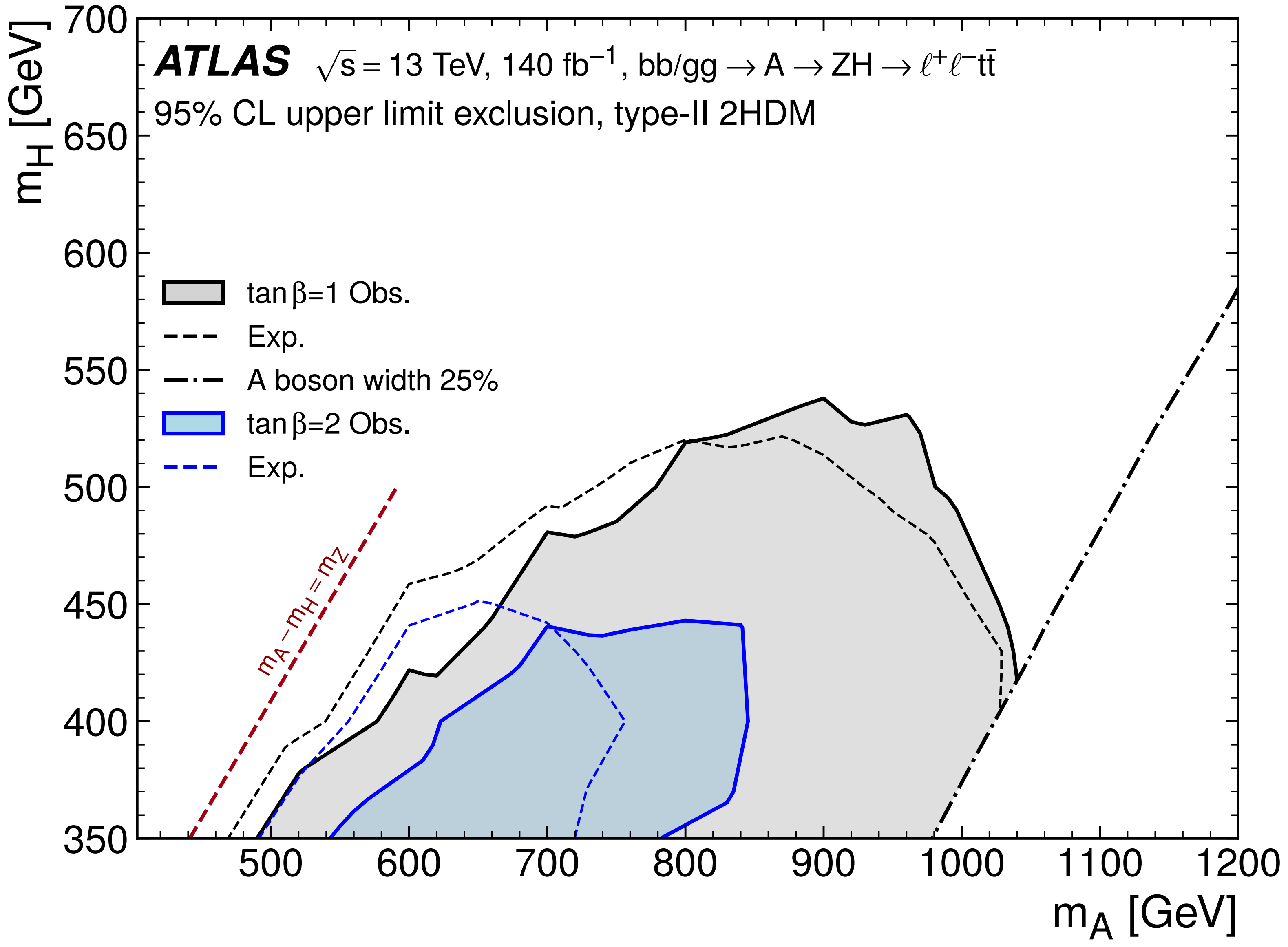


Search for additional Higgs bosons

- Many models predict additional Higgs bosons (SUSY, MSSM, 2HDM)
  - Combined search for heavy Higgs boson (H) decaying into higgs pair (Nikos):
    - H->hh->bbbb (high mass)
    - H->hh-> bb$\tau\tau$ (medium mass) (Nikos, Carl, Jordan)
    - H->hh->bb$\gamma\gamma$ (low mass)
  - Search for CP-odd Higgs boson decaying to heavy CP-even Higgs boson and a Z (Nikos)
  - Search for di-Higgs production in association with vector boson (Nikos)







Conclusion

- ATLAS ideal detector to study complete SM
  - Mapping out the complete Higgs/Electroweak/top sector
  - Liverpool involved in many key analysis

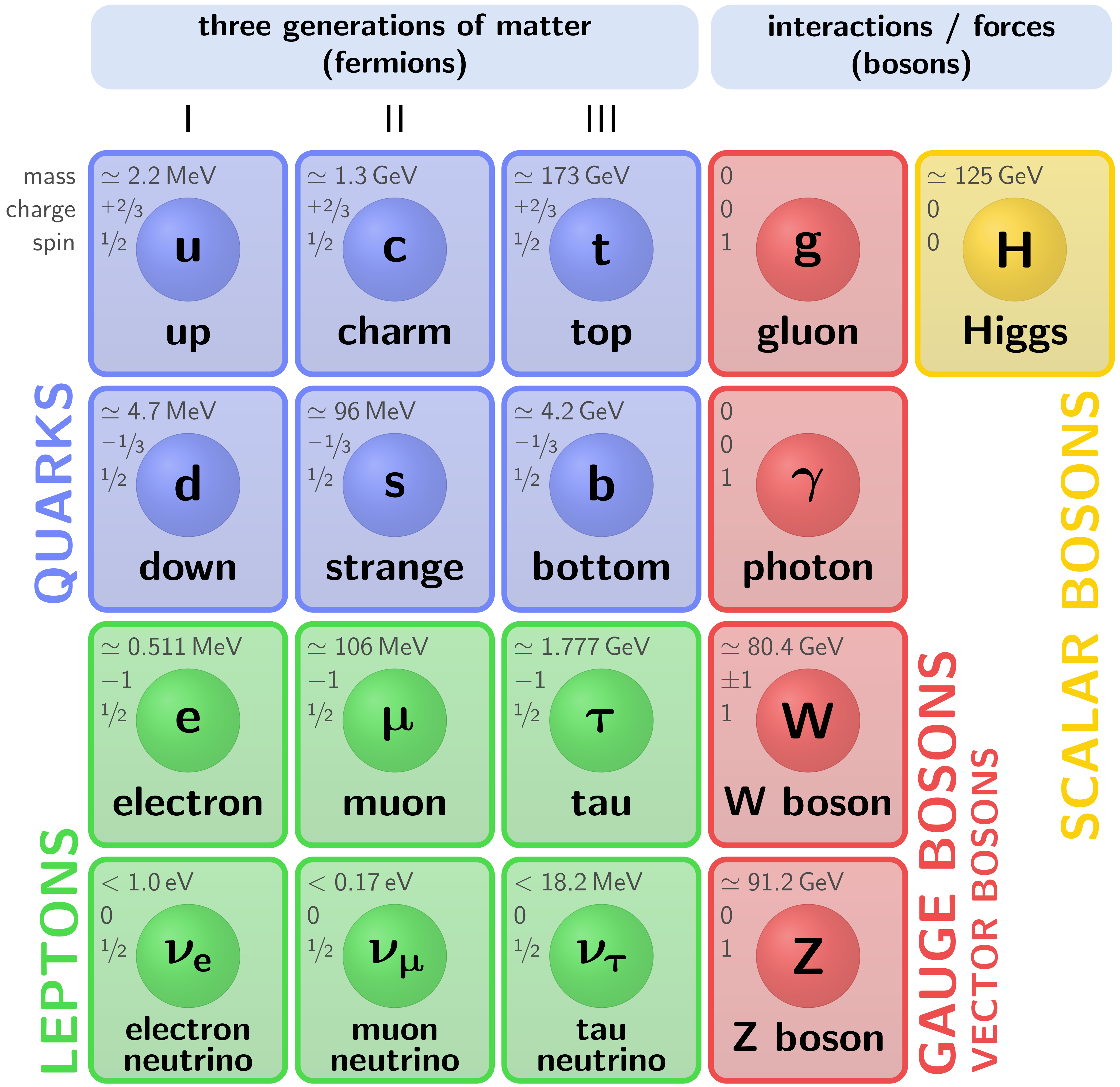
- Future data allows to search for even rarest processes
  - Strong involvement from Liverpool both in Analysis and object reconstruction
  - 2^{nd} generation of leptons would verify Higgs mechanism across generation
  - Di-Higgs measurement offers unique opportunity to determine shape of Higgs potential
  - Plans to study even rarer triple-Higgs production to determine full potential

- EFT powerful tool to combine many different analysis
  - Study on new CP-violating interactions in top sector presented
  - Most stringent limits on combined EFT interactions in Higgs physics
  - Future combination of many measurements

Backup

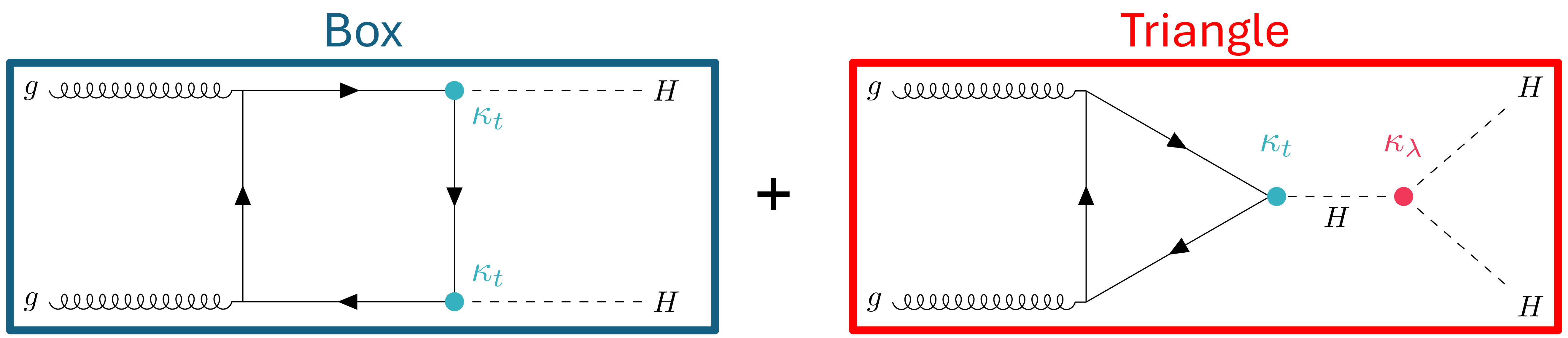
Testing the SM

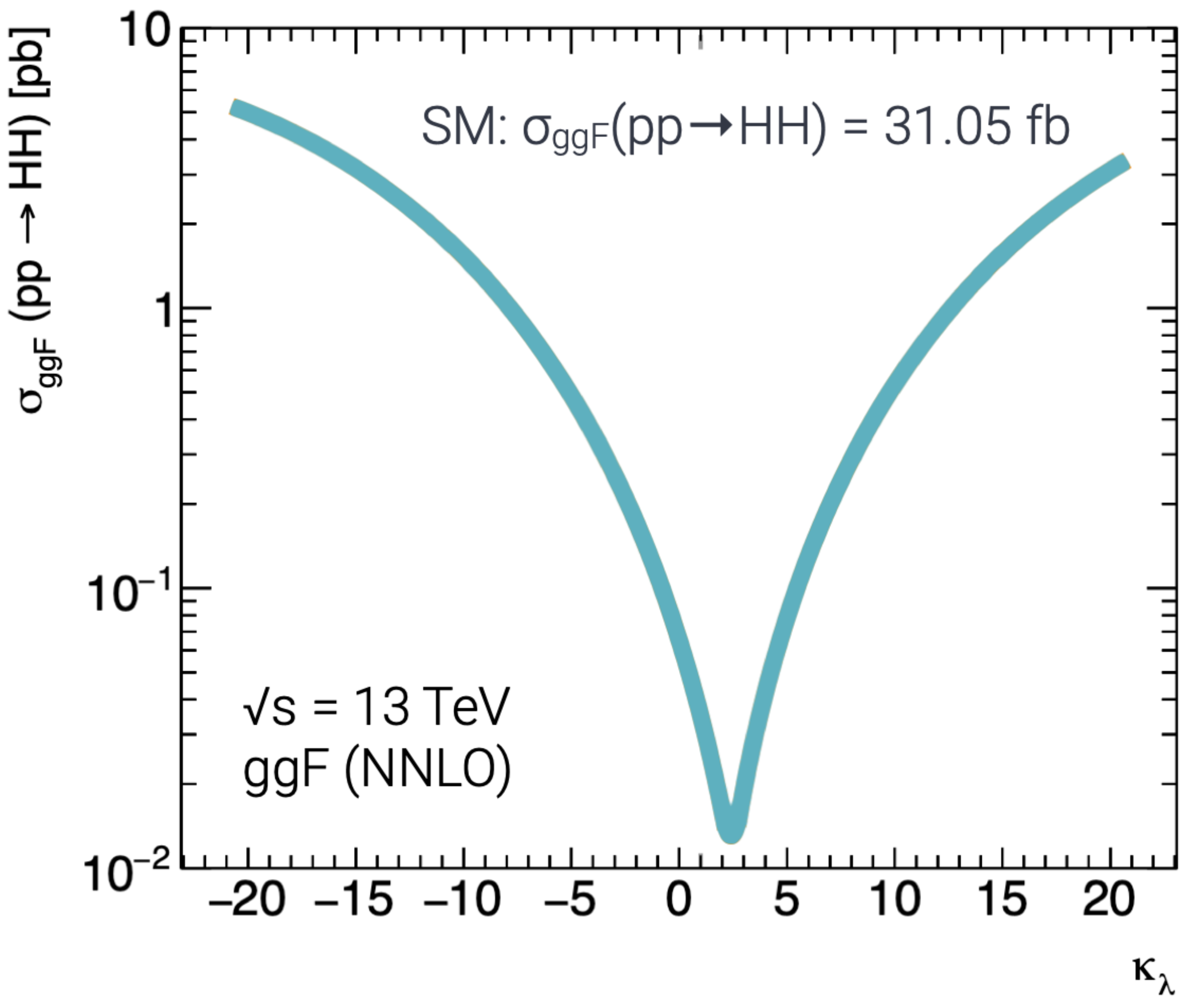
- ATLAS can measure all types of interactions
- Top quark
  - Heaviest particle in the SM
  - Only “bare” quark in the SM
  - LHC is a true top factory
    - No other running collider able to produce top quarks
  - Focus of my PhD thesis done at Nikhef
- Higgs boson
  - Discovered in 2012
  - Crucial part in giving particles their mass
  - By studying the Higgs boson we can access the Higgs potential
    - Focus of my study here in liverpool



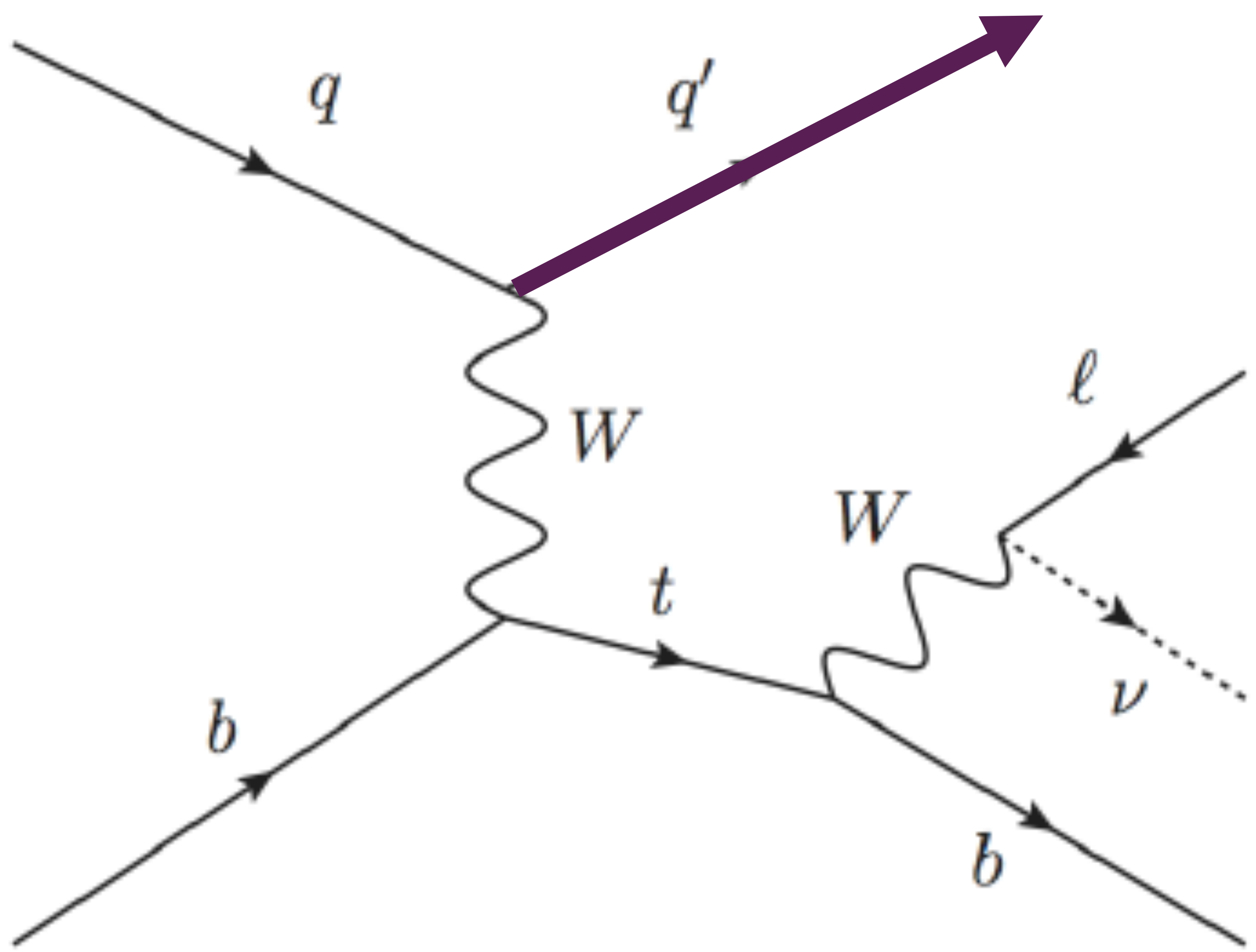
GGF HH Production

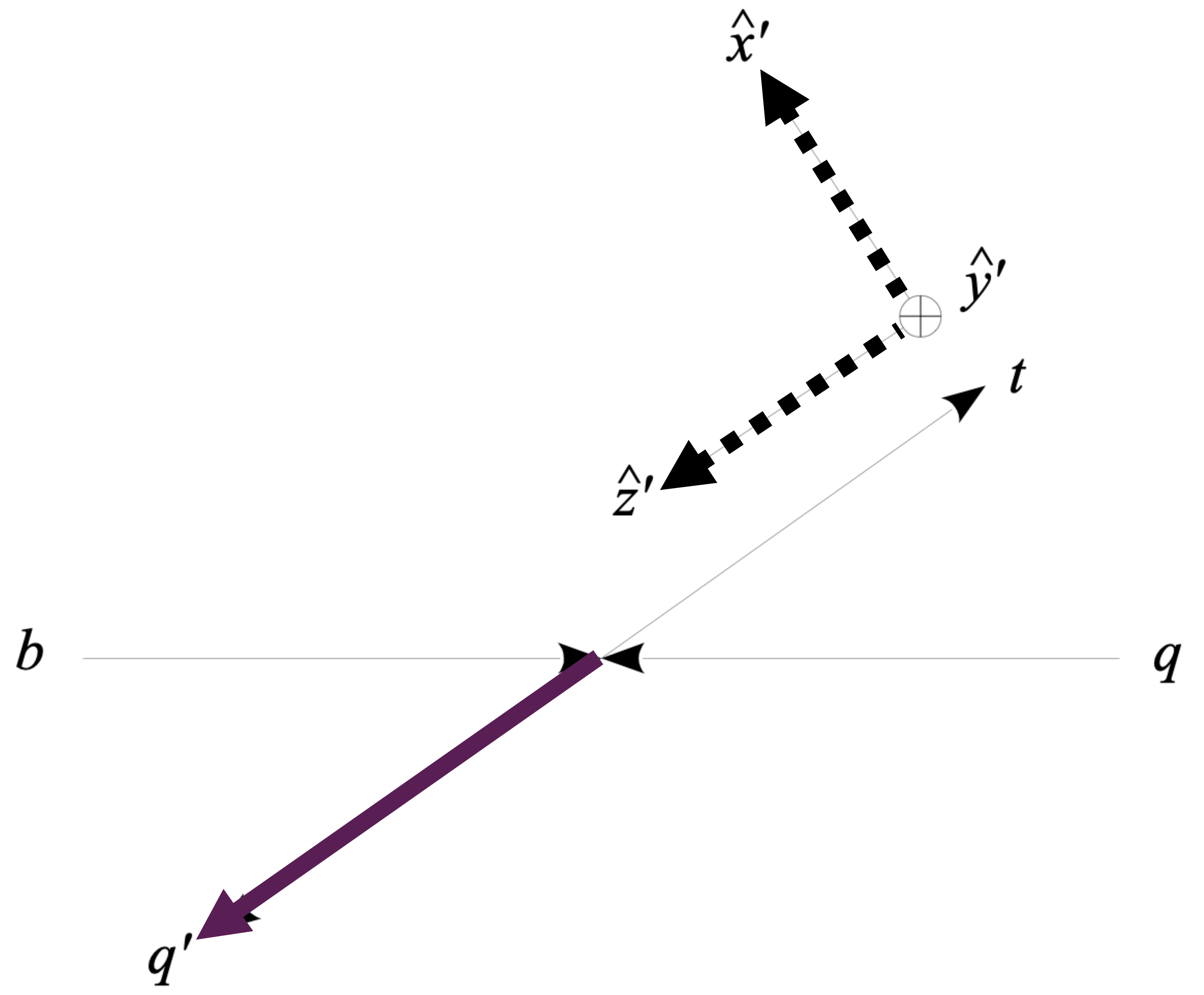
- ~4000 HH pairs produced in Run 2
- σ ~ |B|^2 + |T|^2 + 2Re(B*T)
- ggF: $\sigma = 31\ fb$
- Acces to Higgs self-coupling κ_λ

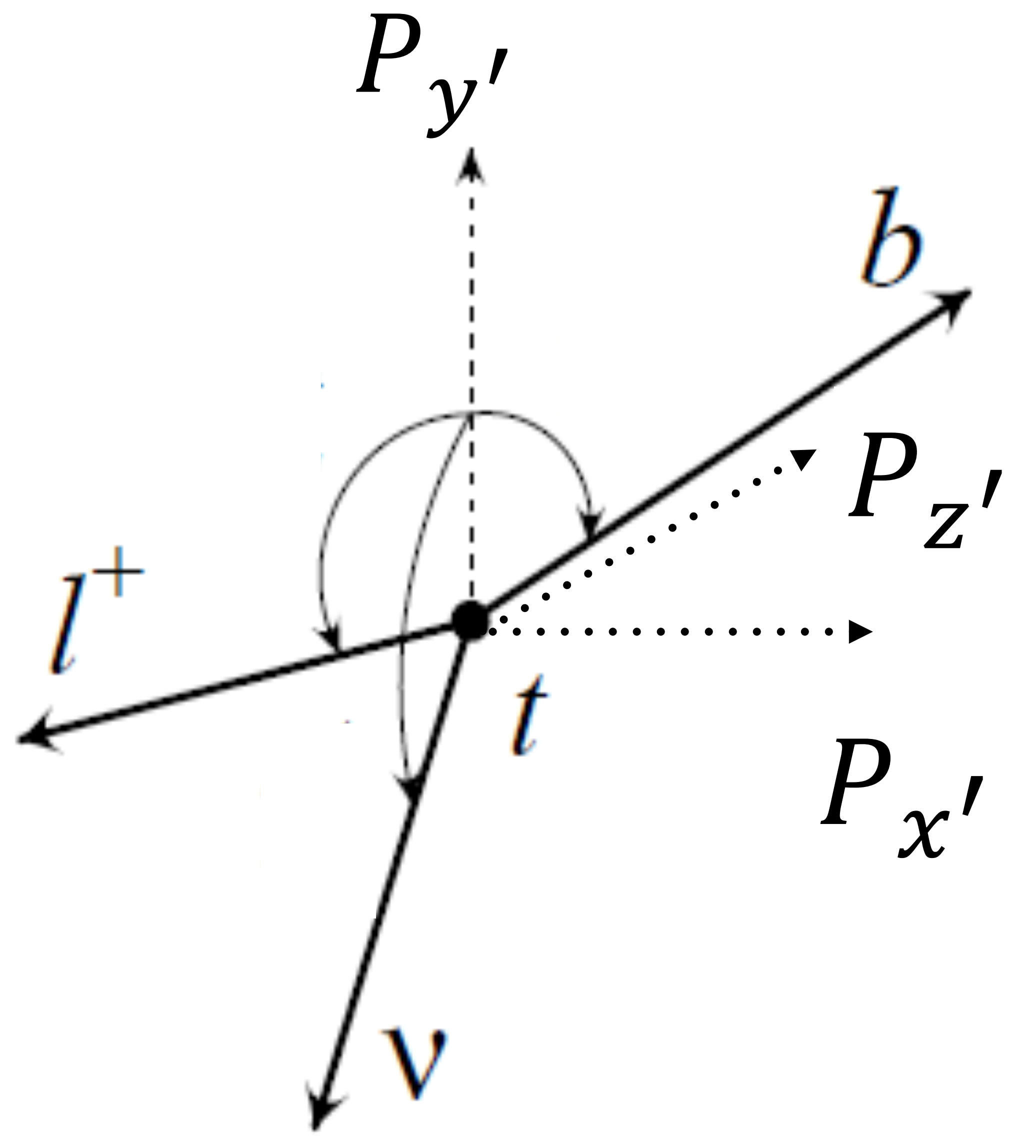




t-channel single top







- Top quarks are polarized
- Measure polarization via angular decay distribution
- Measure angle of lepton in coordinate system (x', y', z'):
- Measure new CP violation via $\cos(\theta_{ly})$

$\cos(\theta_{lx})$

$\cos(\theta_{ly})$

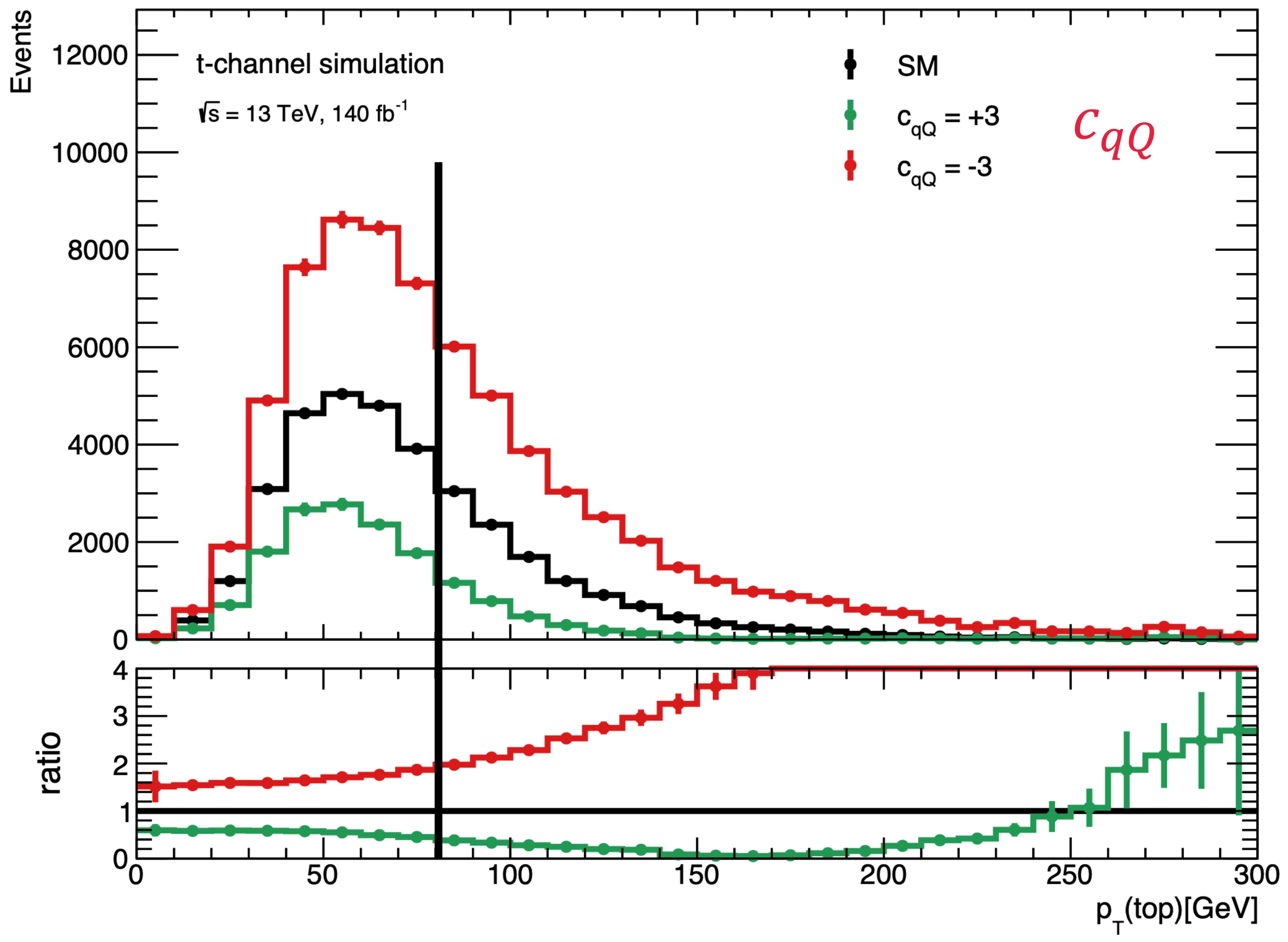
$\cos(\theta_{lz})$

c_{tW} and c_{itw} sensitivity on Angles

$\cos(\theta_{lx})$ $\cos(\theta_{ly})$ $\cos(\theta_{lz})$

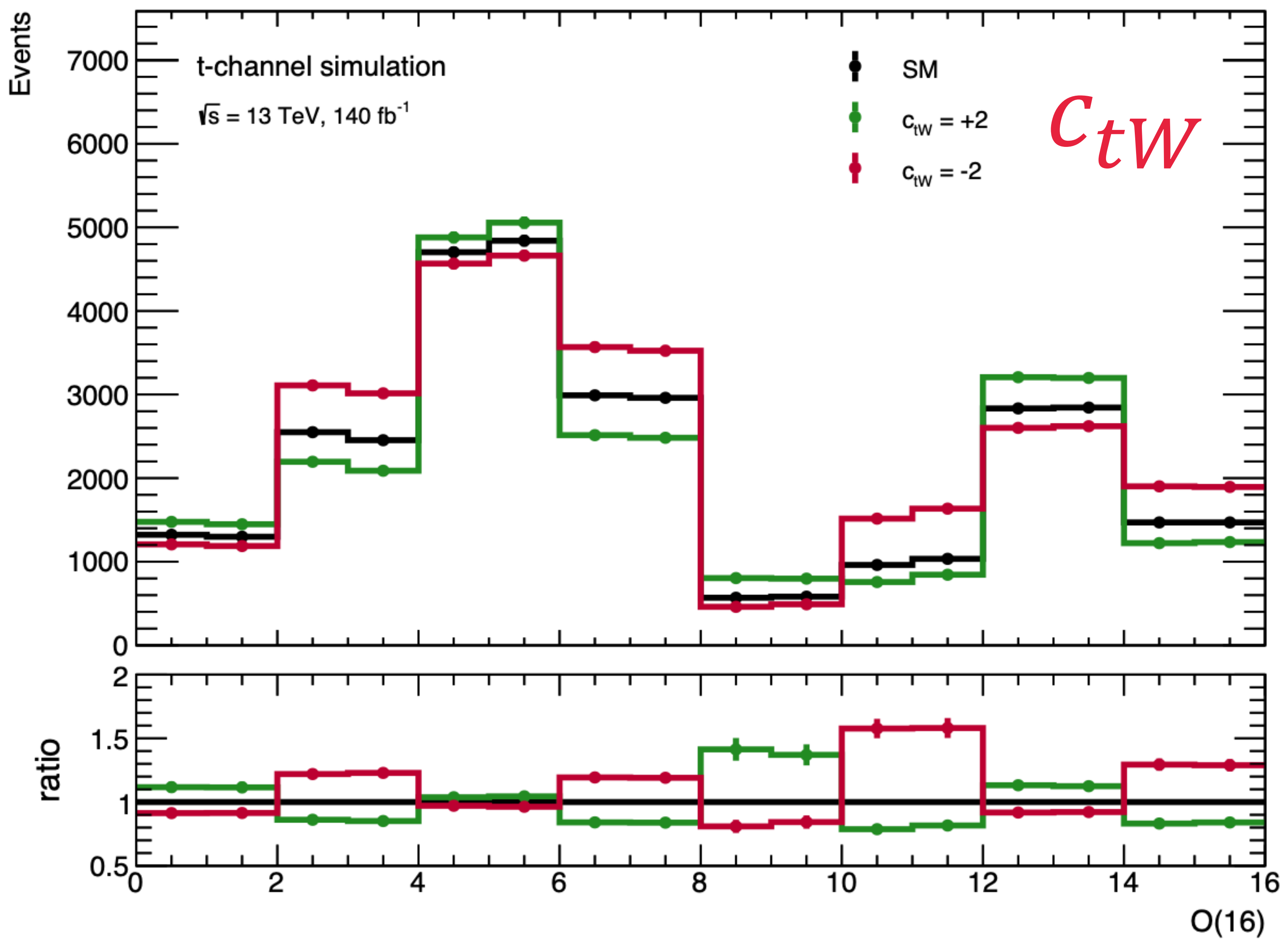
CQQ sensitivity

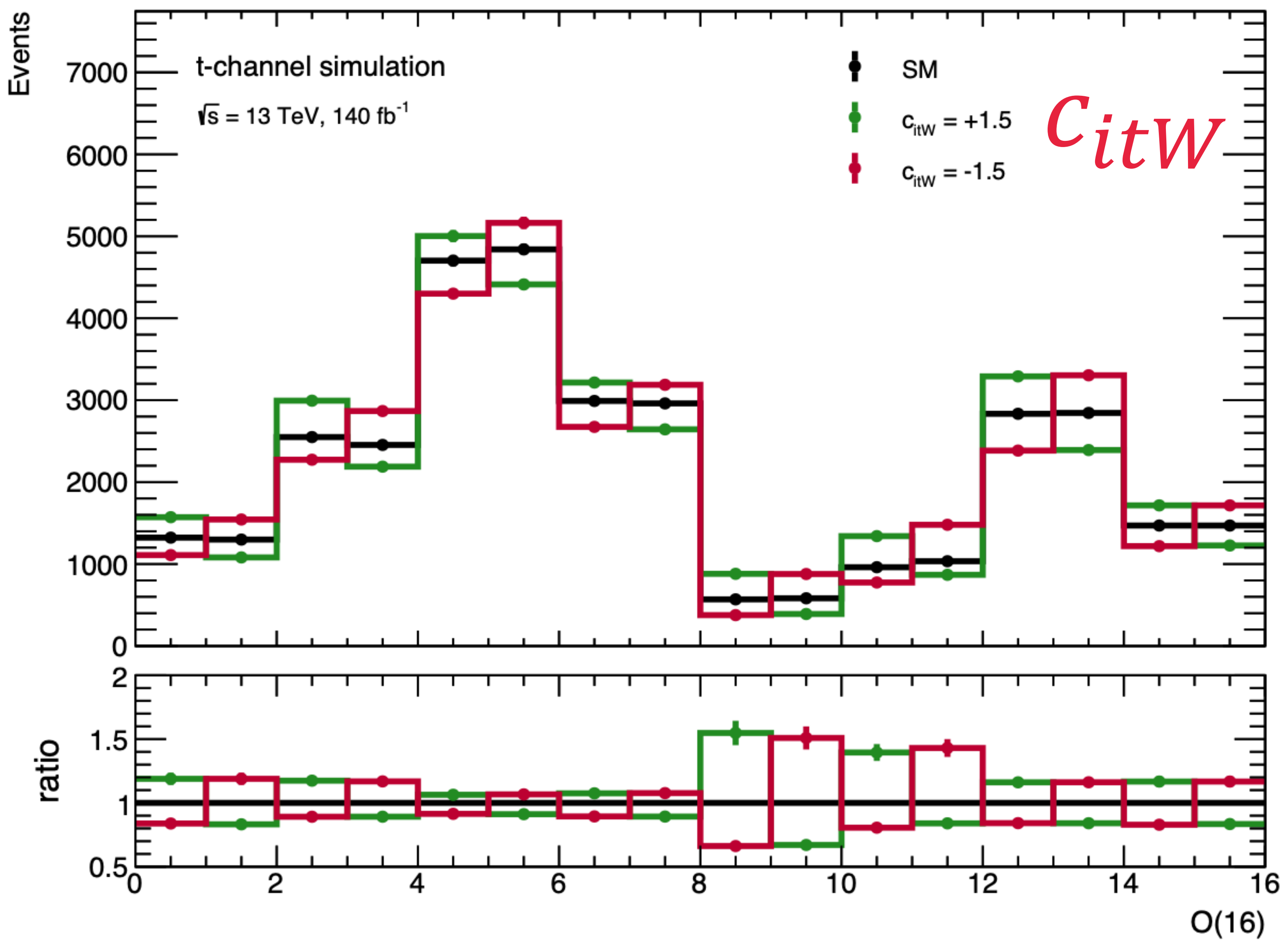
- Large sensitivity through top p_T
  - Grows with momentum
- Use 2 bins in p_T
  - Larger/smaller than 80 GeV

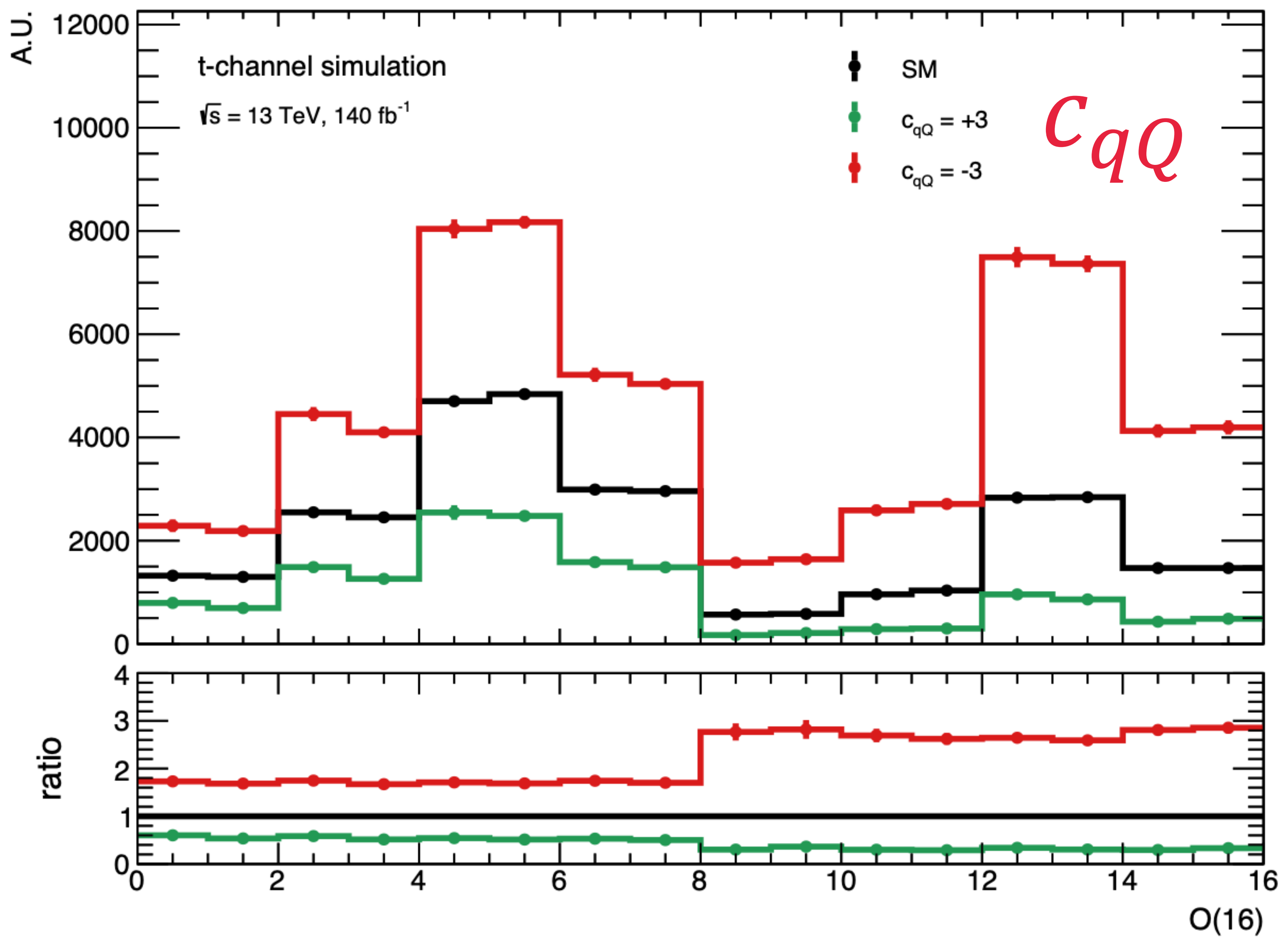


Final observable O(16): EFT sensitivity

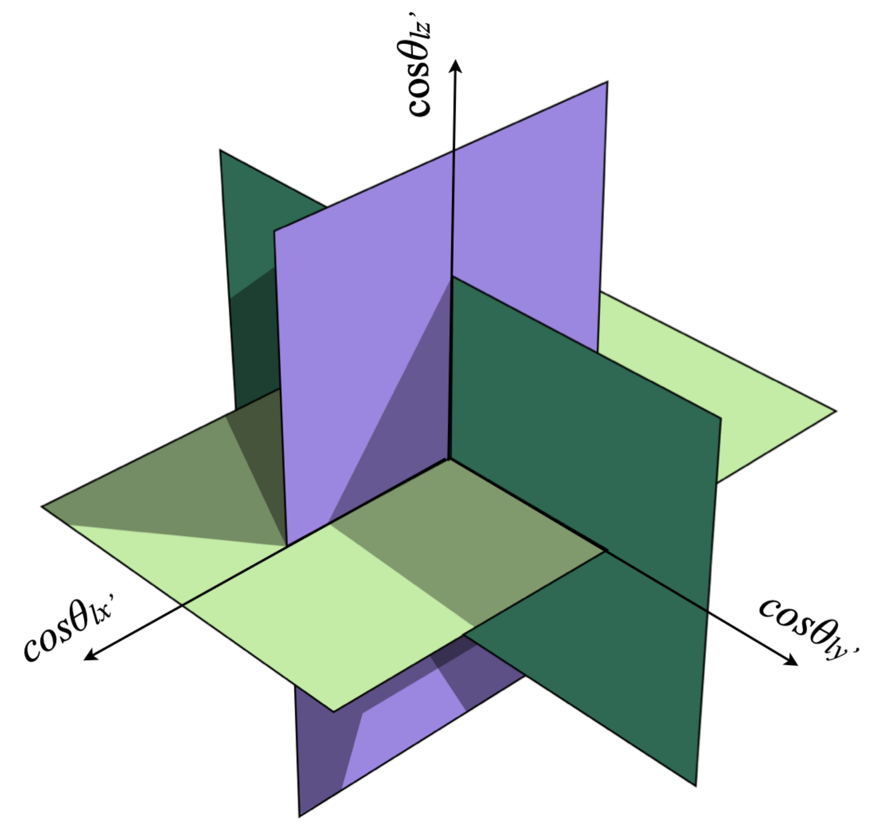
$\mathcal{O}_{tW}$ **-> angular variables(real + imaginary),** $\mathcal{O}_{qQ}^{3,1}$ **->** p_T **- spectrum**



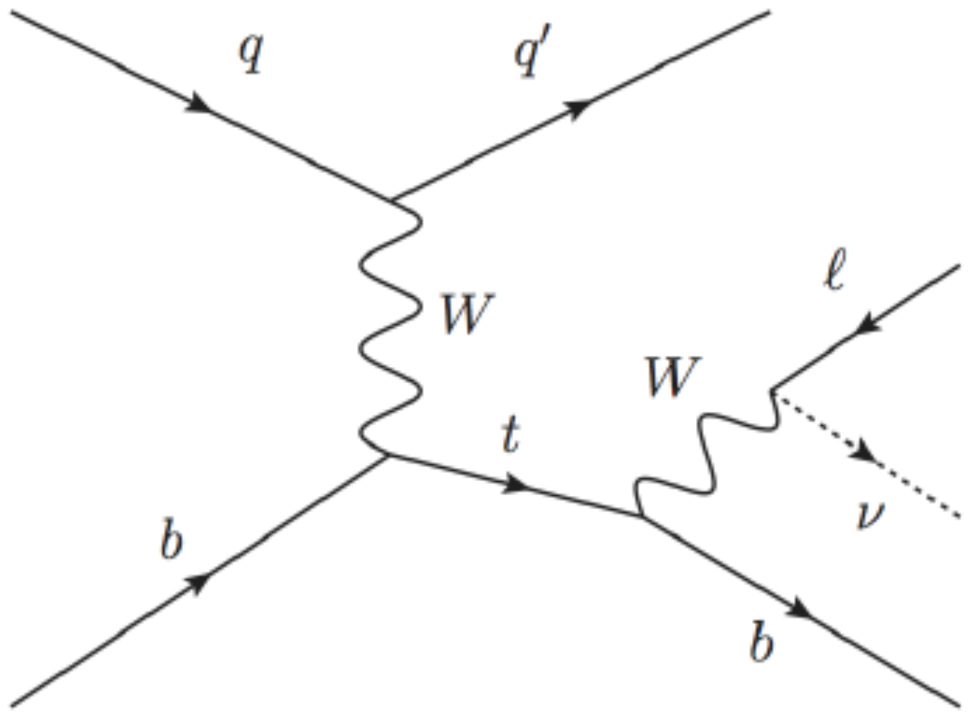




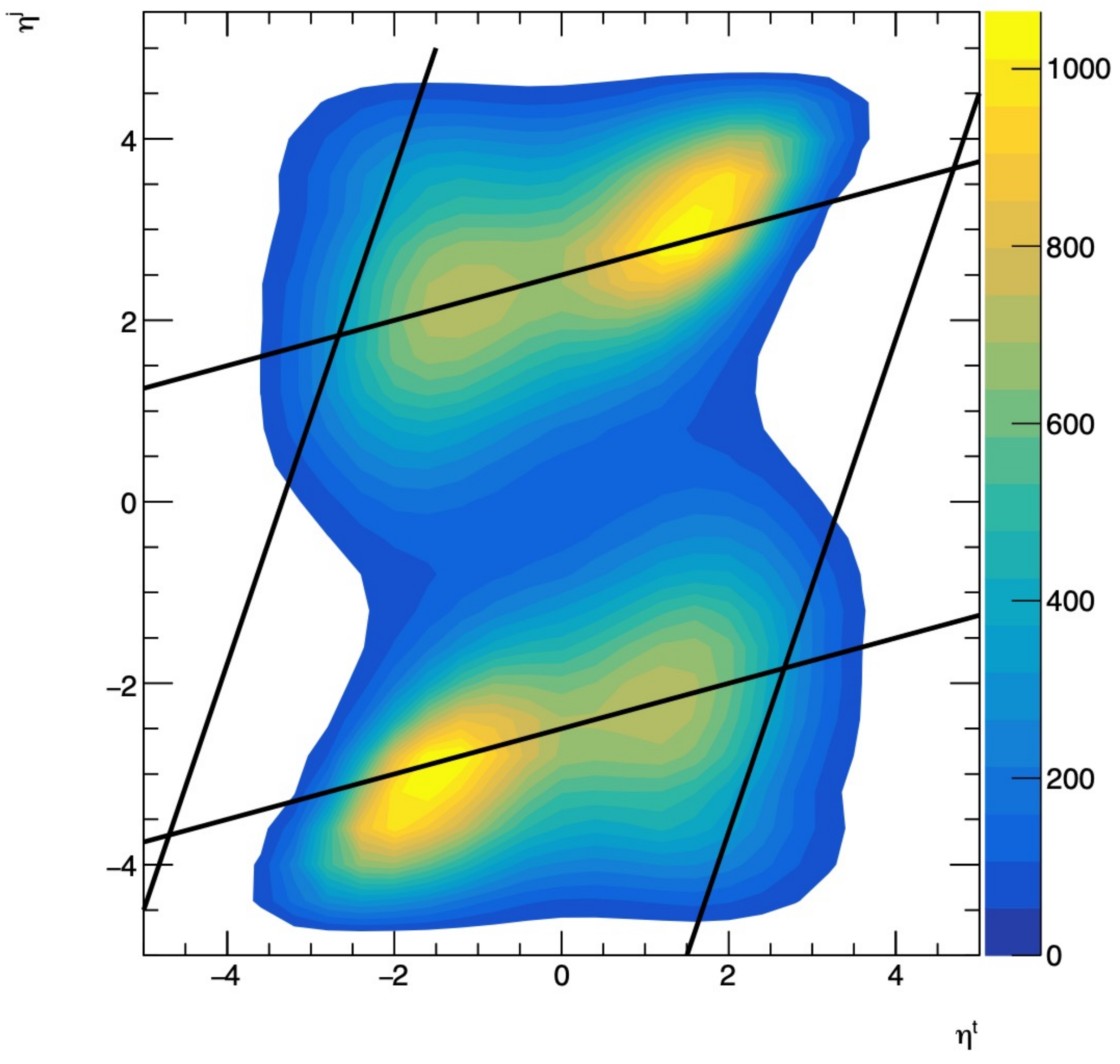
- $O(16) = (\cos(\theta_y) > 0) + 2(\cos(\theta_x) > 0) + 4(\cos(\theta_z) > 0) + 8(p_T^t > 80GeV)$
- **Can measure 3 EFT parameters simultaneously**
    - **Enhanced sensitivity at high momentum**



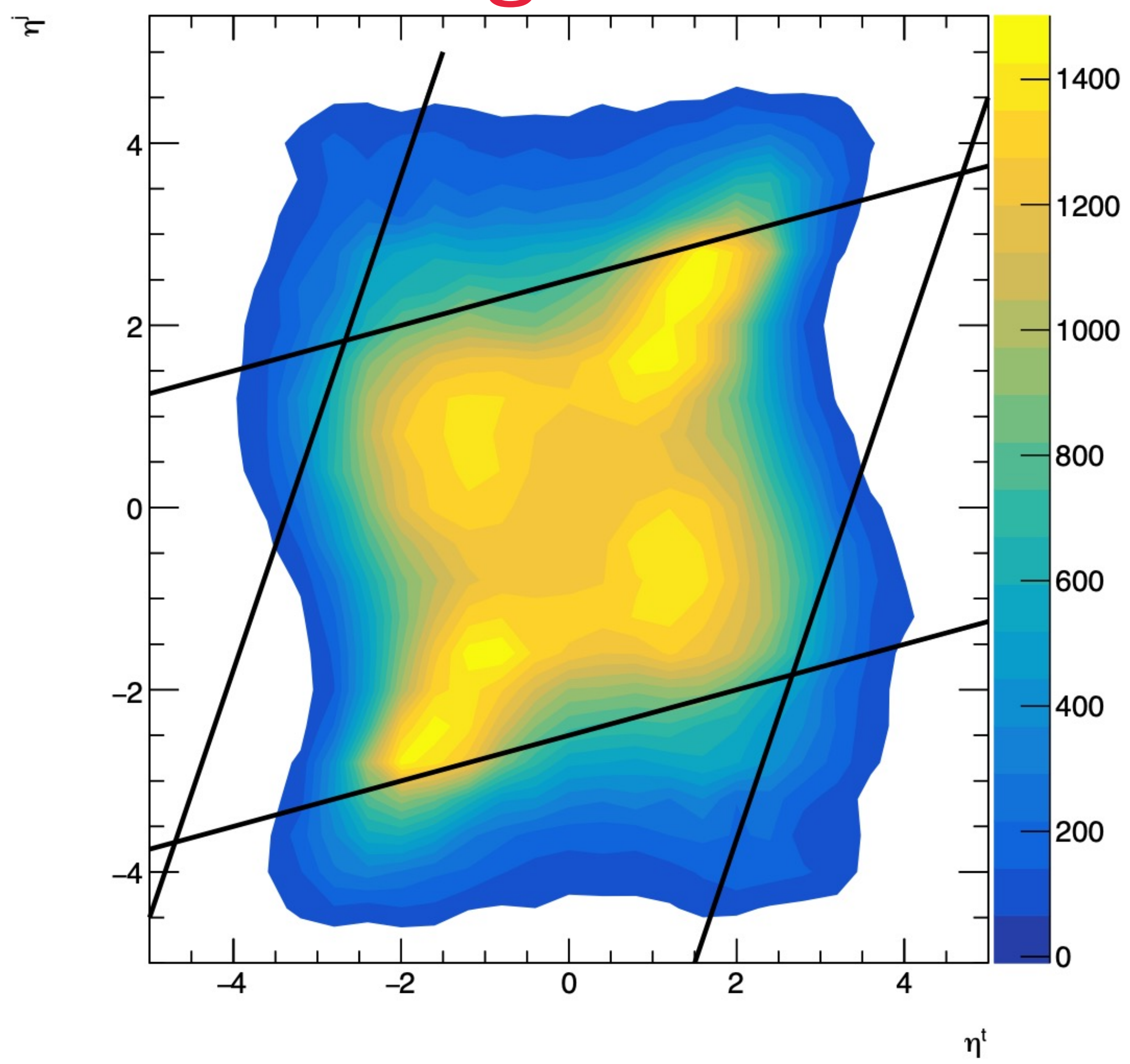
T-channel selection



t-chan



Backgrounds



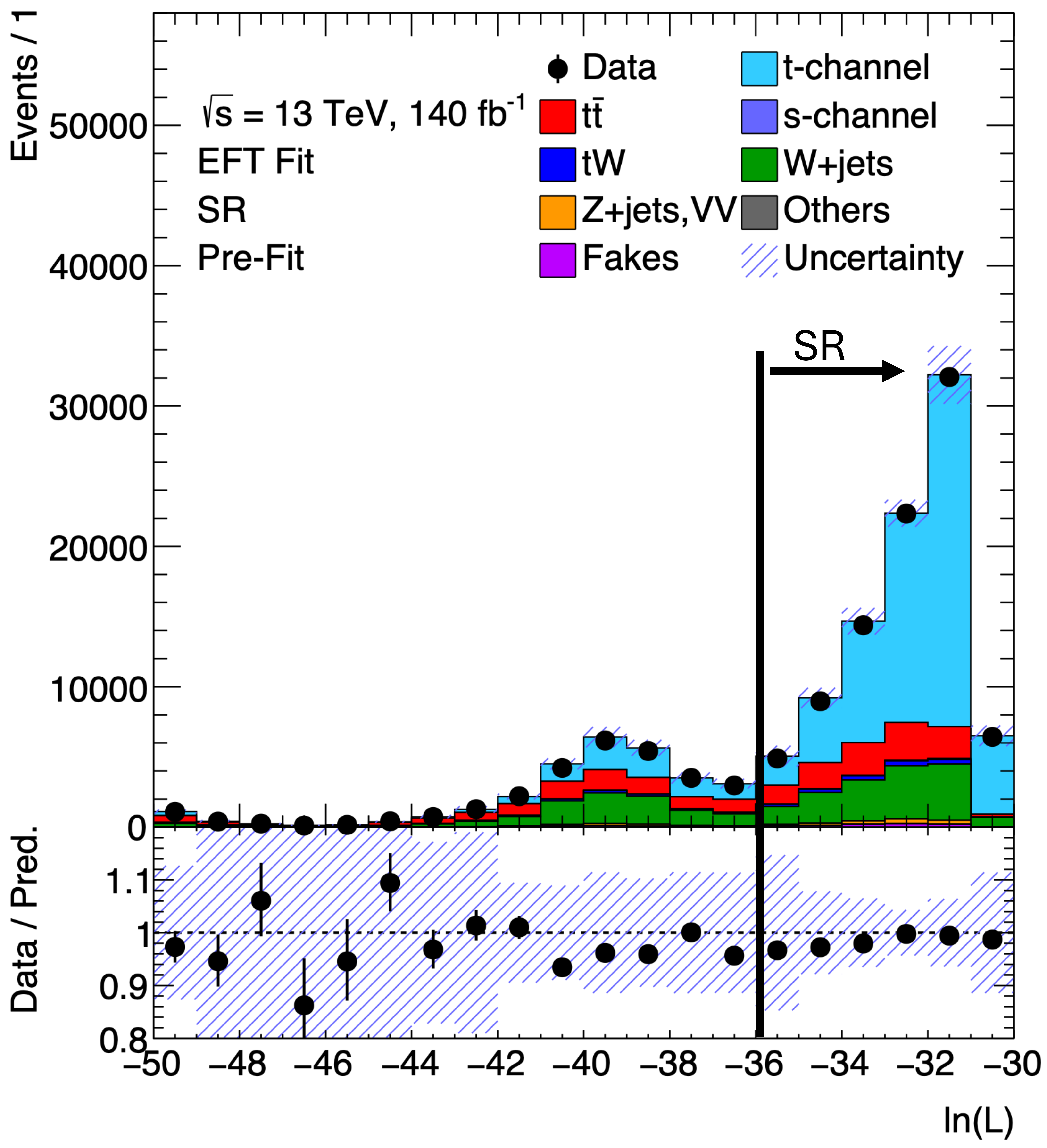
Preselection region	Signal region	$t\bar{t}$ control region	W+jets control region
=1 charged tight lepton ($p_T > 30$ GeV and $\lvert\eta\rvert < 2.5$)			
Veto secondary low-p_T charged loose leptons ($p_T > 10$ GeV and $\lvert\eta\rvert < 2.5$)			
=2 jets ($p_T > 30$ GeV and $\lvert\eta\rvert < 4.5$; $p_T > 35$ GeV within $2.7 < \lvert\eta\rvert < 3.5$)			
$E_T^{miss} > 35$ GeV			
$m_T(\ell E_T^{miss}) > 60$ GeV			
$p_T(\ell) > 50\left(1 - \frac{\pi - \lvert\Delta\phi(j_1,\ell)\rvert}{\pi - 1}\right)$ GeV			
=1 b-jet ($\lvert\eta\rvert < 2.5$; 60%WP)		=2 b-jet ($\lvert\eta\rvert < 2.5$; 60%WP)	=1 b-jet ($\lvert\eta\rvert < 2.5$; 60%WP)
	$m_{\ell b} < 153$ GeV $m_{\ell E_T^{miss} b} \in [120.6, 234.6]$ GeV trapez. requirement $m_{j\ell E_T^{miss} b} > 320$ GeV $H_T > 190$ GeV		$m_{\ell b} > 153$ GeV $m_{\ell E_T^{miss} b} \notin [120.6, 234.6]$ GeV veto trapez. requirement $m_{j\ell E_T^{miss} b} < 320$ GeV $H_T < 190$ GeV

Trapezoidal requirement:

$$\eta^j < (3\eta^t + 10.5) \cap \eta^j > (3\eta^t - 10.5) \cap \eta^j > (0.25\eta^t + 2.5) \cup \eta^j < (0.25$$

Klfitter to select events

- **K**inematic **L**ikelihood **FIT(KLFIT)**:
- $$\ln(\mathcal{L}) = B(m_{l\nu}|M_W,\Gamma_W) + B(m_{Wb}|M_t,\Gamma_t)$$
- $$+ \sum_{l,b,q,\nu} W(E_{obj}^{meas}|E_{obj})$$
  - Use cut on likelihood at -36
    - Selects t-channel events vs background events
    - Selects well reconstructed events
      - Neutrino estimation off for low likelihood events
    - Not using “KLFit-corrected" 4-momentum
  - Normalization of t-channel is free parameter
- Main backgrounds:
  - Top pair production
  - W+jets production



t-chan EFT Parameterization

- EFT fit after detector simulation
    - Parametrize each bin in EFT parameters:

$$N_{EFT}(c_{tW}, c_{itW}, c_{qQ}) = \left[1 + \sum_{x=c_{tW},c_{itW},c_{qQ}} a_x \cdot c_x + \sum_{x,y=c_{tW},c_{itW},c_{qQ}} b_{x,y} \cdot c_x \cdot c_y\right] N_{SM}$$

    - Strong linear (shape) dependence!!

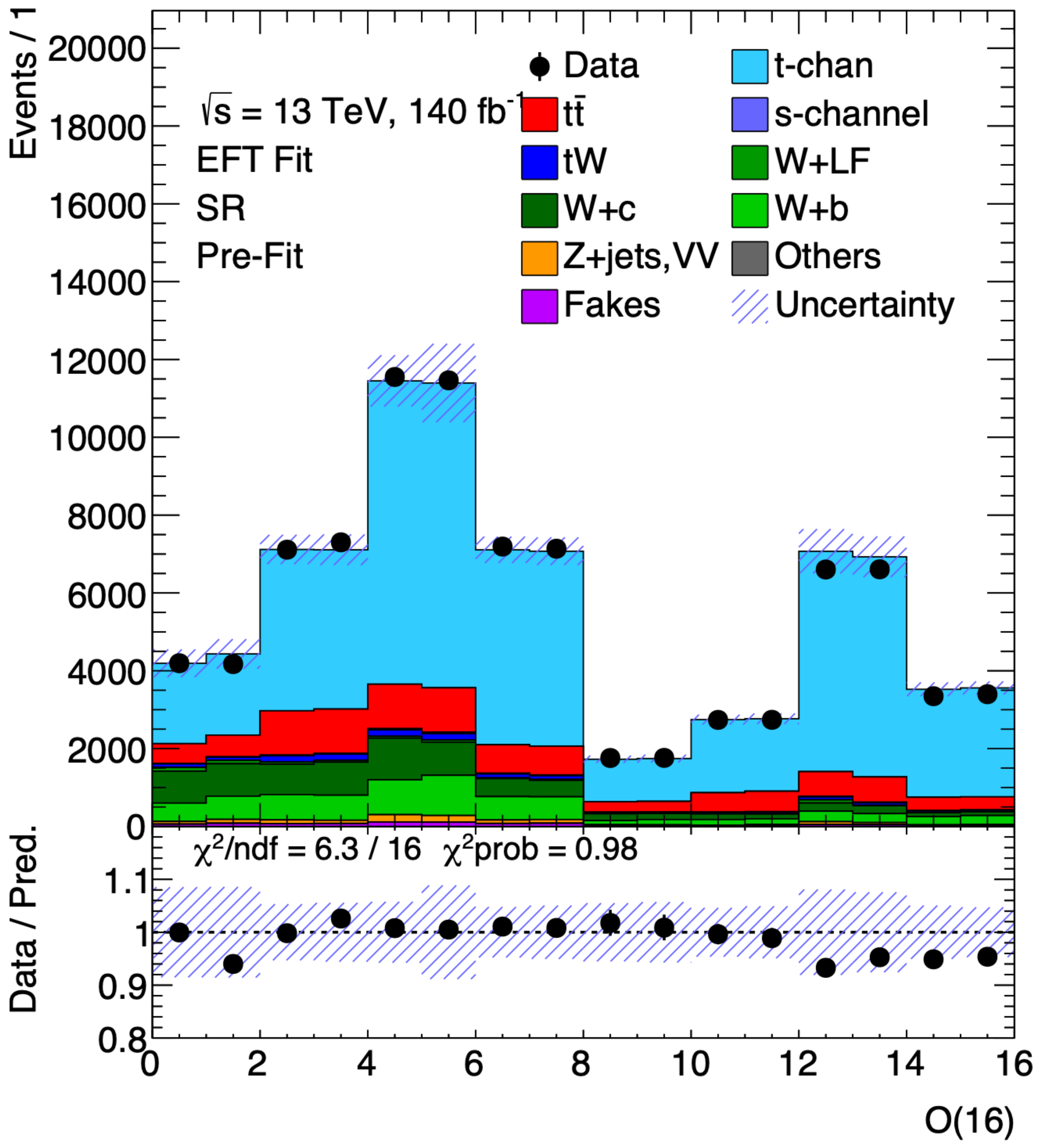

σ(ctW)/σ(SM)
t-chan SR
σ(ctW)/σ(SM)
Fit
O
Bin0 y = 1.00 + 0.05*ctW + 0.01*ctW*ctW
Bin1 y = 1.00 + 0.05*ctW + 0.01*ctW*ctW
Bin2 y = 1.00 + -0.09*ctW + 0.01*ctW*ctW
Bin3 y = 1.00 + -0.09*ctW + 0.01*ctW*ctW
Bin4 y = 1.00 + 0.02*ctW + 0.00*ctW*ctW
Bin5 y = 1.00 + 0.02*ctW + 0.00*ctW*ctW
Bin6 y = 1.00 + -0.09*ctW + 0.00*ctW*ctW
Bin7 y = 1.00 + -0.09*ctW + 0.00*ctW*ctW
Bin8 y = 1.00 + 0.15*ctW + 0.03*ctW*ctW
Bin9 y = 1.00 + 0.13*ctW + 0.03*ctW*ctW
Bin10 y = 1.00 + -0.19*ctW + 0.04*ctW*ctW
Bin11 y = 1.00 + -0.19*ctW + 0.05*ctW*ctW
Bin12 y = 1.00 + 0.05*ctW + 0.01*ctW*ctW
Bin13 y = 1.00 + 0.05*ctW + 0.01*ctW*ctW
Bin14 y = 1.00 + -0.11*ctW + 0.01*ctW*ctW
Bin15 y = 1.00 + -0.11*ctW + 0.02*ctW*ctW
ctW
σ(citW)/σ(SM)
t-chan SR
σ(citW)/σ(SM)
Fit
Bin0 y = 1.00 + 0.11*citW + 0.01*citW*citW
Bin1 y = 1.00 + -0.12*citW + 0.01*citW*citW
Bin2 y = 1.00 + 0.09*citW + 0.01*citW*citW
Bin3 y = 1.00 + -0.09*citW + 0.01*citW*citW
Bin4 y = 1.00 + 0.05*citW + -0.00*citW*citW
Bin5 y = 1.00 + -0.05*citW + -0.00*citW*citW
Bin6 y = 1.00 + 0.06*citW + -0.00*citW*citW
Bin7 y = 1.00 + -0.06*citW + -0.00*citW*citW
Bin8 y = 1.00 + 0.29*citW + 0.04*citW*citW
Bin9 y = 1.00 + -0.27*citW + 0.03*citW*citW
Bin10 y = 1.00 + 0.19*citW + 0.05*citW*citW
Bin11 y = 1.00 + -0.19*citW + 0.06*citW*citW
Bin12 y = 1.00 + 0.11*citW + 0.00*citW*citW
Bin13 y = 1.00 + -0.11*citW + 0.00*citW*citW
Bin14 y = 1.00 + 0.11*citW + 0.01*citW*citW
Bin15 y = 1.00 + -0.11*citW + 0.00*citW*citW
citW
σ(cqQ)/σ(SM)
t-chan SR
σ(cqQ)/σ(SM)
Fit
Bin0 y = 1.00 + -0.19*cqQ + 0.02*cqQ*cqQ
Bin1 y = 1.00 + -0.19*cqQ + 0.01*cqQ*cqQ
Bin2 y = 1.00 + -0.19*cqQ + 0.02*cqQ*cqQ
Bin3 y = 1.00 + -0.19*cqQ + 0.01*cqQ*cqQ
Bin4 y = 1.00 + -0.19*cqQ + 0.01*cqQ*cqQ
Bin5 y = 1.00 + -0.19*cqQ + 0.01*cqQ*cqQ
Bin6 y = 1.00 + -0.20*cqQ + 0.01*cqQ*cqQ
Bin7 y = 1.00 + -0.20*cqQ + 0.01*cqQ*cqQ
Bin8 y = 1.00 + -0.40*cqQ + 0.06*cqQ*cqQ
Bin9 y = 1.00 + -0.40*cqQ + 0.06*cqQ*cqQ
Bin10 y = 1.00 + -0.40*cqQ + 0.06*cqQ*cqQ
Bin11 y = 1.00 + -0.39*cqQ + 0.05*cqQ*cqQ
Bin12 y = 1.00 + -0.38*cqQ + 0.05*cqQ*cqQ
Bin13 y = 1.00 + -0.38*cqQ + 0.05*cqQ*cqQ
Bin14 y = 1.00 + -0.42*cqQ + 0.06*cqQ*cqQ
Bin15 y = 1.00 + -0.42*cqQ + 0.06*cqQ*cqQ
cqQ

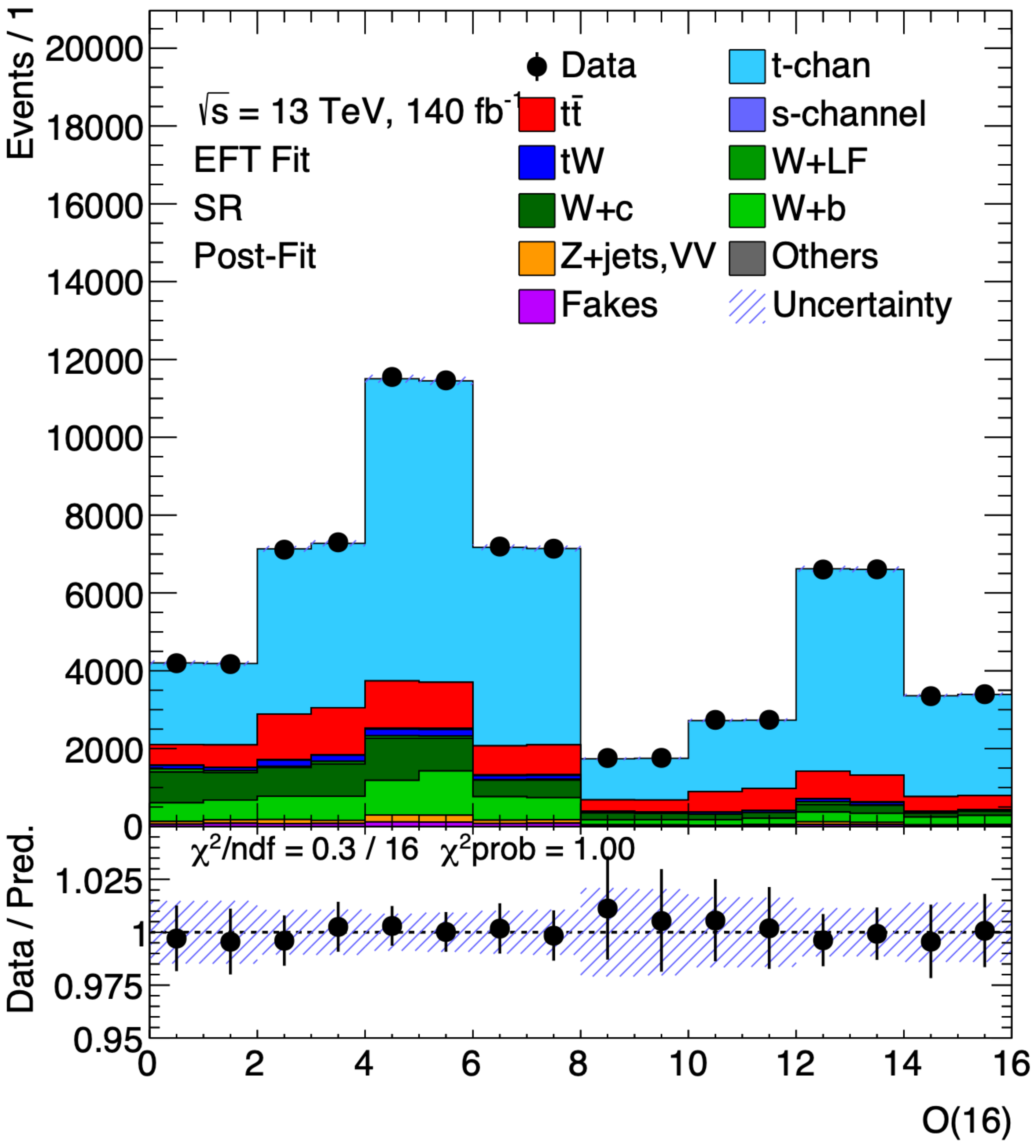
$t\bar{t}$ eft Parameterization

- $t\bar{t}$ also depends on c_{tW} and c_{itW} via decay
  - New since previous analysis

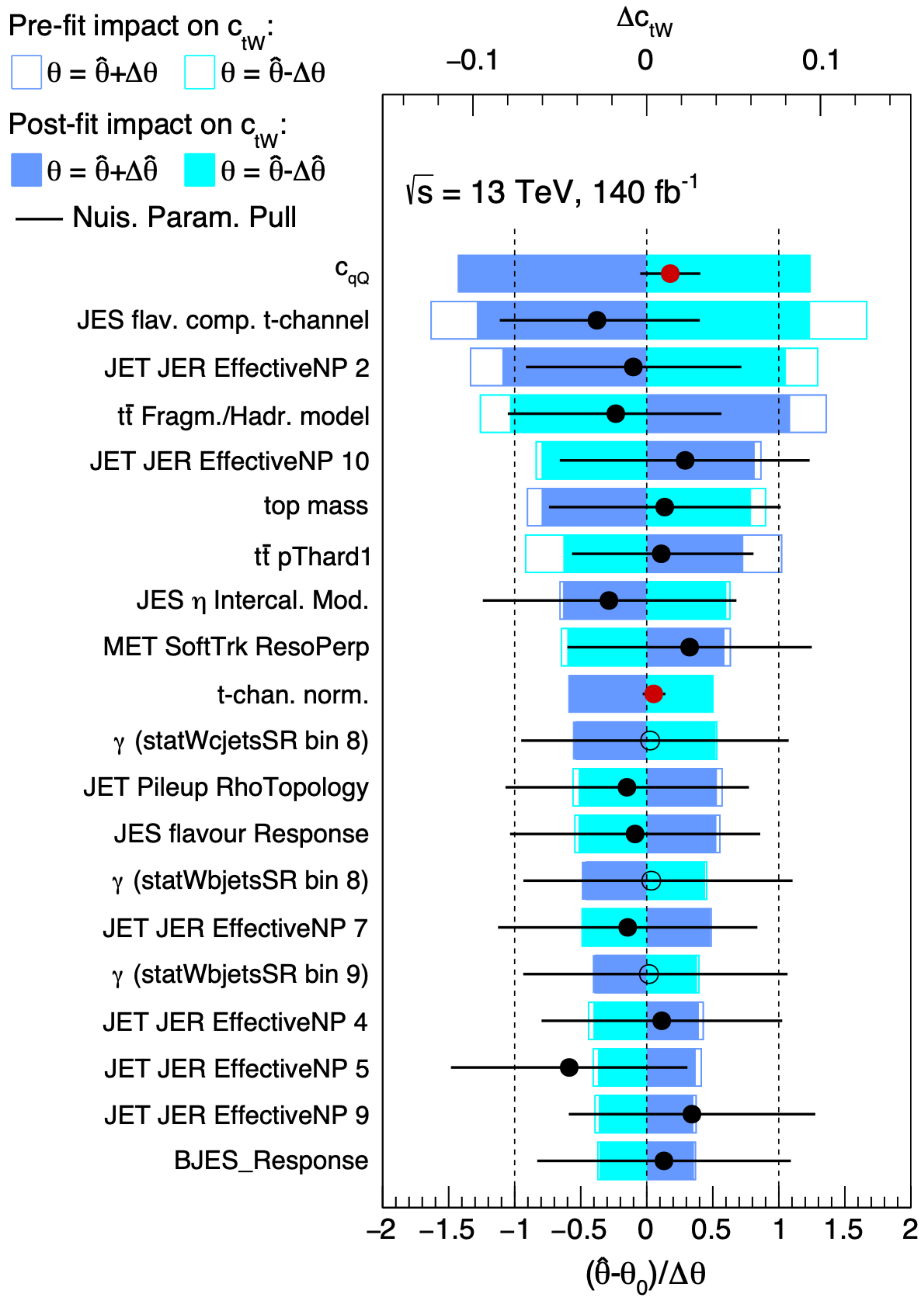
Pre/Post-fit plots

- Small (pre-fit) deficit in last 4 bins
  - All within uncertainties
  -

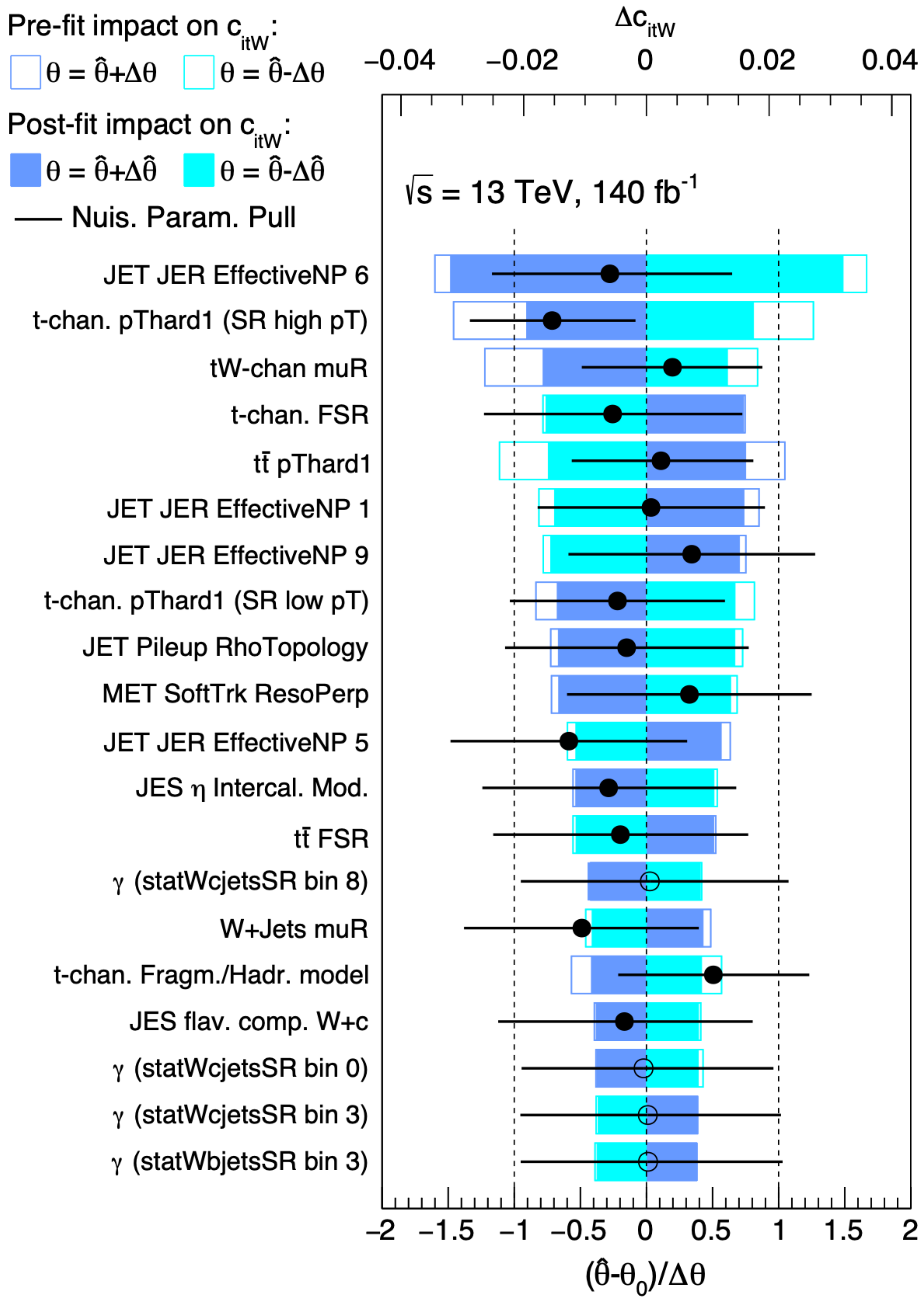




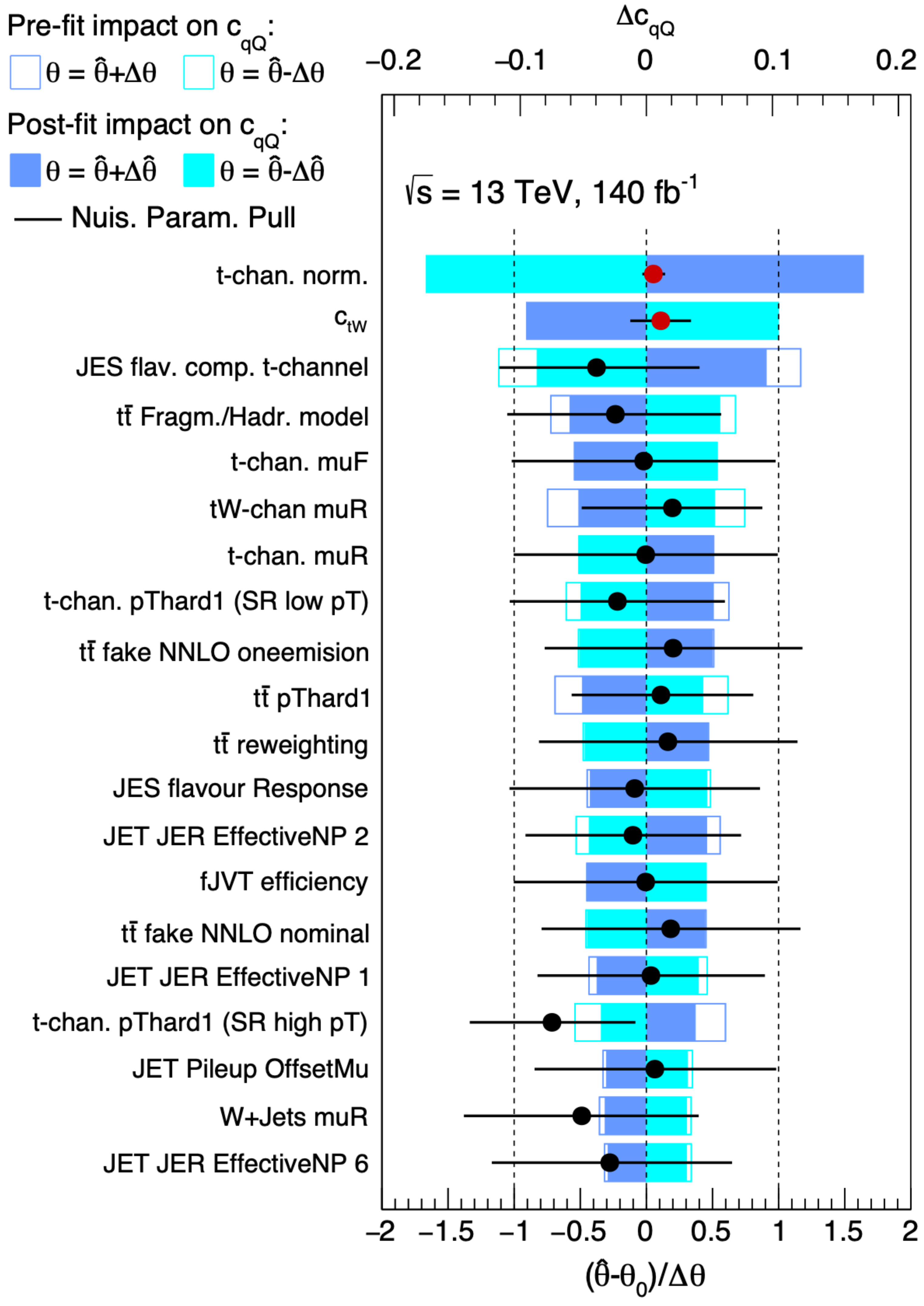
Ranking



Pre-fit impact on c_tW:
θ = θ̂+Δθ
θ = θ̂-Δθ
Post-fit impact on c_tW:
θ = θ̂+Δθ
θ = θ̂-Δθ
Nuis. Param. Pull
Δc_tW
√s = 13 TeV, 140 fb^-1
c_qQ
JES flav. comp. t-channel
JET JER EffectiveNP 2
tt̄ Fragm./Hadr. model
JET JER EffectiveNP 10
top mass
tt̄ pThard1
JES η Intercal. Mod.
MET SoftTrk ResoPerp
t-chan. norm.
γ (statWcjetsSR bin 8)
JET Pileup RhoTopology
JES flavour Response
γ (statWbjetsSR bin 8)
JET JER EffectiveNP 7
γ (statWbjetsSR bin 9)
JET JER EffectiveNP 4
JET JER EffectiveNP 5
JET JER EffectiveNP 9
BJES_Response
(θ̂-θ_0)/Δθ



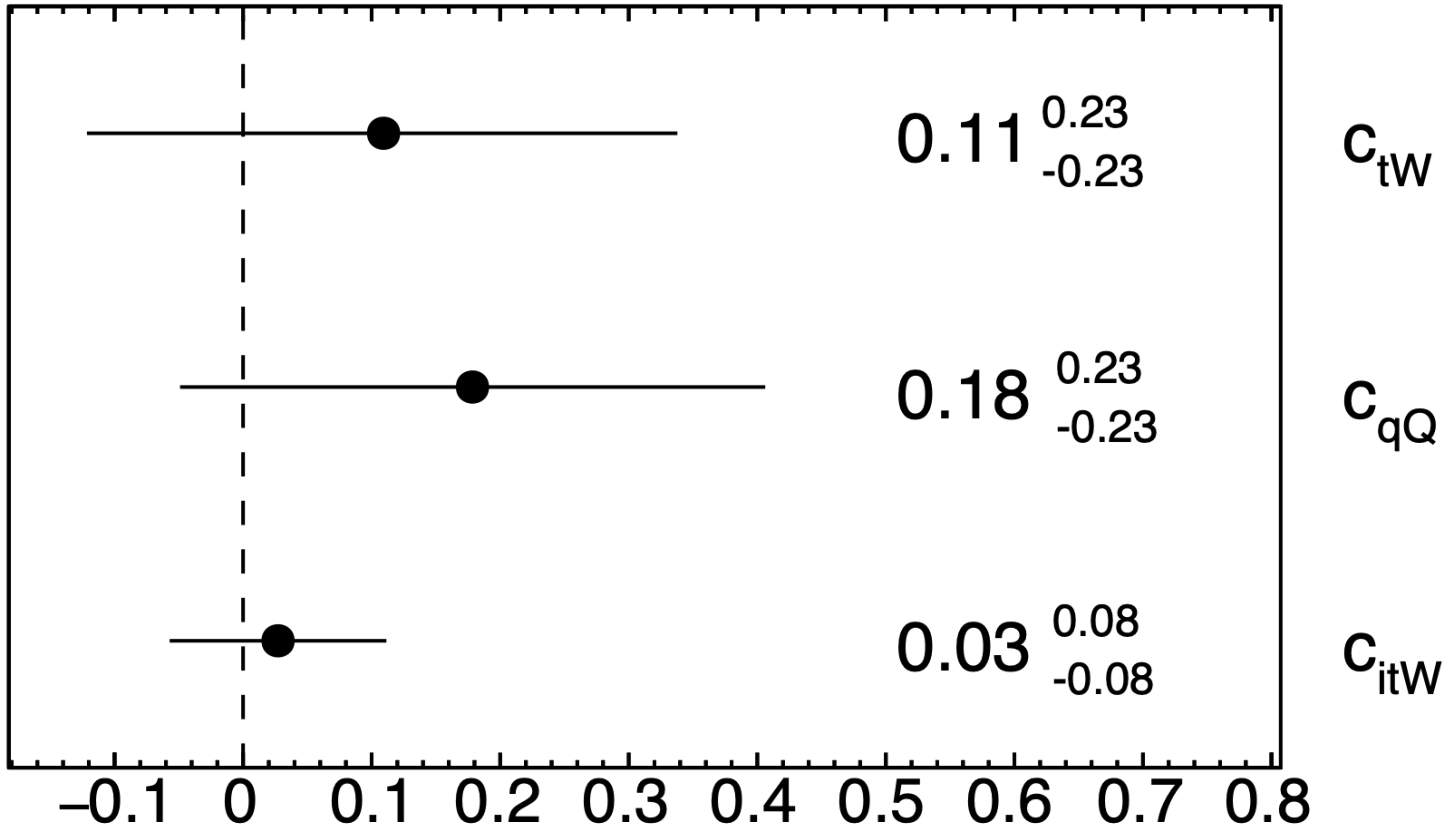
Pre-fit impact on c_itW:
θ = θ̂+Δθ
θ = θ̂-Δθ
Post-fit impact on c_itW:
θ = θ̂+Δθ
θ = θ̂-Δθ
Nuis. Param. Pull
Δc_itW
√s = 13 TeV, 140 fb^-1
JET JER EffectiveNP 6
t-chan. pThard1 (SR high pT)
tW-chan muR
t-chan. FSR
tt̄ pThard1
JET JER EffectiveNP 1
JET JER EffectiveNP 9
t-chan. pThard1 (SR low pT)
JET Pileup RhoTopology
MET SoftTrk ResoPerp
JET JER EffectiveNP 5
JES η Intercal. Mod.
tt̄ FSR
γ (statWcjetsSR bin 8)
W+Jets muR
t-chan. Fragm./Hadr. model
JES flav. comp. W+c
γ (statWcjetsSR bin 0)
γ (statWcjetsSR bin 3)
γ (statWbjetsSR bin 3)
(θ̂-θ_0)/Δθ



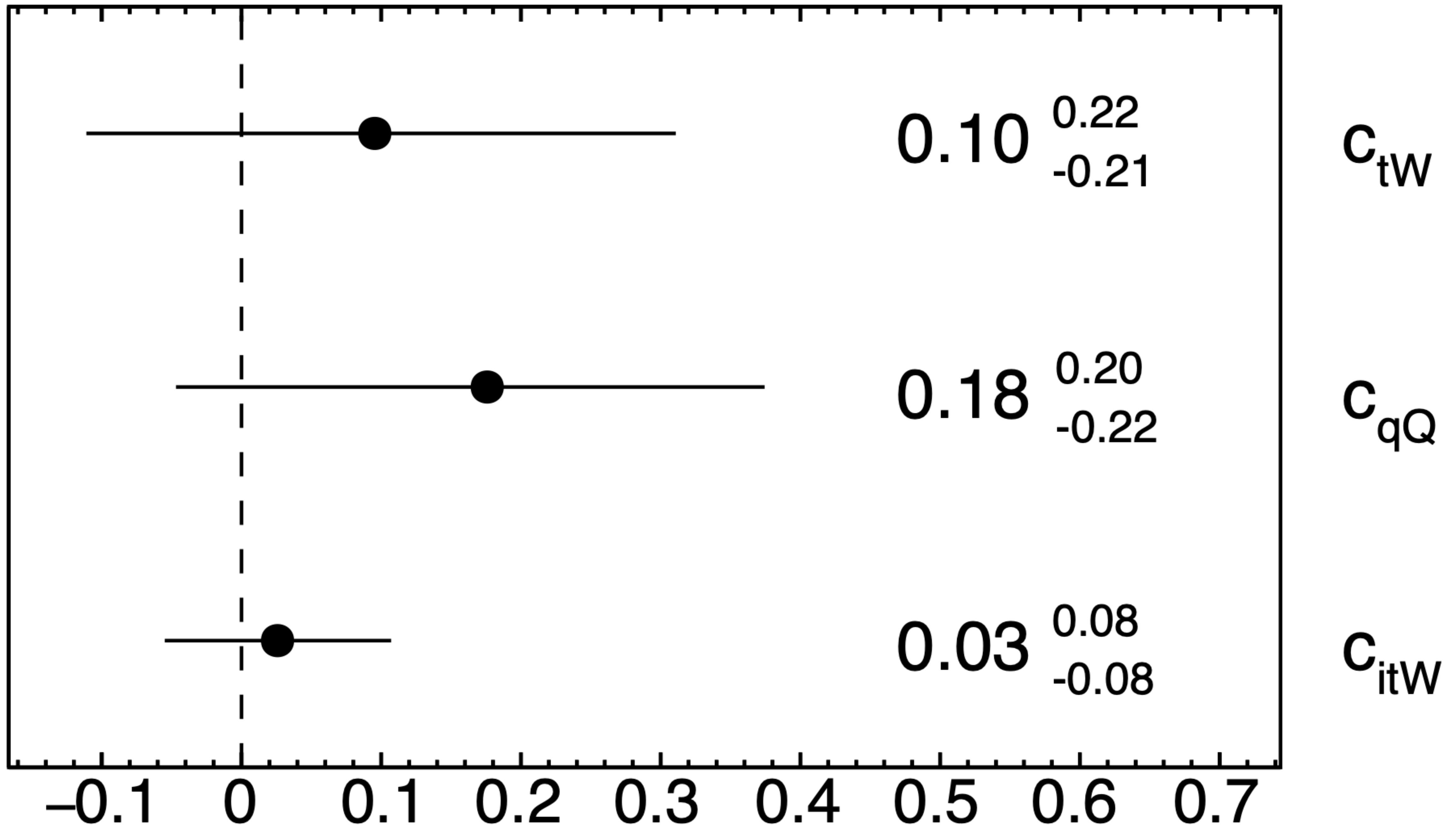
Pre-fit impact on c_qQ:
θ = θ̂+Δθ
θ = θ̂-Δθ
Post-fit impact on c_qQ:
θ = θ̂+Δθ
θ = θ̂-Δθ
Nuis. Param. Pull
Δc_qQ
√s = 13 TeV, 140 fb^-1
t-chan. norm.
c_tW
JES flav. comp. t-channel
tt̄ Fragm./Hadr. model
t-chan. muF
tW-chan muR
t-chan. muR
t-chan. pThard1 (SR low pT)
tt̄ fake NNLO oneemision
tt̄ pThard1
tt̄ reweighting
JES flavour Response
JET JER EffectiveNP 2
fJVT efficiency
tt̄ fake NNLO nominal
JET JER EffectiveNP 1
t-chan. pThard1 (SR high pT)
JET Pileup OffsetMu
W+Jets muR
JET JER EffectiveNP 6
(θ̂-θ_0)/Δθ

LINEAR FIT

- Fit EFT parameters simultaneously with overall normalization factors for t-channel, $t\bar{t}$ and W+jets
  - EFT parametrization for both t-channel and $t\bar{t}$

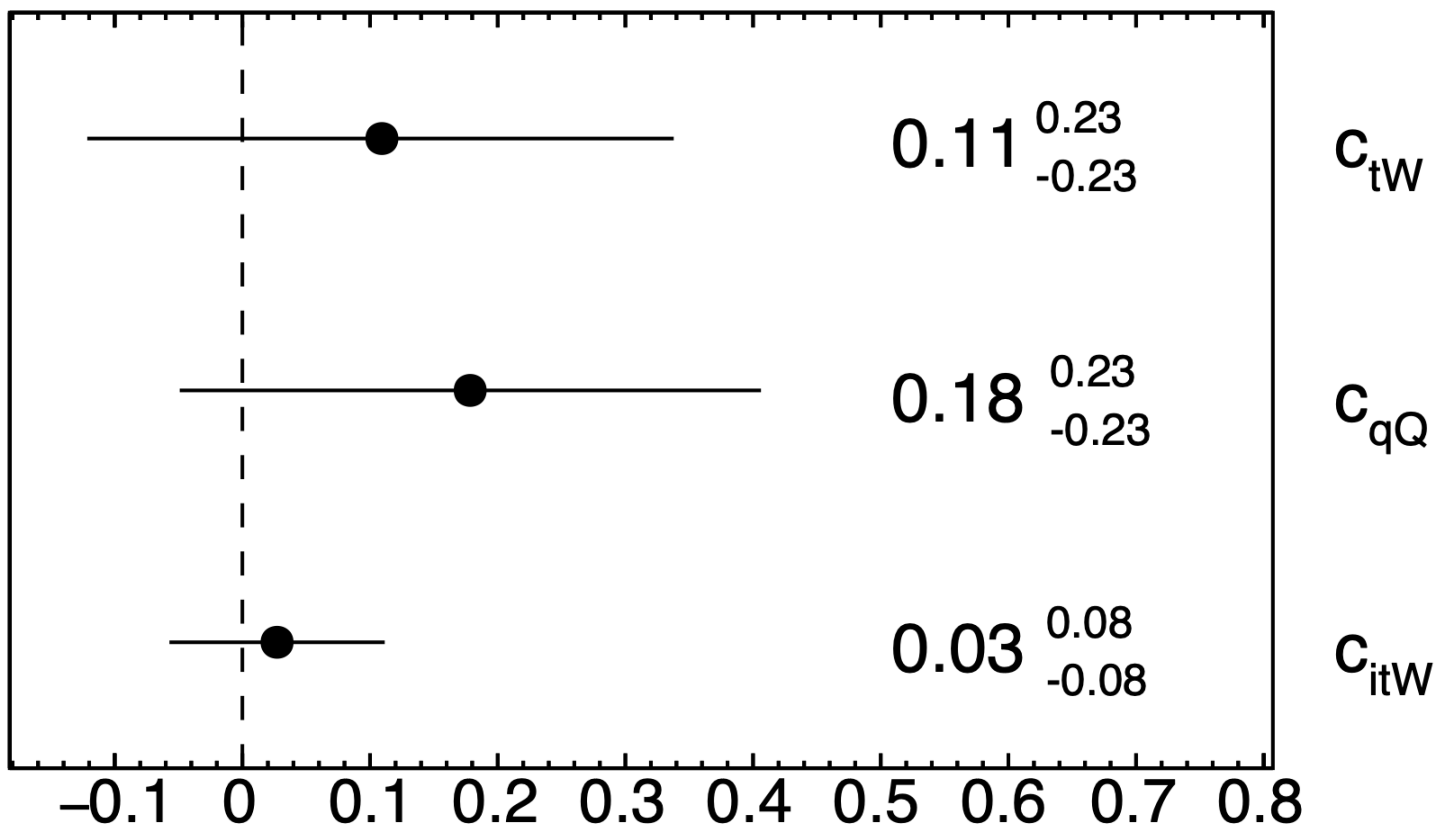


LINEAR EFT FIT

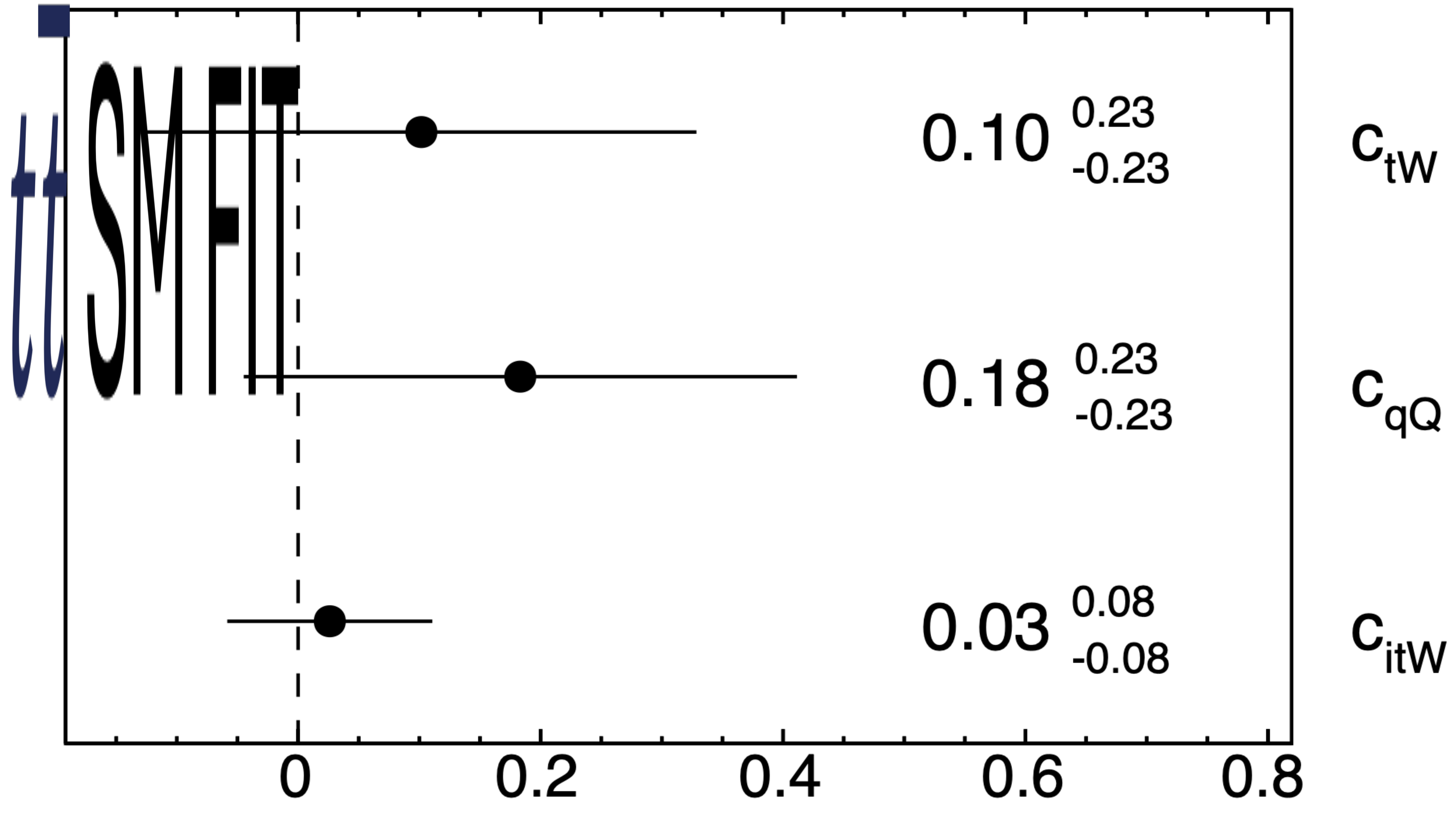


$t\bar{t}$ SM FIT

- Fit EFT parameters simultaneously with overall normalization factors for t-channel, $t\bar{t}$ and W+jets
  - Quadratic EFT parametrization for both t-channel and $t\bar{t}$ (left)
  - Standard Model $t\bar{t}$ (right)

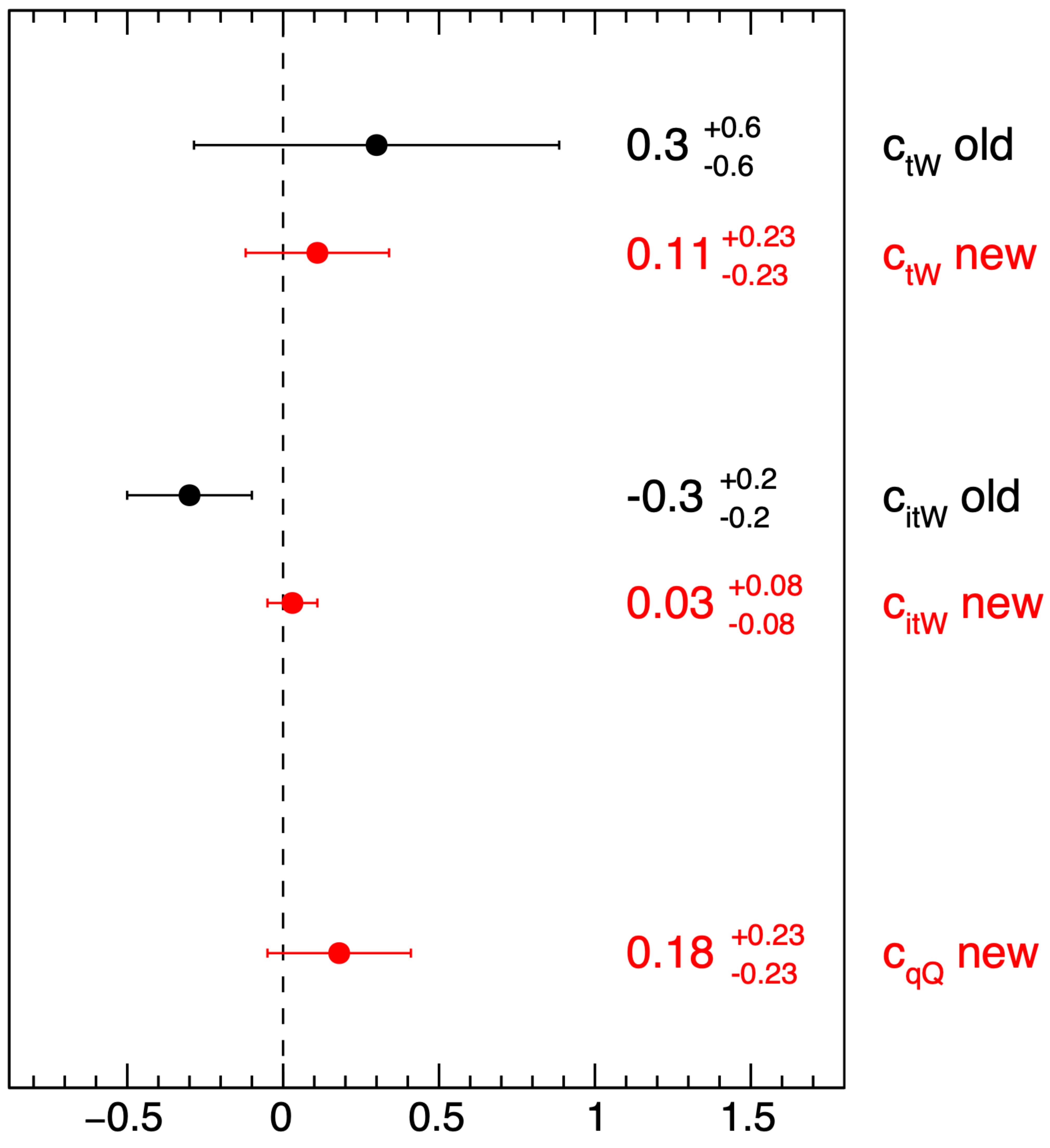


$t\bar{t}$ SM EFT FIT



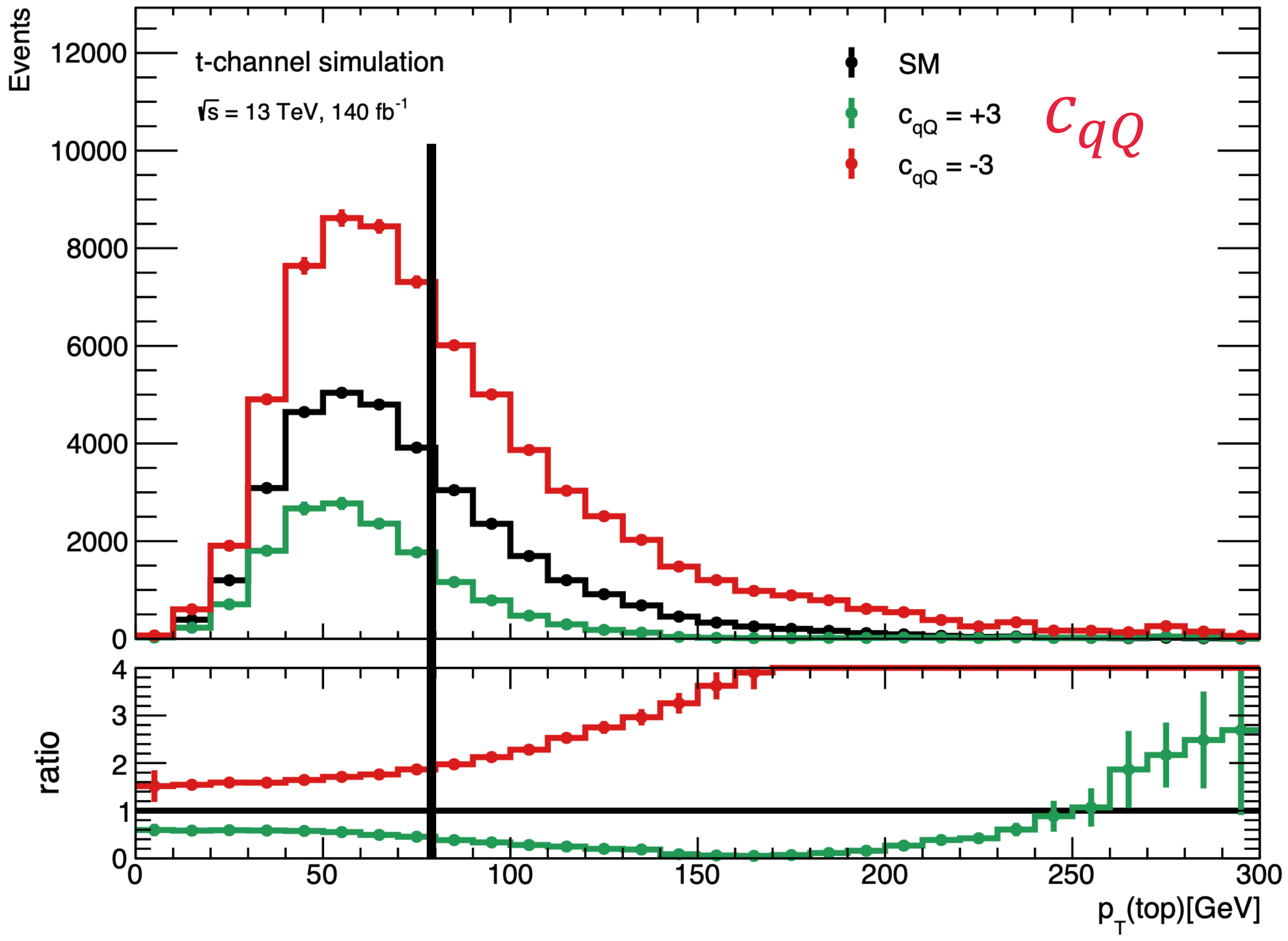
Conclusion

- EFT fit performed on reconstruction level:
  - Taking into account all systematics
  - With EFT Effects on $t\bar{t}$
  - Taking into account all leading EFT contributions in a correlated way
  - Factor 2-3 more sensitive than previous t-chan ATLAS result for c_{tW} and c_{itW}
    - Smaller sensitivity as t-channel cross-section on c_{qQ} but more model independent
    - Large improvements from p_T dependency and better background rejection(2x better)



CQQ sensitivity

- $\mathcal{L} = \mathcal{L}_{SM} + \sum_i \frac{c_i}{\Lambda^2} O_i^6$ —> $M = M_{SM} + \sum_i \frac{c_i}{\Lambda^2} M_i^6$
- $N \propto |M|^2 = M_{SM} + \sum_i c_i |M_{sm} M_i| + \sum_{i,j} c_i c_j |M_{ij}|$
  - Use reweighting method for EFT:
    - $W_{new} = \frac{|M^{new}|^2}{|M^{old}|^2} W_{old}$
  - Large sensitivity through top p_T
    - Grows with momentum
  - Use 2 bins in p_T
    - Larger/smaller than 80 GeV



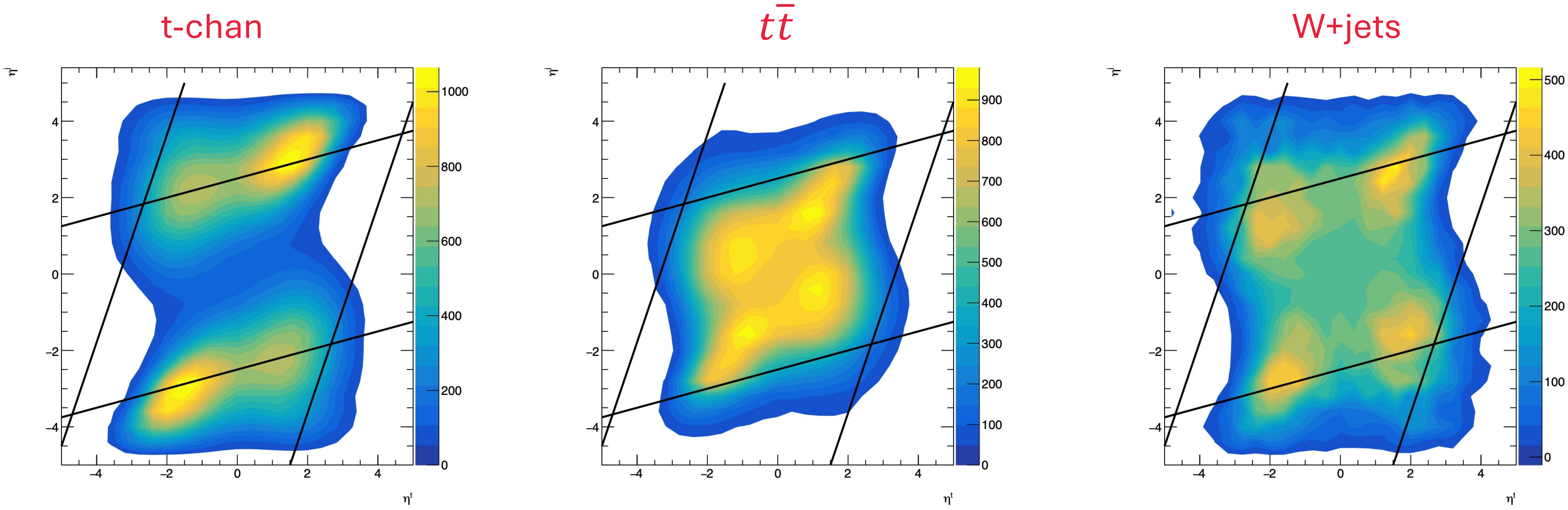
Region definition

- Trapez. Requirement defined as:
- $\eta_j < (3\eta_{\ell E^{miss}_{\mathrm{T}} b} + 10.5) \cap \eta_j > (3\eta_{\ell E^{miss}_{\mathrm{T}} b} - 10.5) \cap \eta_j > (0.25\eta_{\ell E^{miss}_{\mathrm{T}} b} + 2.5) \cup \eta_j < (0.25\eta_{\ell E^{miss}_{\mathrm{T}} b} - 2.5)$

Preselection region	Signal region	$t\bar{t}$ control region	W+jets control region
=1 charged tight lepton ($p_{\mathrm{T}} > 30$ GeV and $\lvert\eta\rvert < 2.5$)			
Veto secondary low-p_{T} charged loose leptons ($p_{\mathrm{T}} > 10$ GeV and $\lvert\eta\rvert < 2.5$)			
=2 jets ($p_{\mathrm{T}} > 30$ GeV and $\lvert\eta\rvert < 4.5$; $p_{\mathrm{T}} > 35$ GeV within $2.7 < \lvert\eta\rvert < 3.5$)			
$E_{\mathrm{T}}^{\mathrm{miss}} > 35$ GeV			
$m_{\mathrm{T}}(\ell E_{\mathrm{T}}^{\mathrm{miss}}) > 60$ GeV			
$p_{\mathrm{T}}(\ell) > 50\left(1 - \frac{\pi - \lvert\Delta\phi(j_1,\ell)\rvert}{\pi - 1}\right)$ GeV			
=1 b-jet ($\lvert\eta\rvert < 2.5$; 60%WP)		=2 b-jet ($\lvert\eta\rvert < 2.5$; 60%WP)	=1 b-jet ($\lvert\eta\rvert < 2.5$; 60%WP)
	$m_{\ell b} < 153$ GeV & $m_{\ell E_{\mathrm{T}}^{\mathrm{miss}} b} \in [120.6, 234.6]$ GeV trapez. requirement $m_{j\ell E_{\mathrm{T}}^{\mathrm{miss}} b} > 320$ GeV $H_{\mathrm{T}} > 190$ GeV		$m_{\ell b} > 153$ GeV Or $m_{\ell E_{\mathrm{T}}^{\mathrm{miss}} b} \notin [120.6, 234.6]$ GeV veto trapez. requirement $m_{j\ell E_{\mathrm{T}}^{\mathrm{miss}} b} < 320$ GeV $H_{\mathrm{T}} < 190$ GeV

Trapezoidal cut

- Greatly reduces backgrounds while keeping signal
  - Optimized on S/B and $S/\sqrt{S+B}$



Previous results of polarization fit

- Fit both c_{tw} and c_{itw} to unfolded distributions of $\cos(\theta_{xl})$ and $\cos(\theta_{yl})$
  - $c_{tW} = 0.3 \pm 0.6$
  - $c_{itW} = -0.3 \pm 0.2$