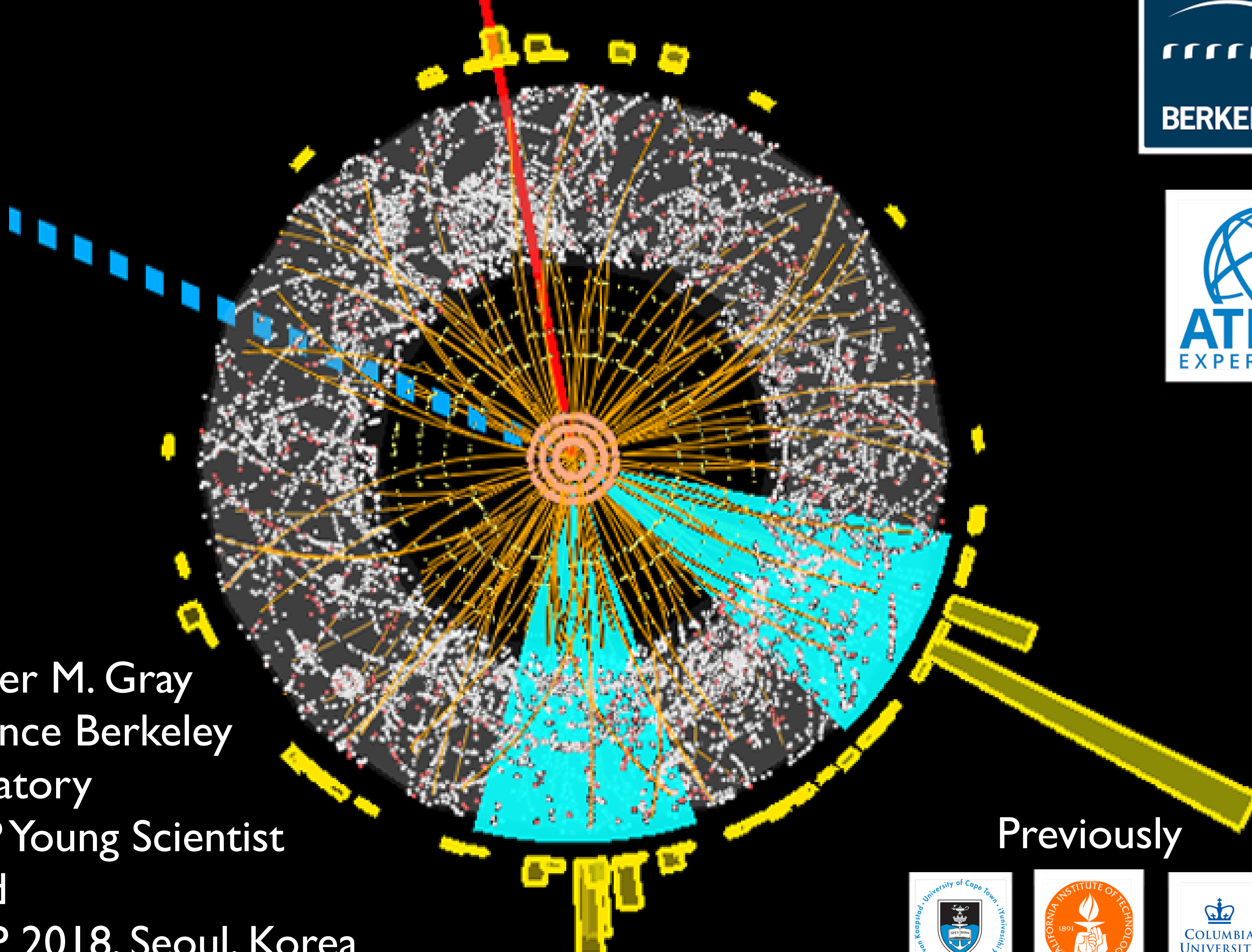
From the ATLAS pixel detector to probing the coupling of the Higgs to quarks



Heather M. Gray
Lawrence Berkeley Laboratory
IUPAP Young Scientist Award
ICHEP 2018, Seoul, Korea

BERKELEY LAB

ATLAS EXPERIMENT

Previously

University of Cape Town

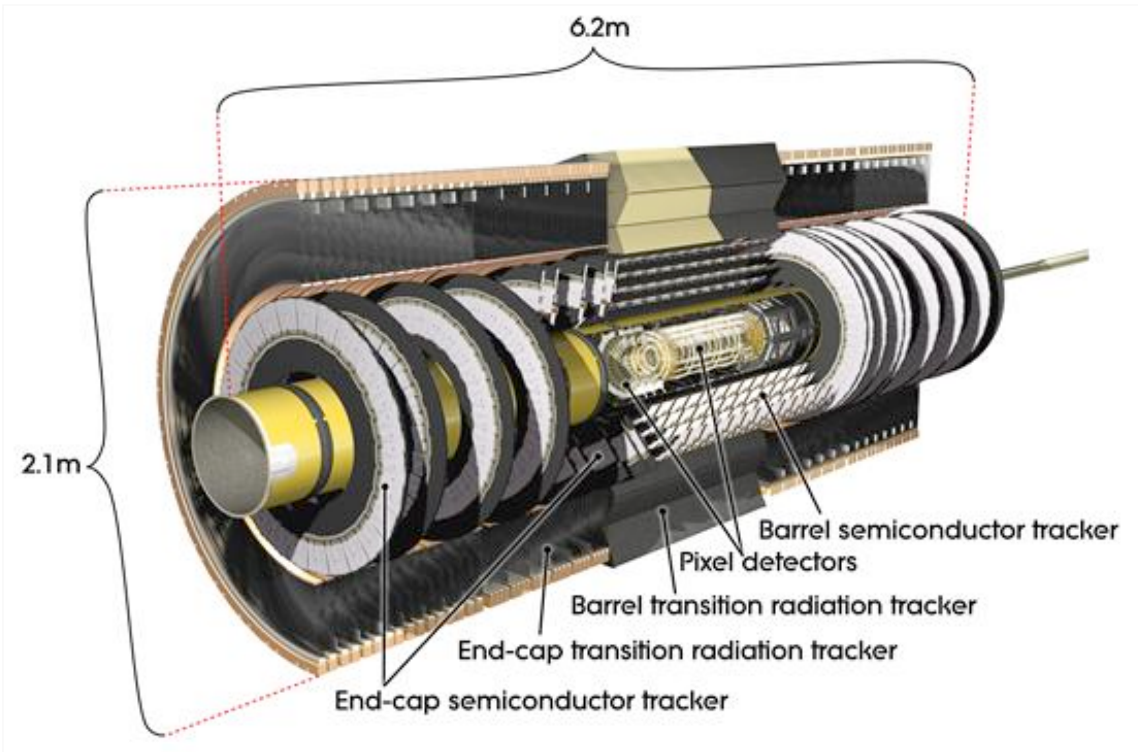
California Institute of Technology

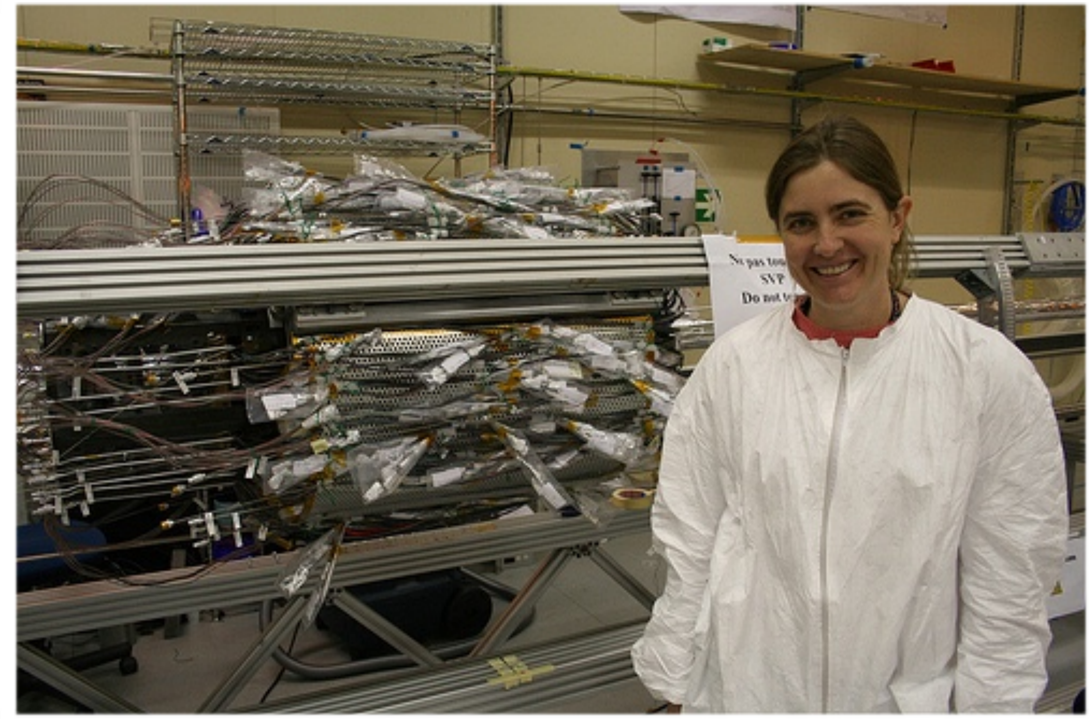
Columbia University

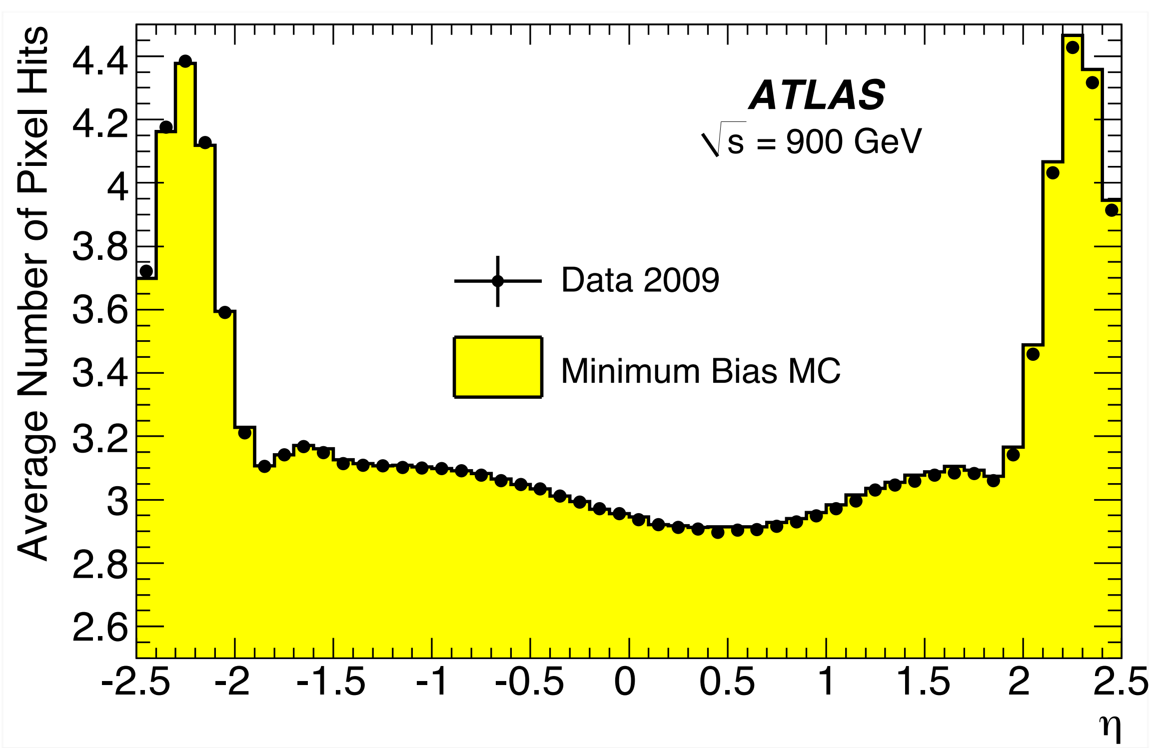
CERN

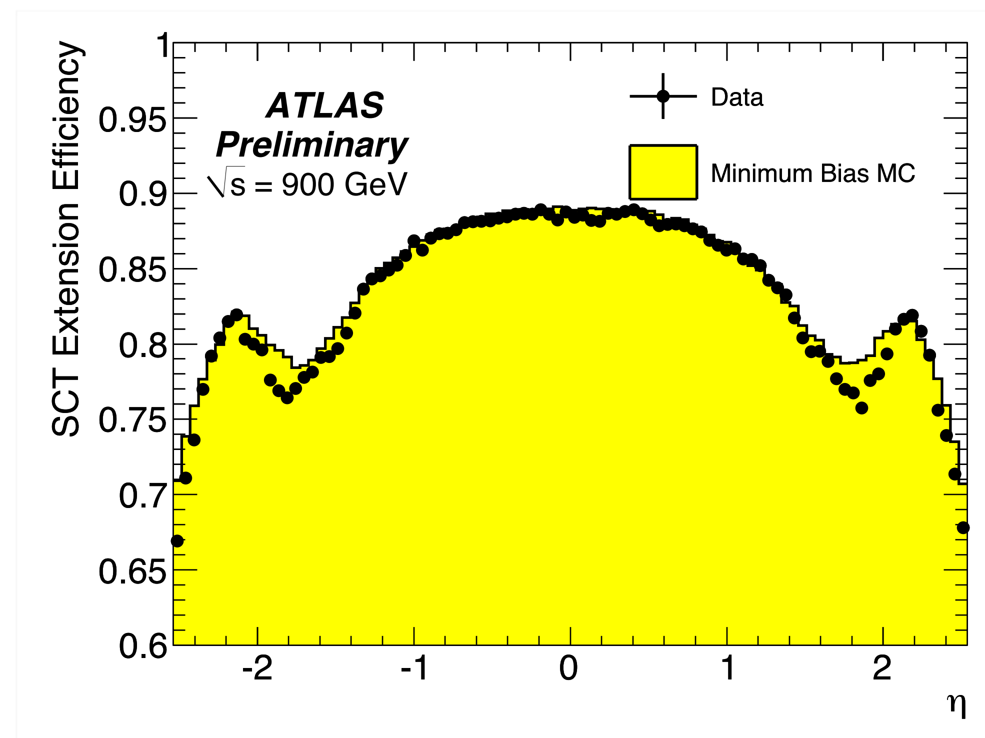
Pixel Detector

Phys.Lett. B688 (2010) 21-42









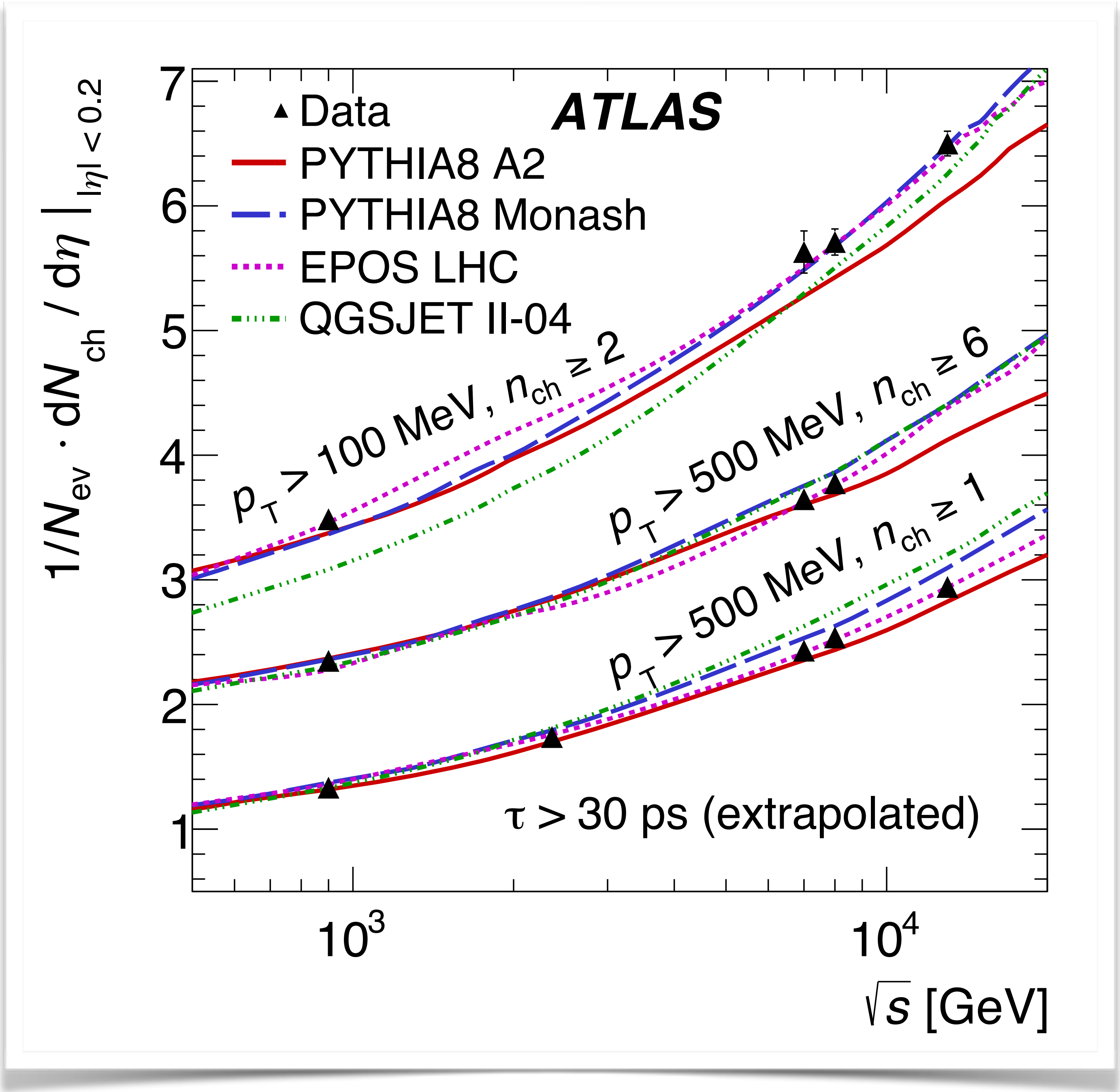
Charged particle multiplicity

PLB688 (2010) 21-42

New J. Phys. 13 (2011) 053033

PLB 758 (2016) 67

EPJC 76 (2016) 502

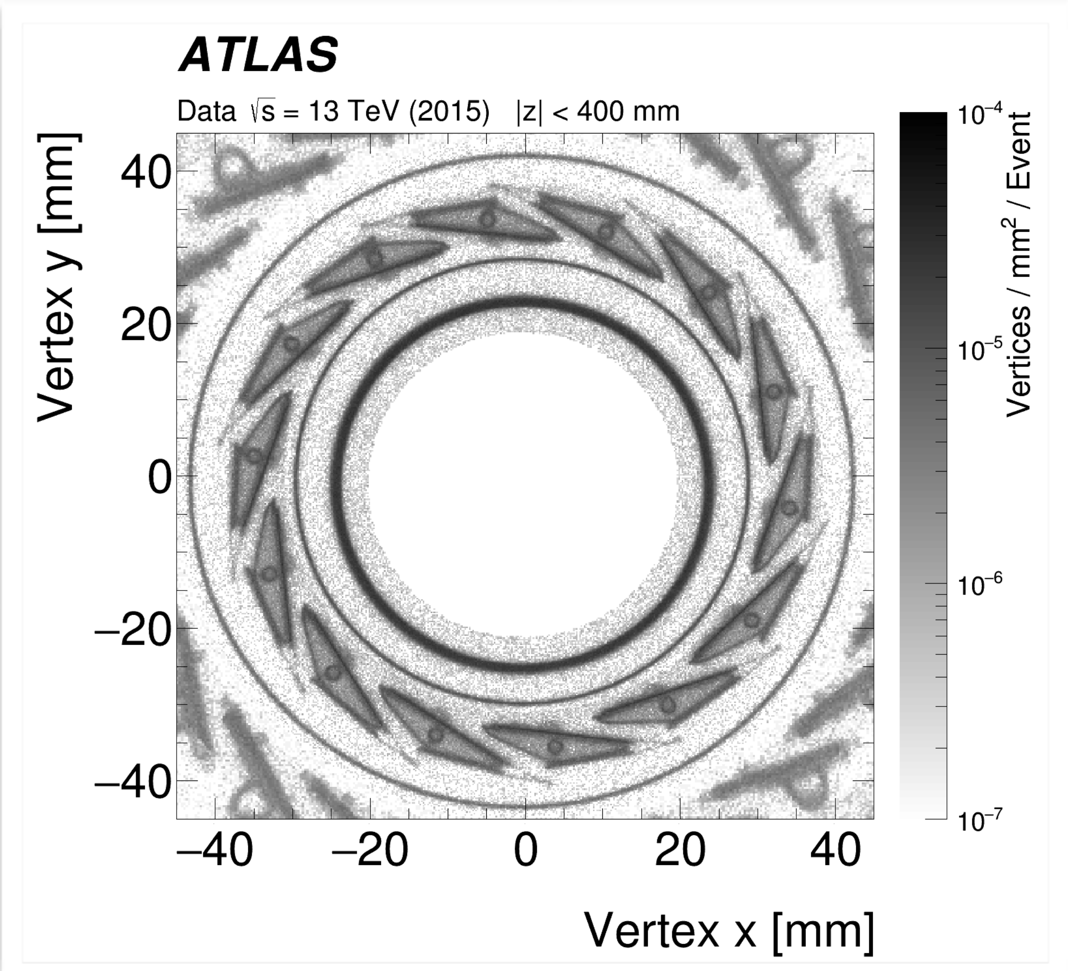


Material and Alignment

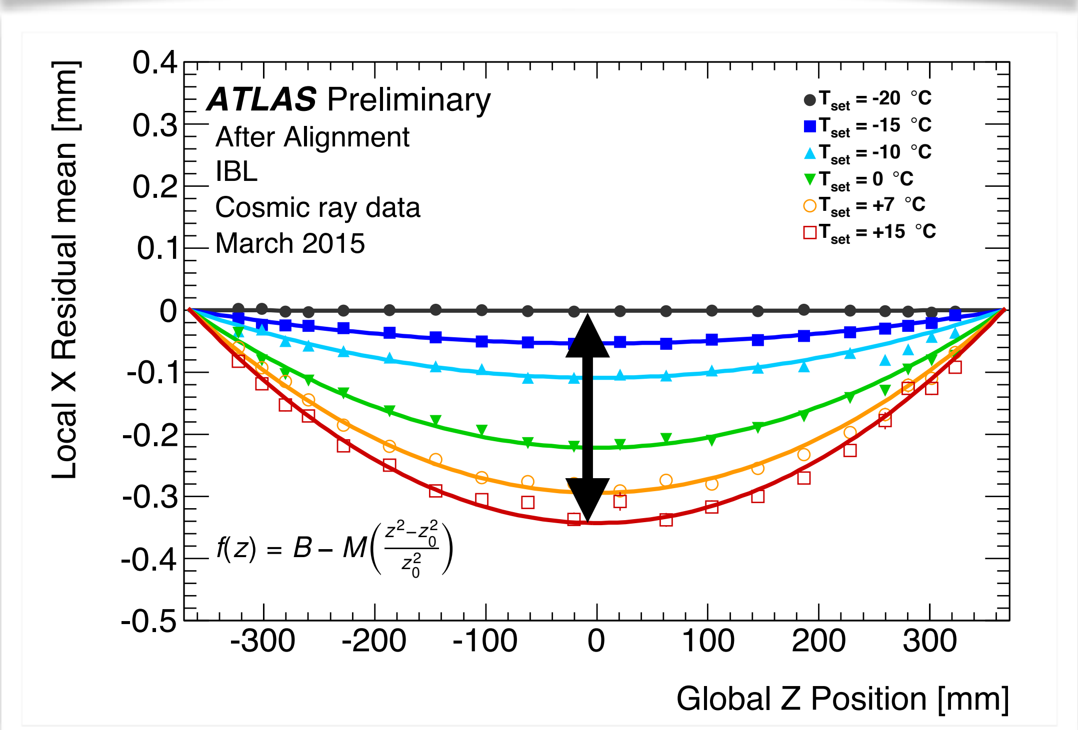
JINST 12 (2017) P12009

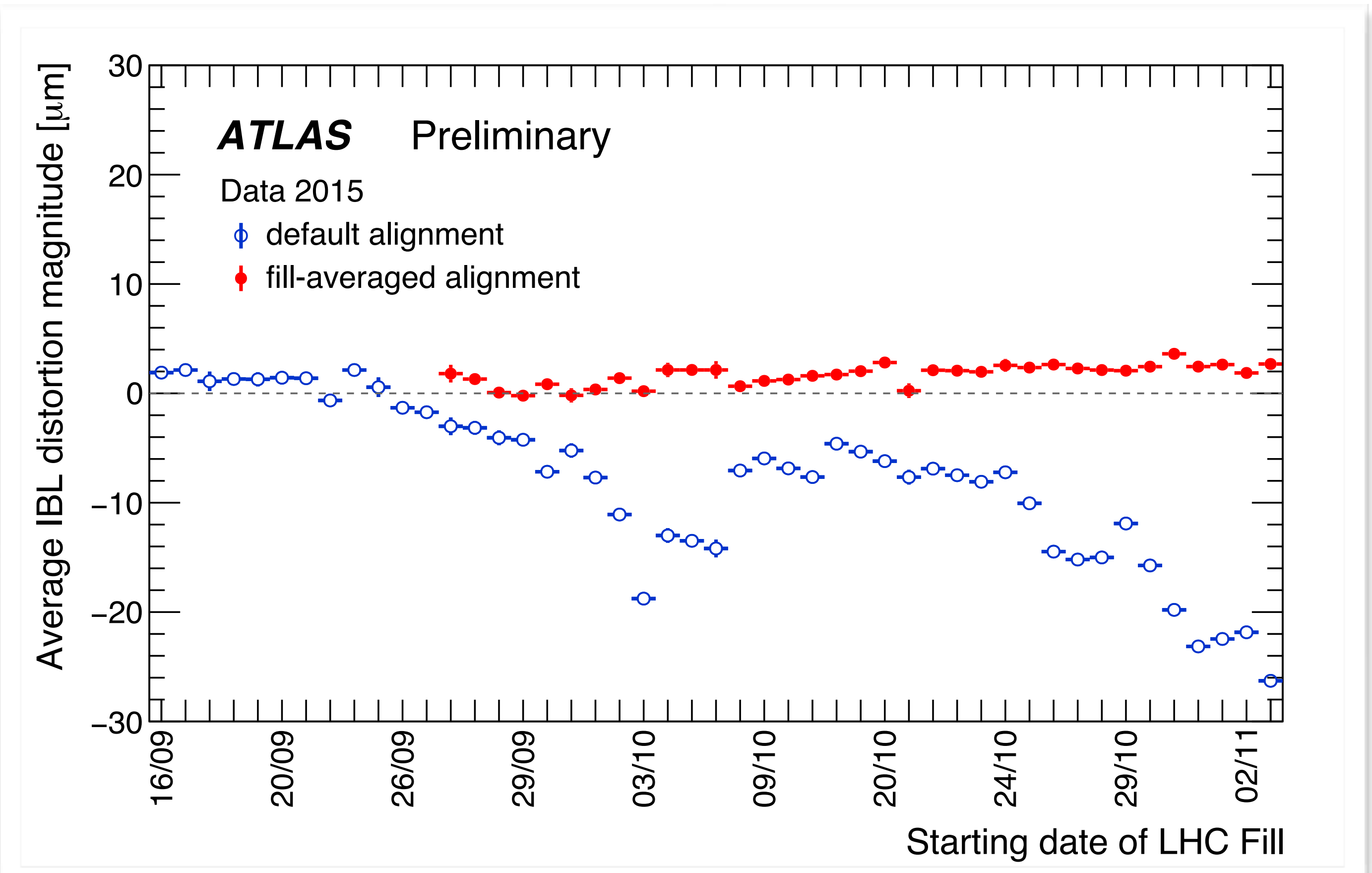
ATL-INDET-PUB-2015-001

IDTR-2015-011

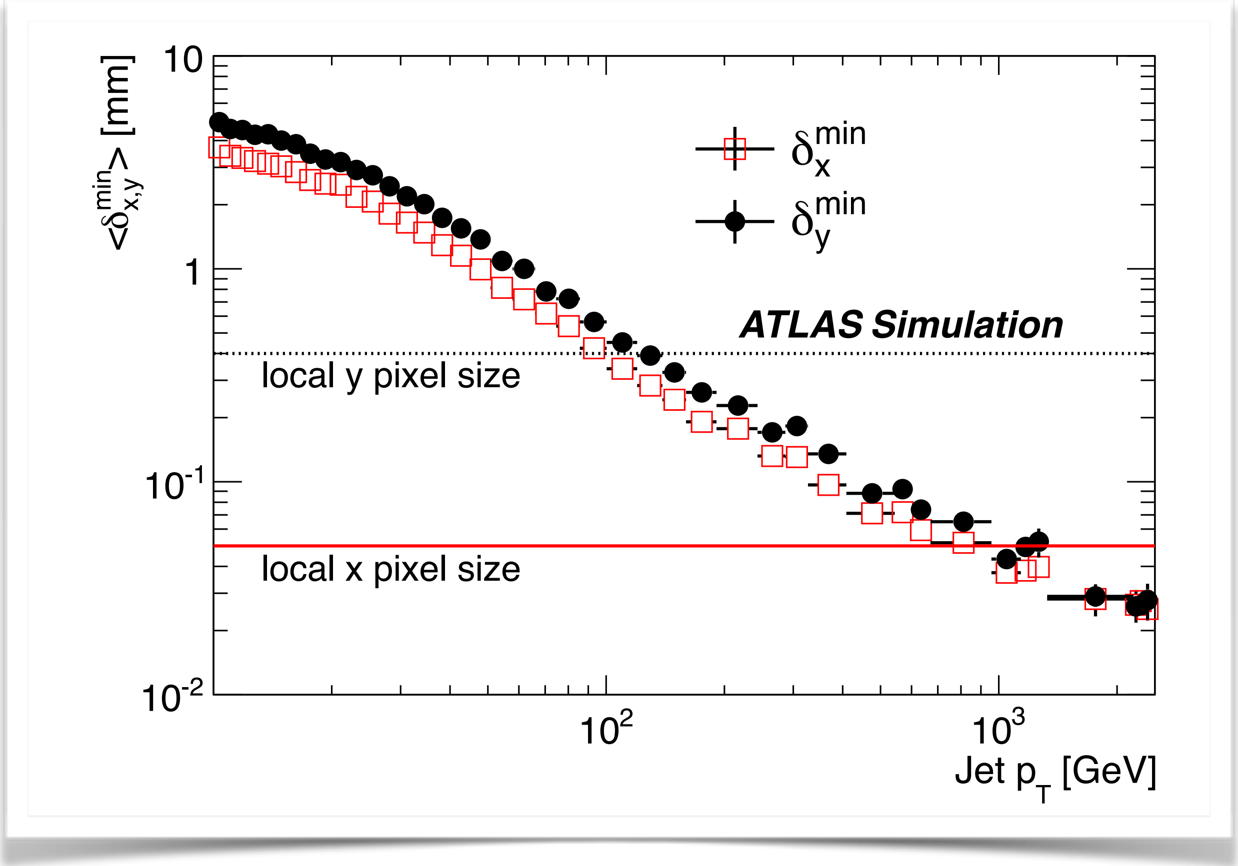


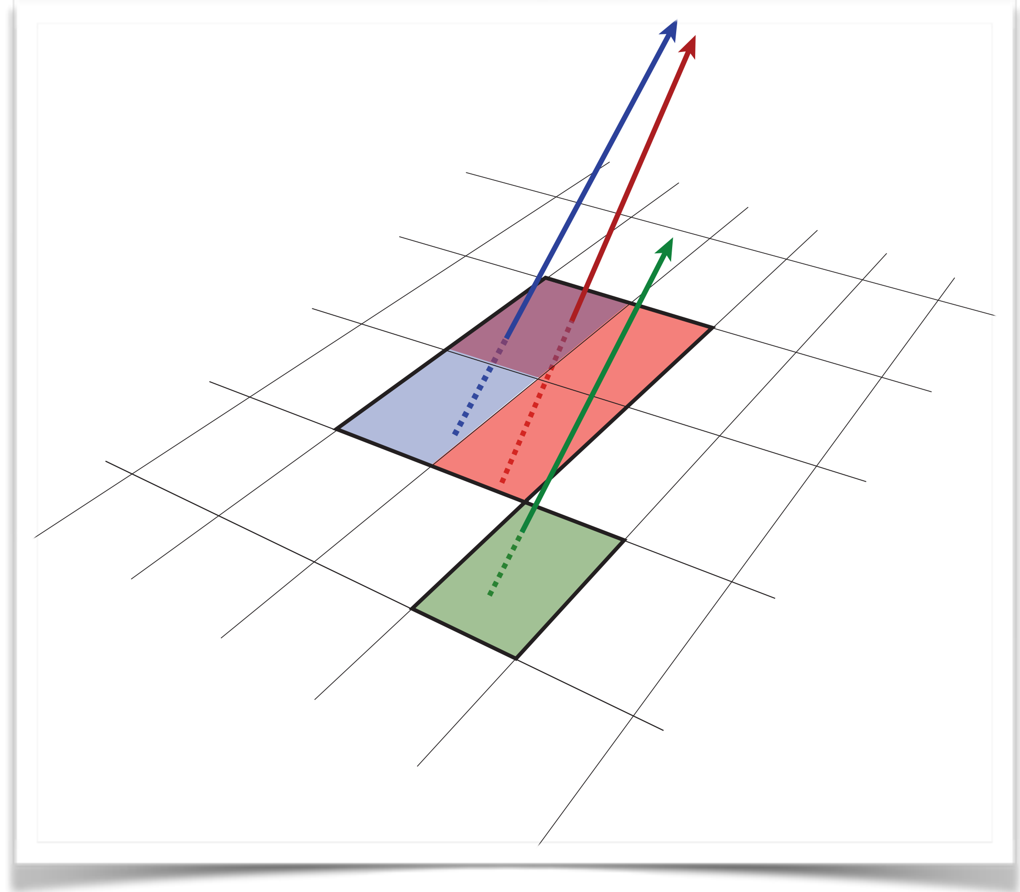
Material description in simulation describes data to within 20%

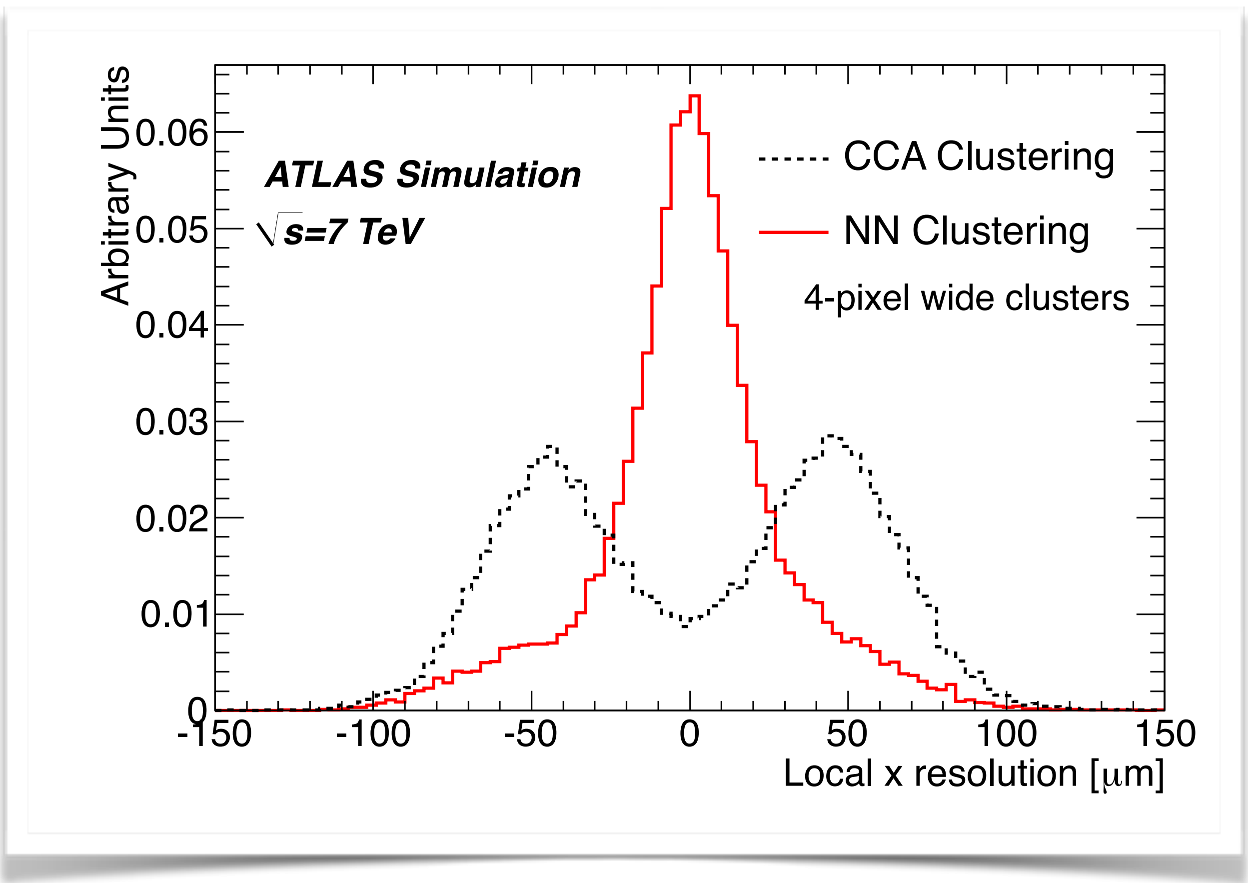




Cluster Splitting with Neural Networks







- Improved impact parameter resolution
- Reduces shared clusters in jet cores by factor of 3: better tracking in boosted jets

JINST 9 (2014) P09009

Probing Higgs-Quark Couplings

- Higgs discovered via its decays to bosons
- Fermionic couplings added by hand to the Lagrangian
  - Not needed for electroweak symmetry breaking

Higgs-Quark Couplings

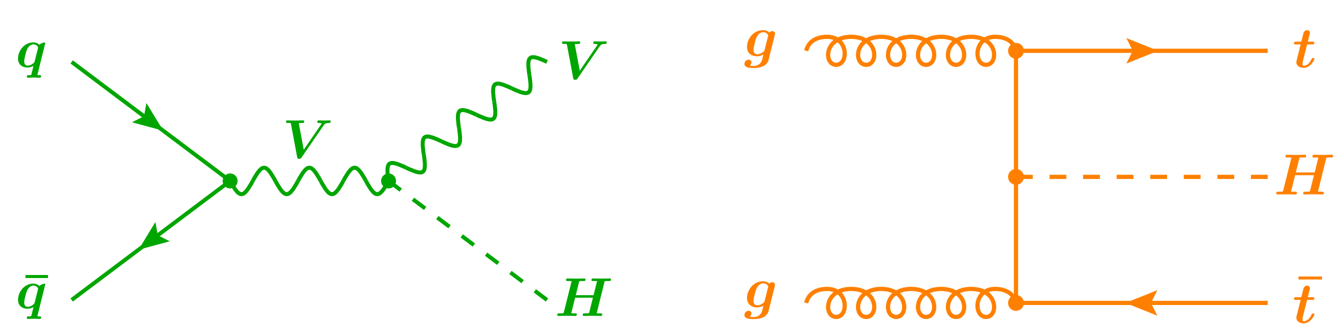
- **Indirect**
  - ggF production
  - H→γγ decay
- **Direct**
  - H→bb decay
  - H→cc decay
  - ttH production

Main Higgs Decay Modes

Decay branching fractions for m_H = 125 GeV

- H→bb: 58 %
- H→WW*: 21%
- H→τ⁺τ⁻: 6.3%
- H→ZZ*: 2.6%
- H→γγ: 0.2%

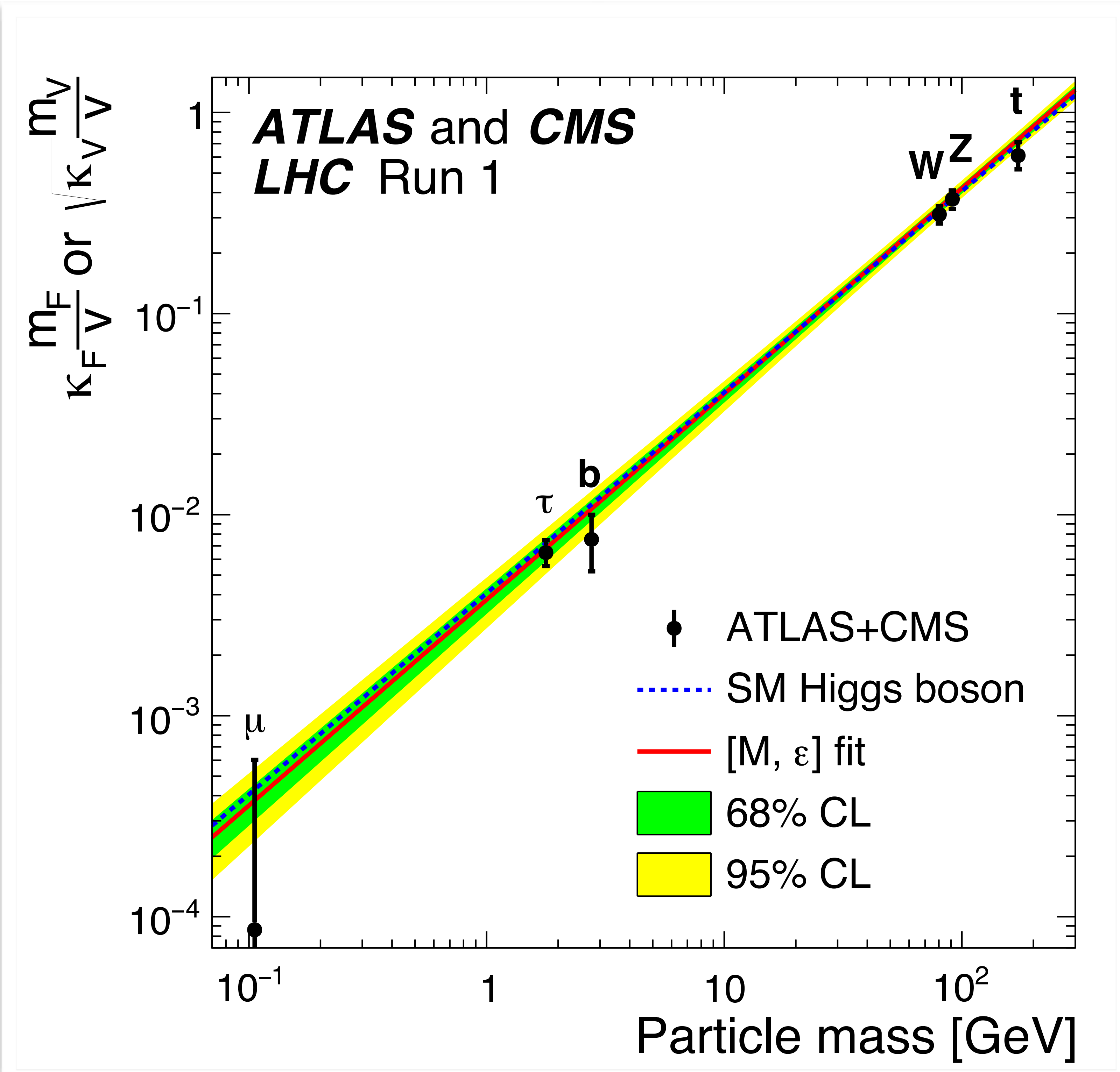
Key Higgs Production Modes



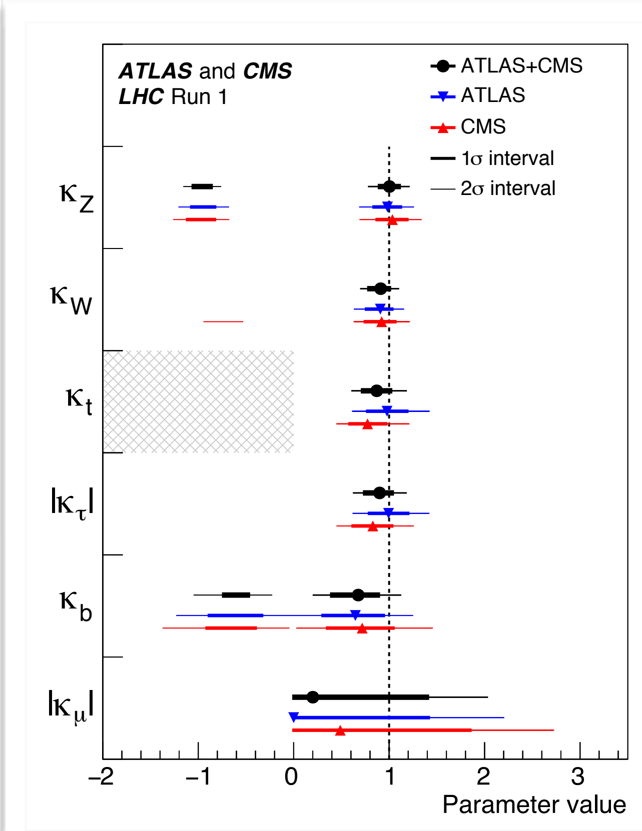
More details in talk by G. Piacquadio

Higgs couplings at the end of Run-1

JHEP 08 (2016) 045



Generally very good agreement with SM

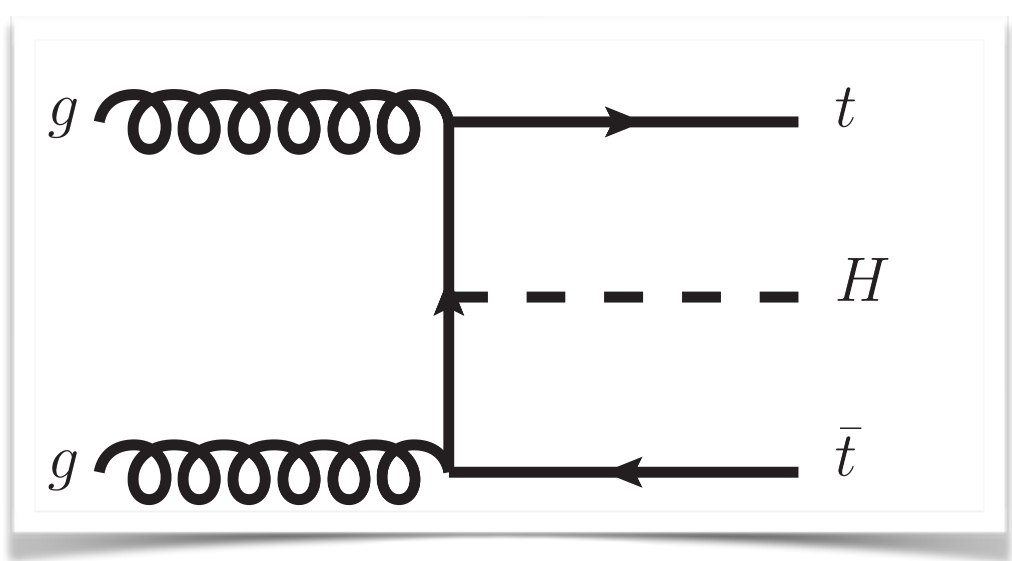


Much better precision for bosons than fermions
No direct evidence for Higgs coupling to quarks

Results from Run-1 ATLAS and CMS Higgs combination

Higgs coupling to top quarks

- Indirect constraints of O(15%) by the end of Run-1
- Measure the top-Higgs Yukawa coupling directly with ttH production
  - Probes NP contributions
- Tiny cross-section of 0.5 pb (100x smaller than ggF)
  - Combine information from multiple top and Higgs decays
- Four analyses used to probe ttH production: γγ, ZZ, bb, multilepton*
  - All channels include at least two b-jets from the top decay (+ 2W's)



*Mostly WW + ττ

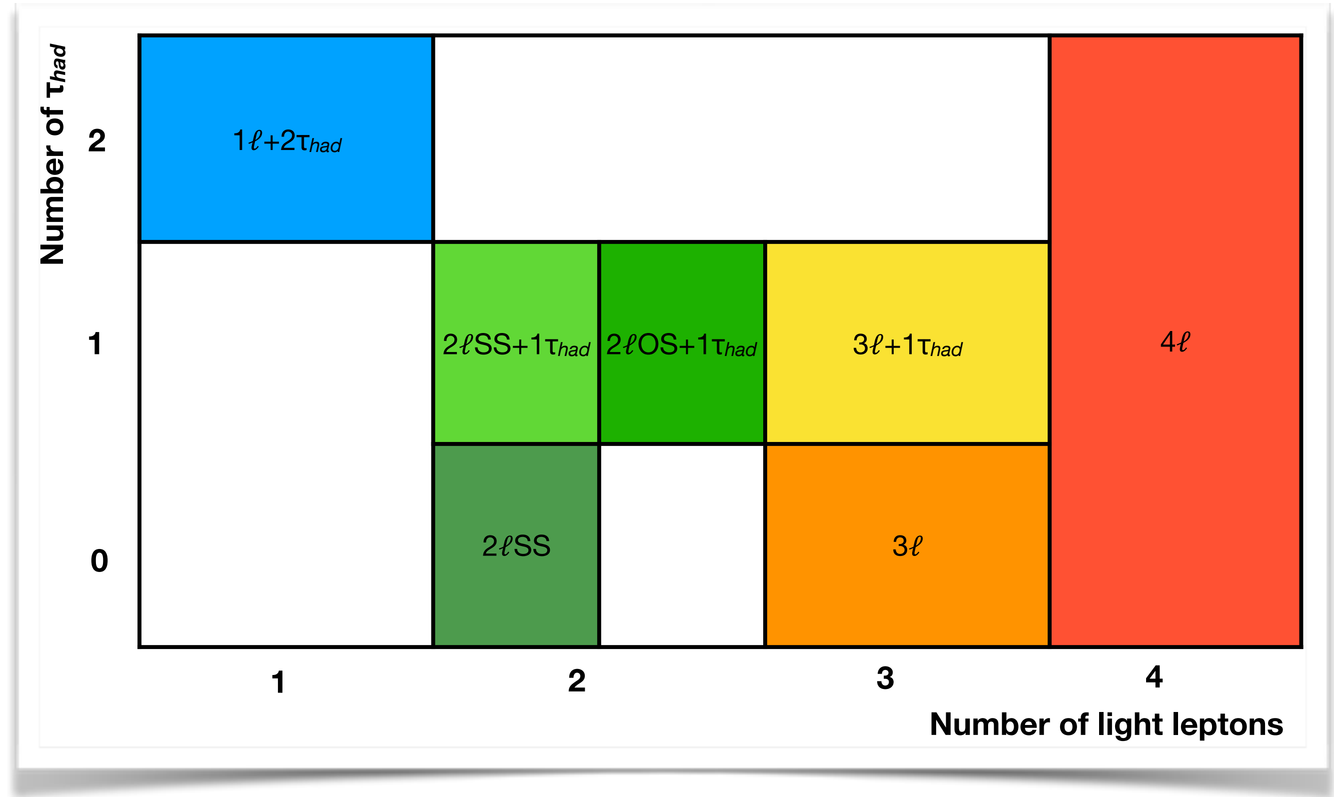
More details in talk by Y. Horii

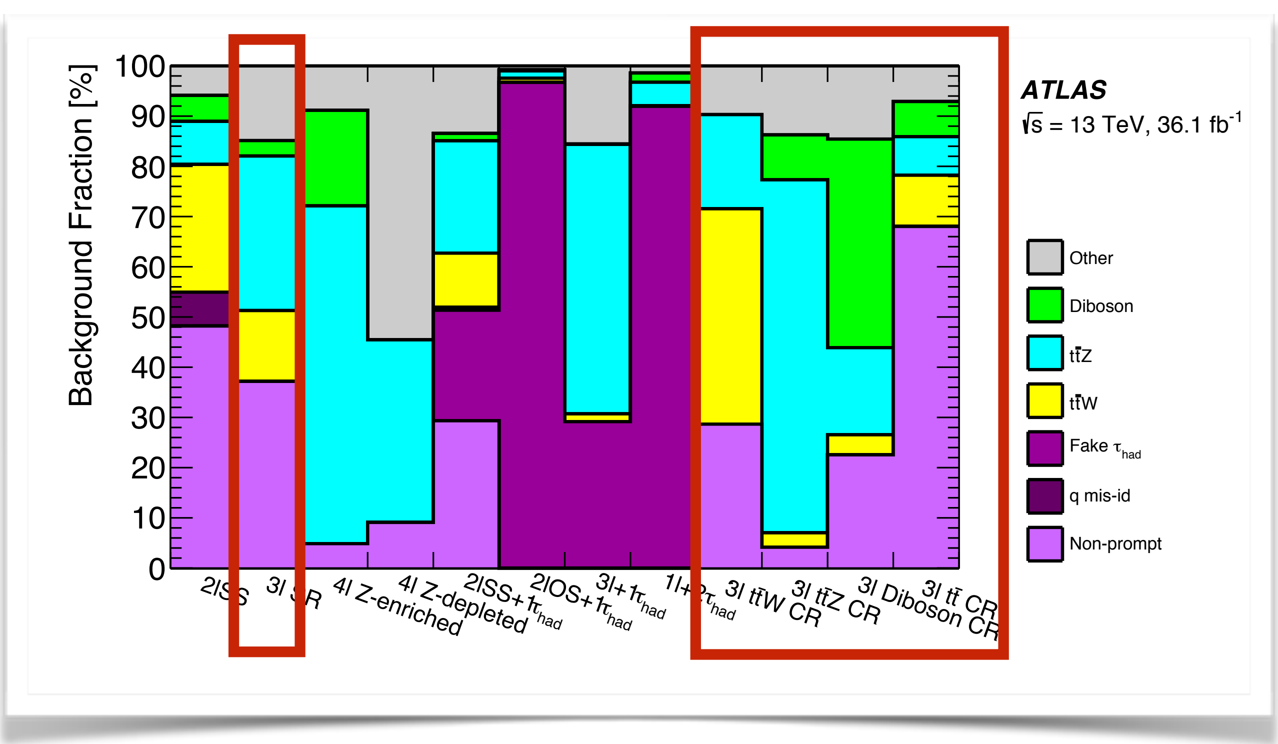
ttH(Multilepton)

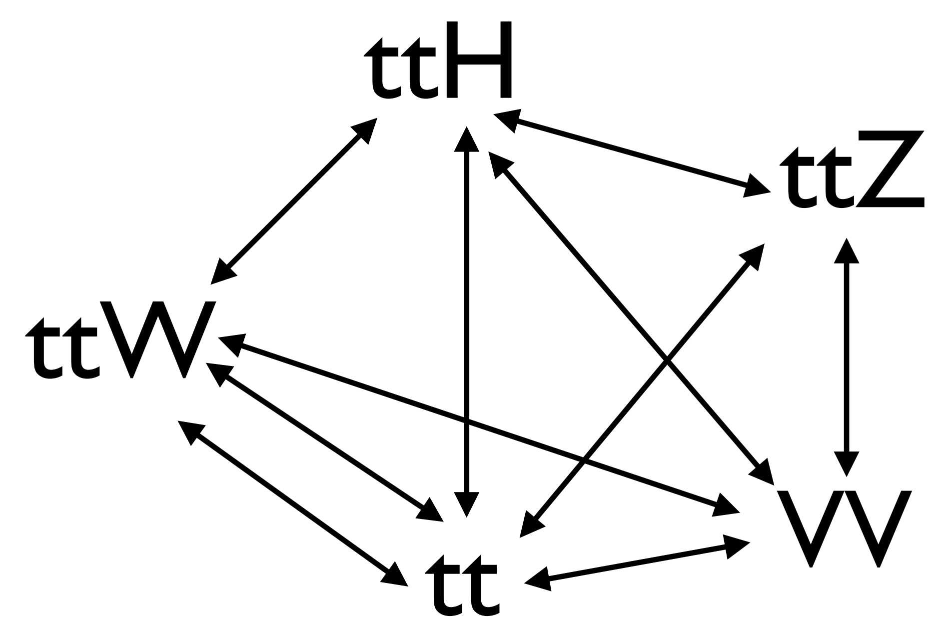
Phys. Rev. D 97 (2018) 072003

- Select events by the number of light leptons and hadronic-τ
- Single or dilepton triggers
- ≥1 b-jet; 2-4 jets
- BDT to extract ttH signal from ttW, ttZ, VV and tt background
- 5D multinomial BDT used in the 3l channel: extract signal and define control regions simultaneously

Categories



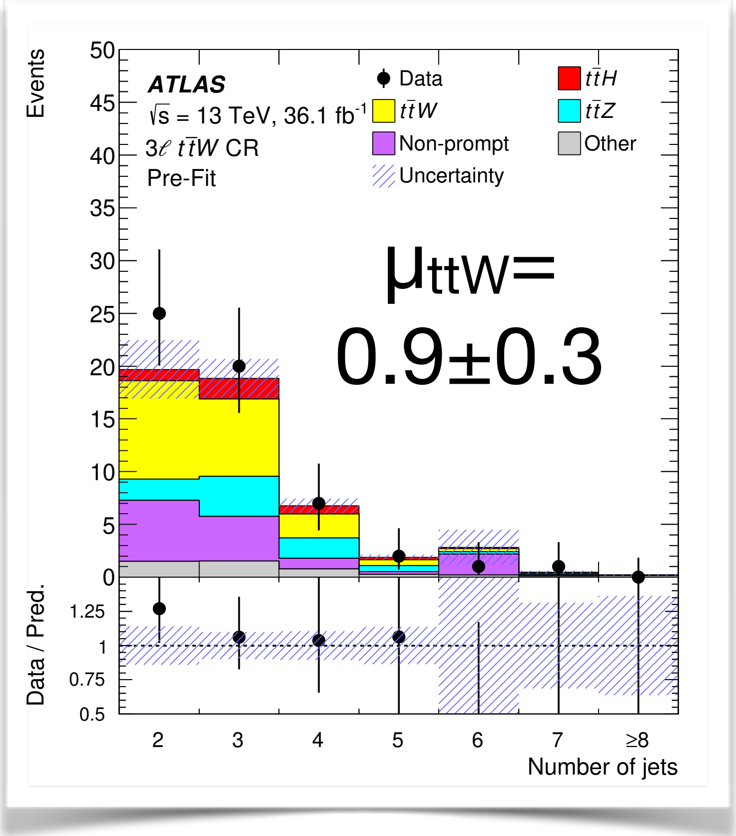


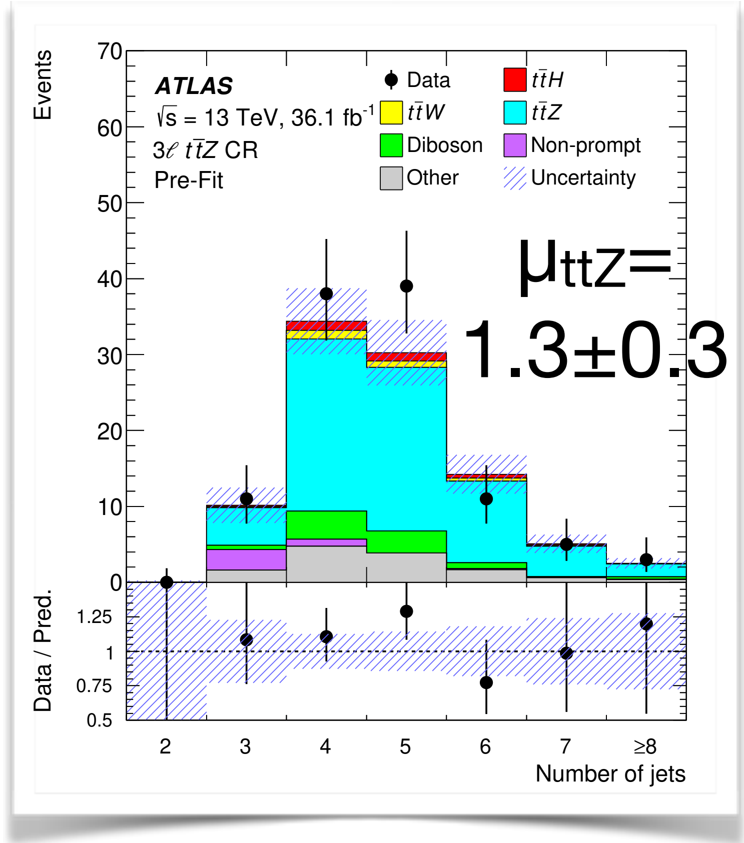


Selected ttH(ML) Challenges

Phys. Rev. D 97 (2018) 072003

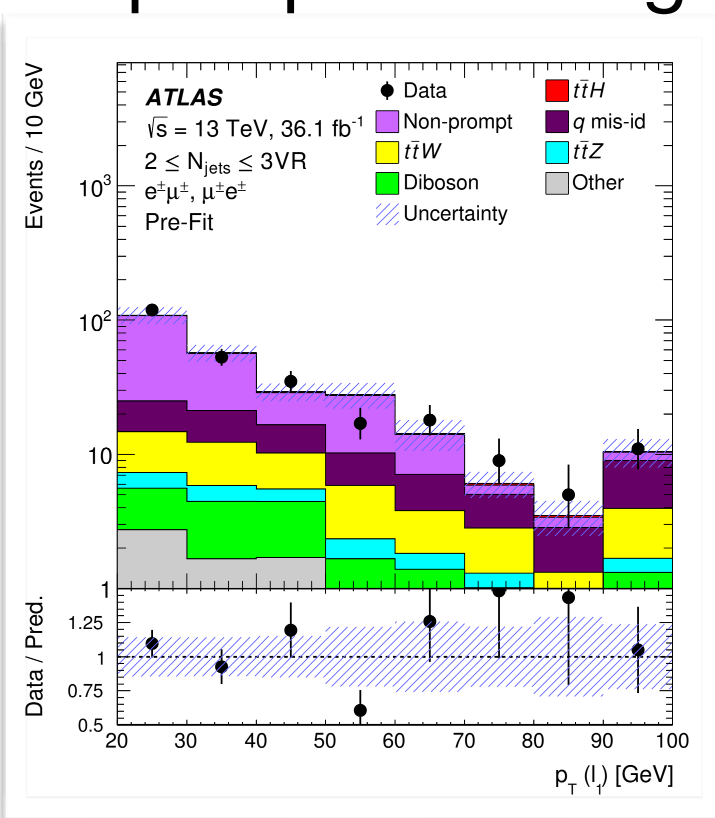
Background modelling

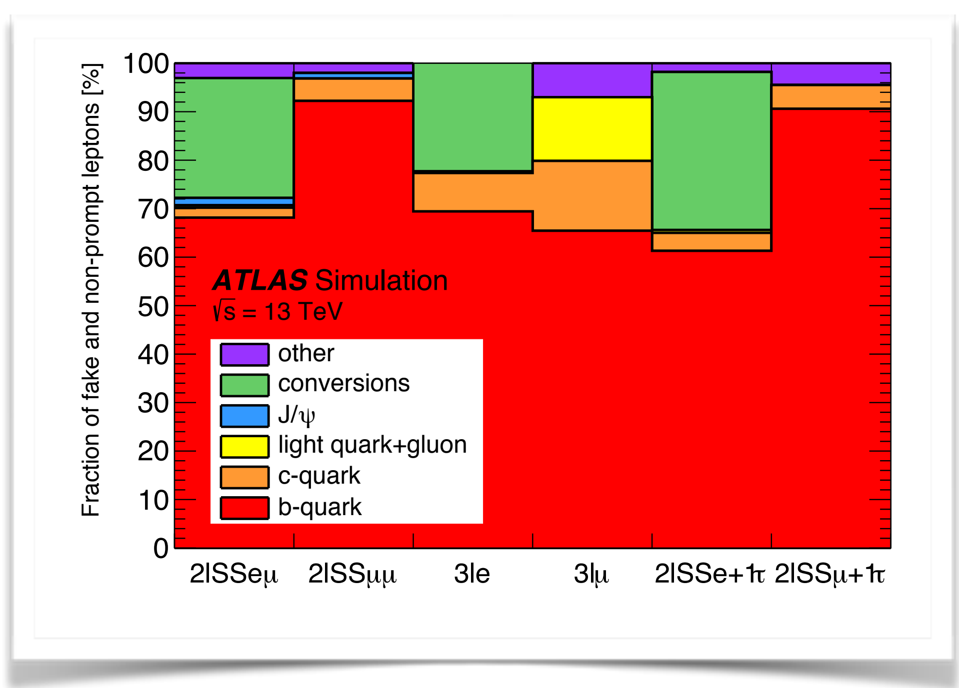




Cross-check analysis extracting background from data

Non-prompt lepton backgrounds



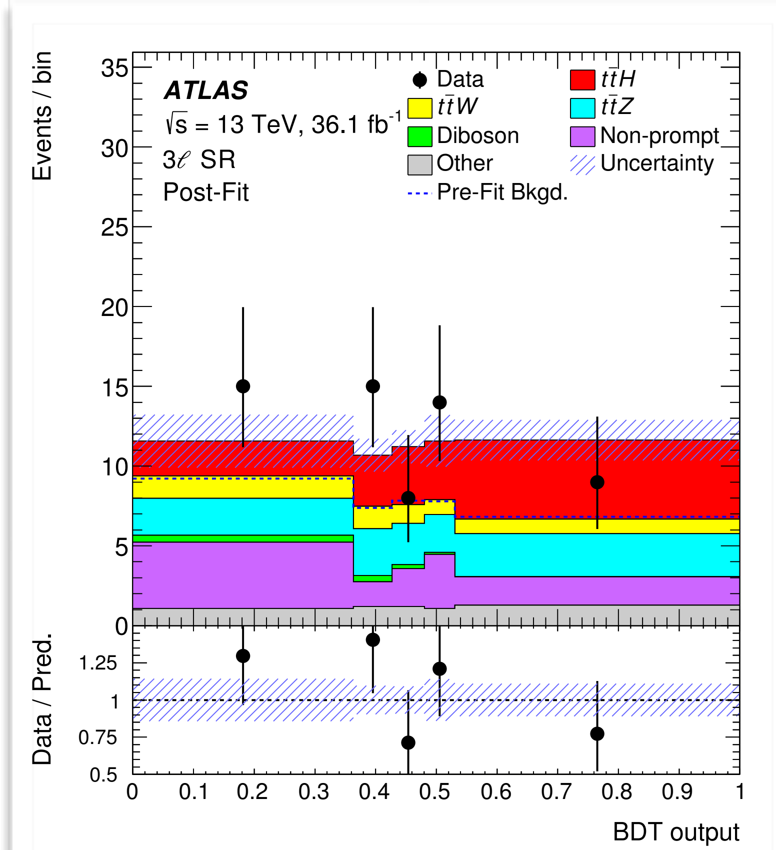


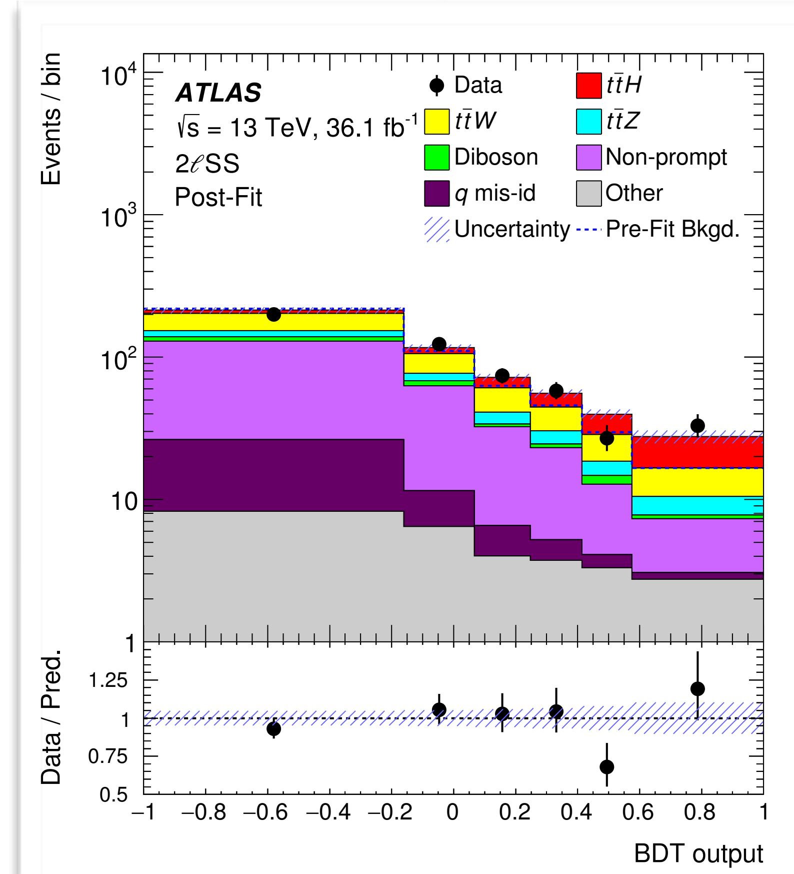
Estimated from control regions

Observation of ttH Production

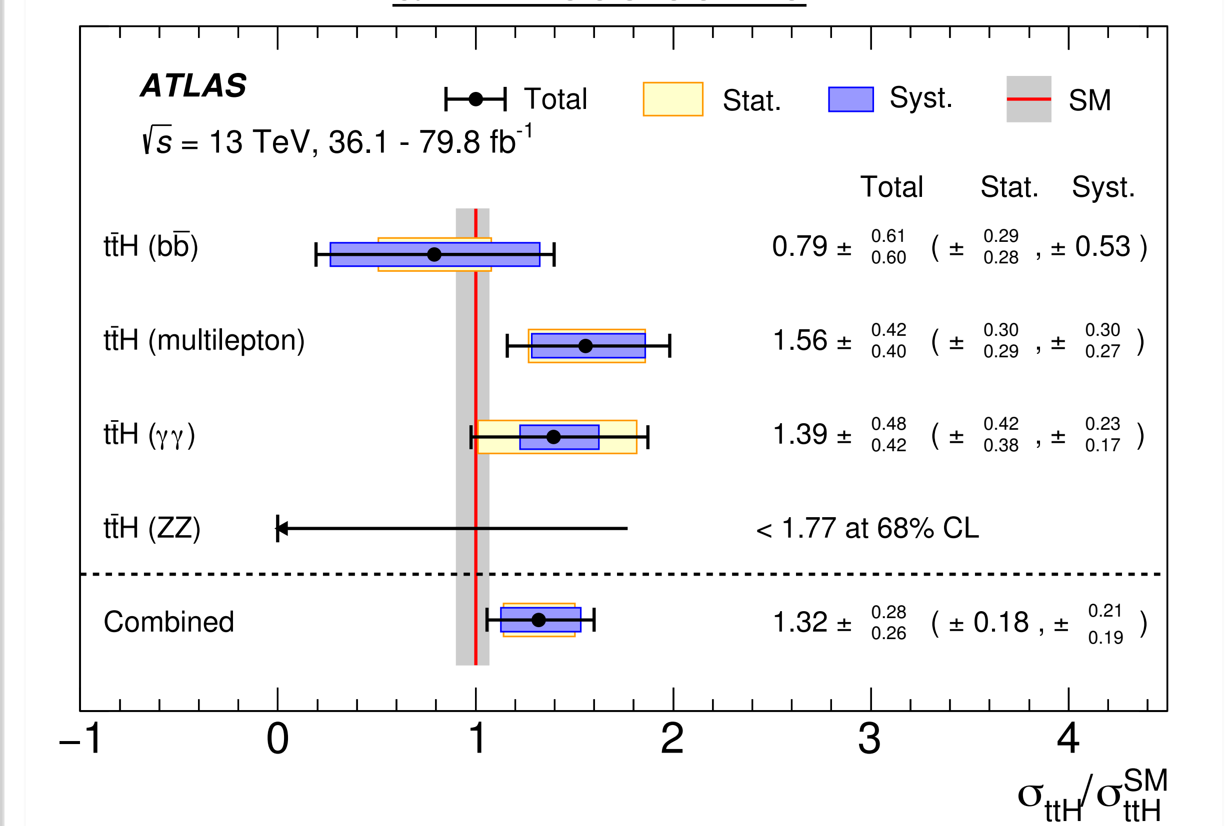
Phys. Rev. D 97 (2018) 072003

- ttH(multilepton) results
- Expected significance: 2.8σ
- Observed significance: 4.1σ





arXiv:1806.00425

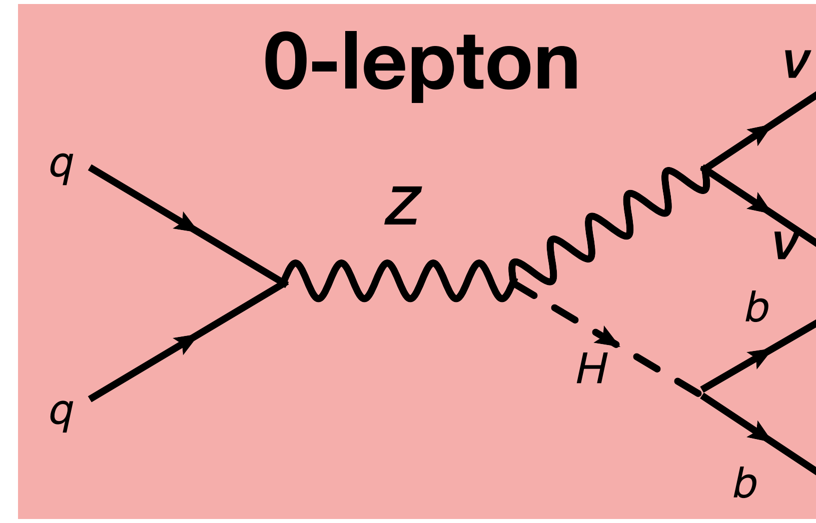


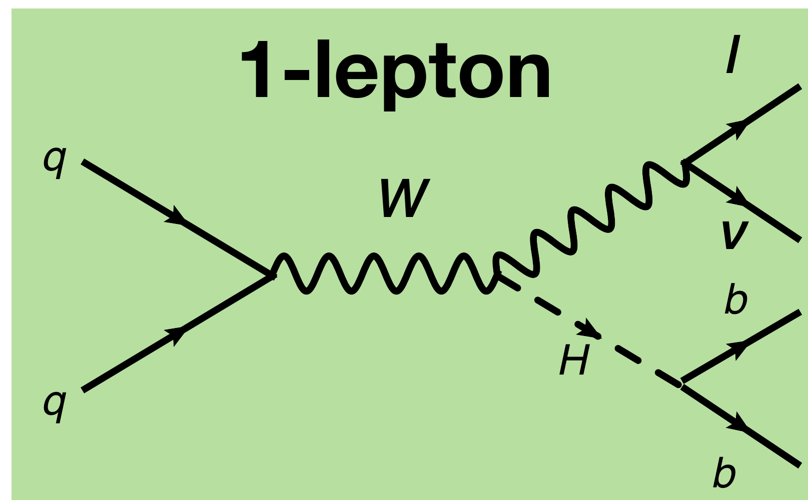
- Combination of all channels and all analysed data
- Expected significance: 5.1σ
- Observed significance: 6.3σ

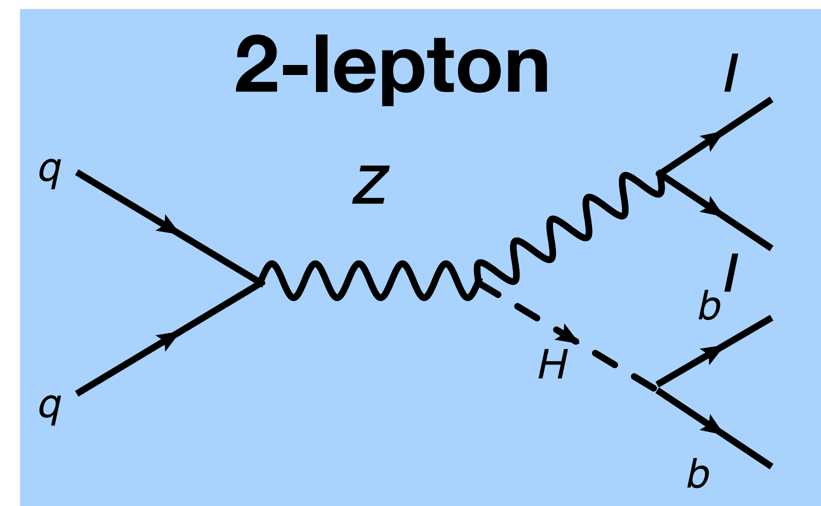
Higgs coupling to bottom quarks

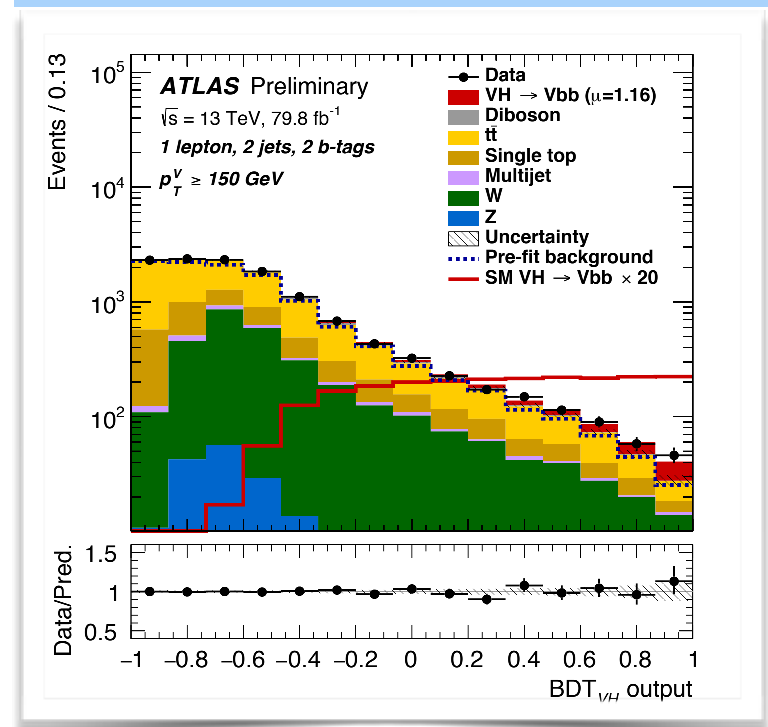
JHEP 12 (2017) 024
JHEP 01 (2015) 069
ATLAS-CONF-2018-036

- Largest branching ratio (58%), but challenging due to large backgrounds
- ATLAS probes: VBF, VH and ttH
- Most powerful channel is VH (V=W, Z)
- Three channels
  - 0-lepton: Z(νν)H(bb)
  - 1-lepton: W(lν)H(b)
  - 2-lepton: Z(ll)H(bb)
- Lepton or MET triggers
- Two b-jets
- BDT to extract Higgs from large V+jets and tt backgrounds
- Complex profile likelihood fit to extract signal and constrain backgrounds





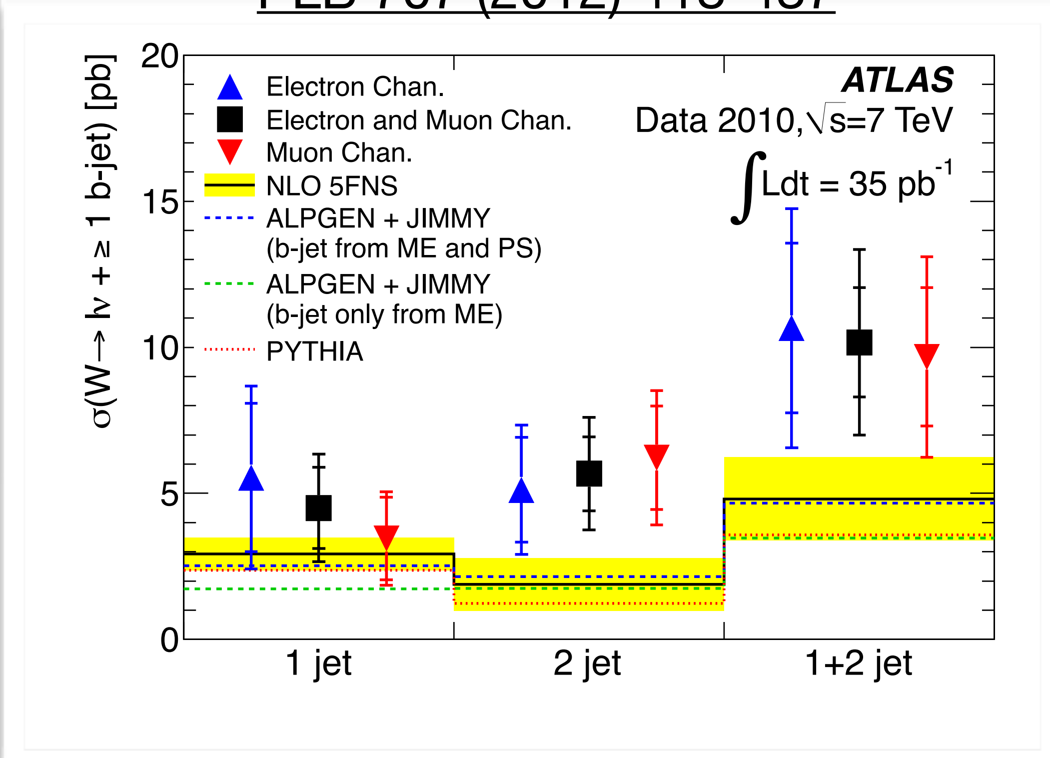




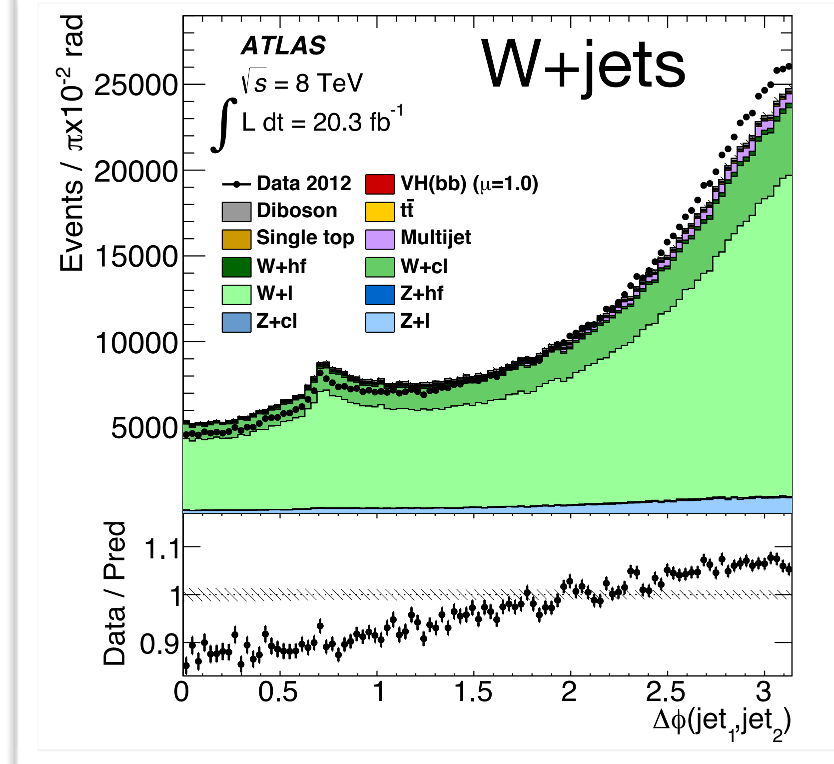
More details in talk by Y. Enari

Selected H→bb Challenge: Backgrounds

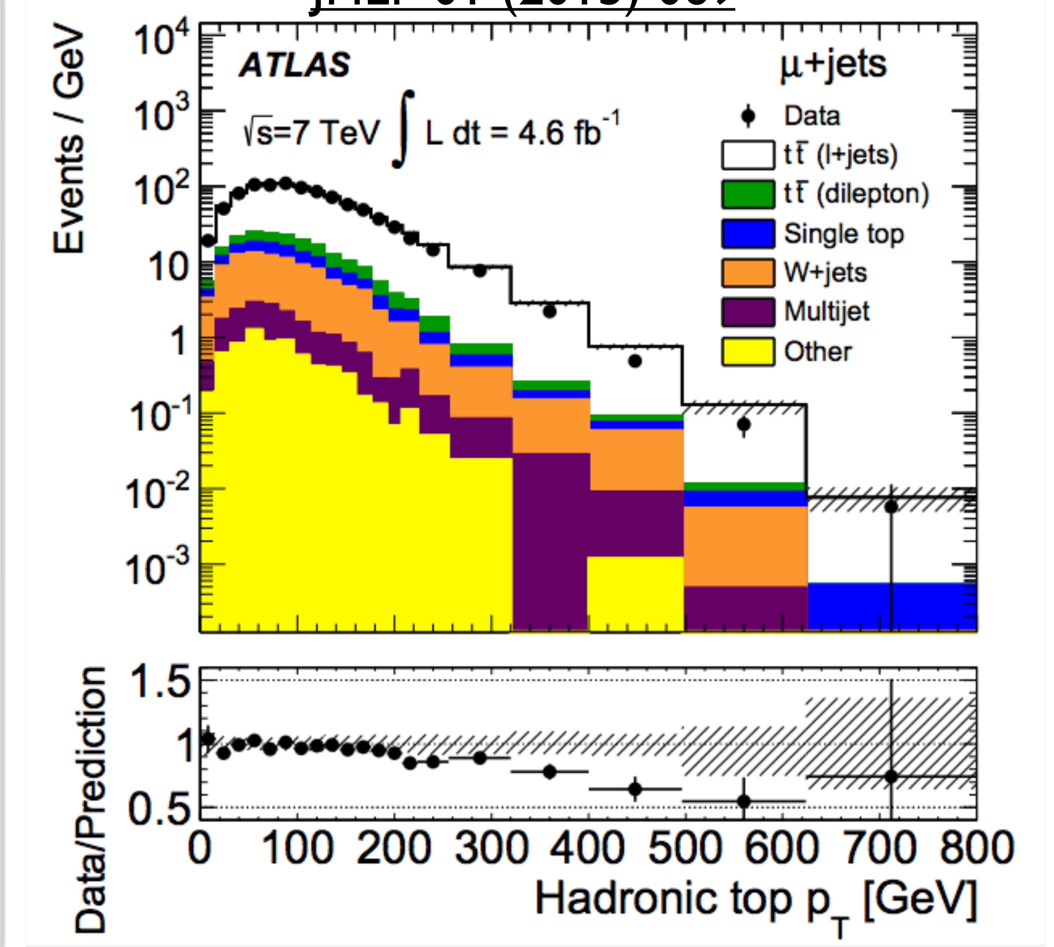
PLB 707 (2012) 418-437



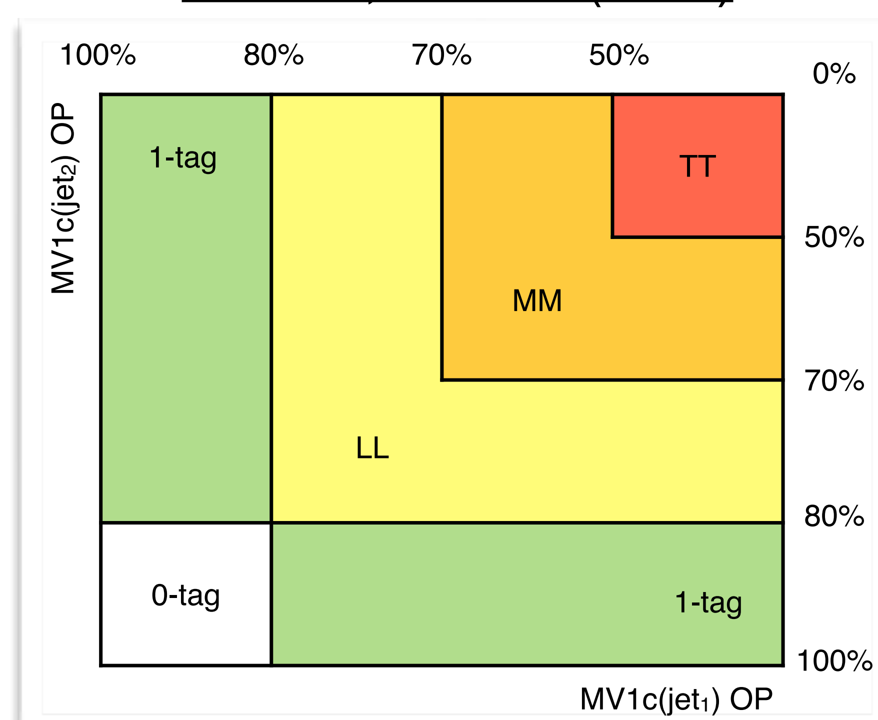
PRD 90, 072004 (2014)



JHEP 01 (2015) 069

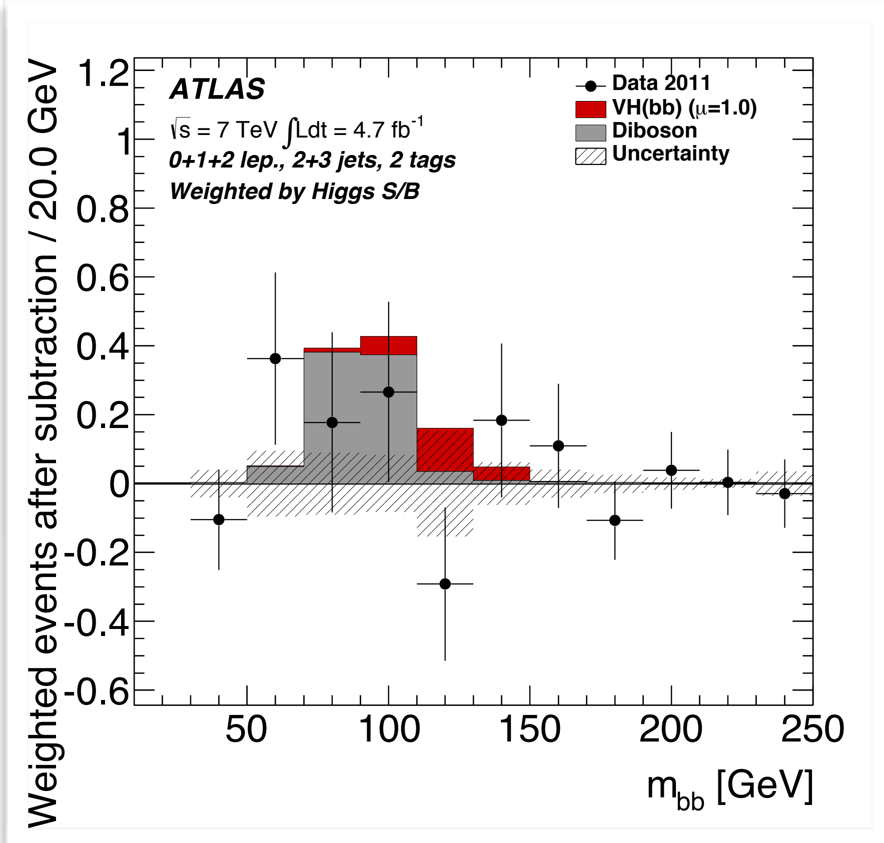


PRD 90, 072004 (2014)

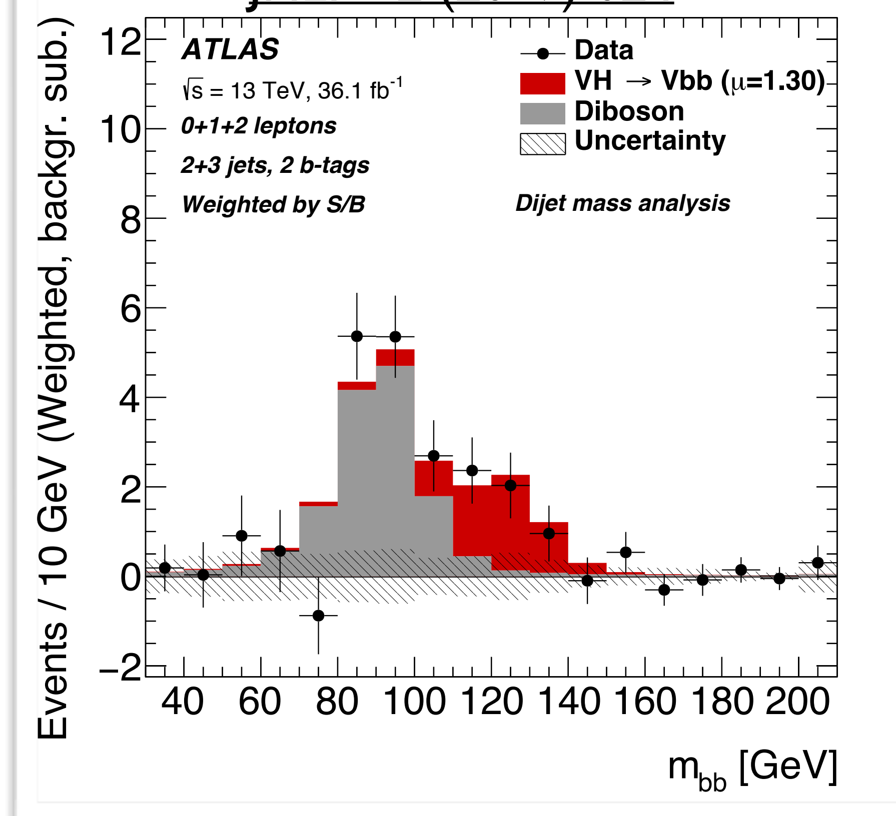


Getting to H→bb observation

7 TeV
5 fb^{-1}
-
0.7σ exp



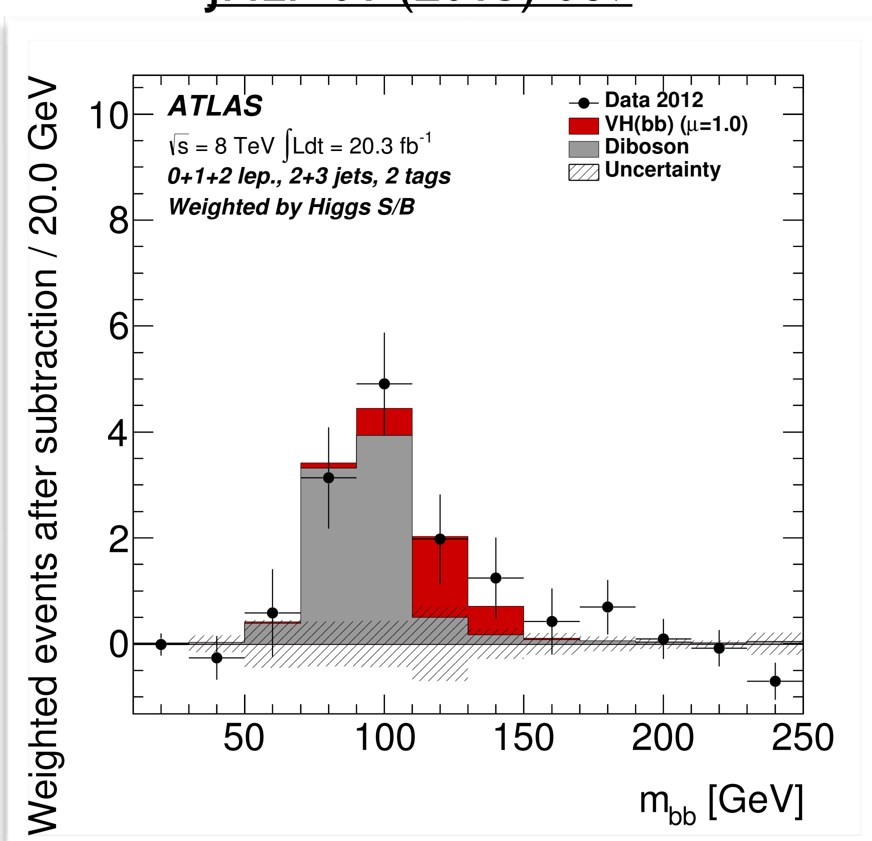
JHEP 12 (2017) 024



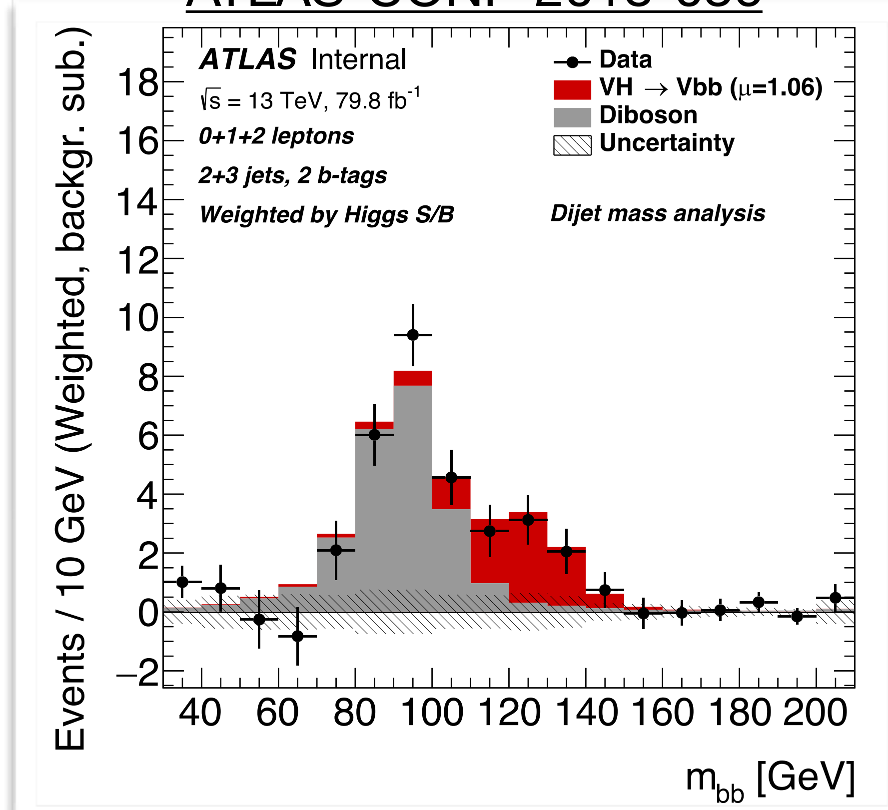
13 TeV
36 fb^{-1}
3.5σ obs.
3.0σ exp

JHEP 01 (2015) 069

8 TeV
20 fb-1
1.7σ obs
2.5σ exp



ATLAS-CONF-2018-036



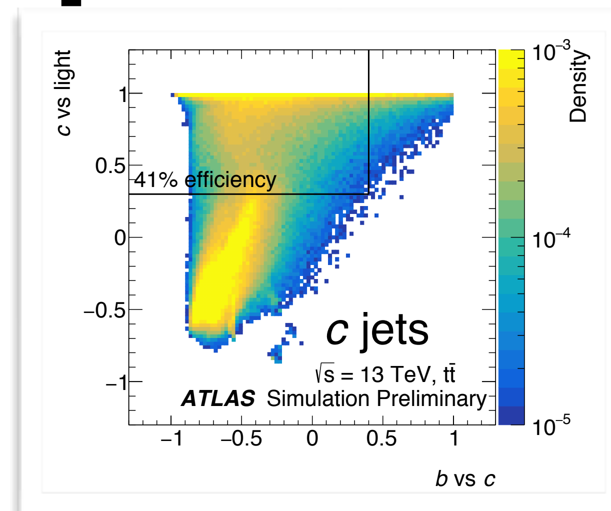
13 TeV
80 fb^{-1},
4.9σ obs
4.3σ exp

7-13 TeV,
VH+VBF+ttH
Combination
5.4σ obs
5.5σ exp

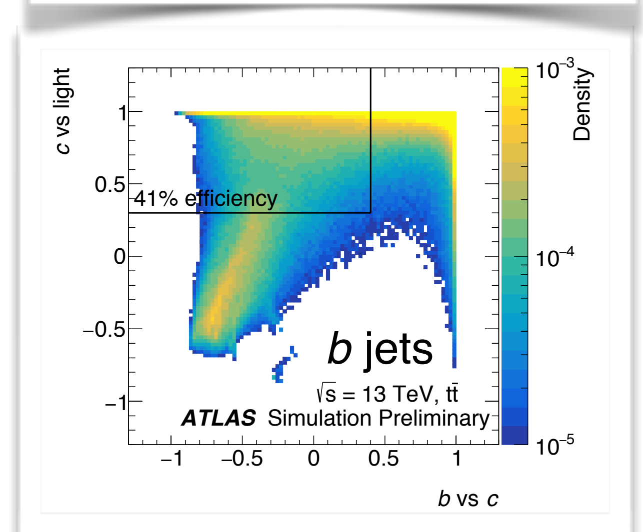
Higgs coupling to charm quarks

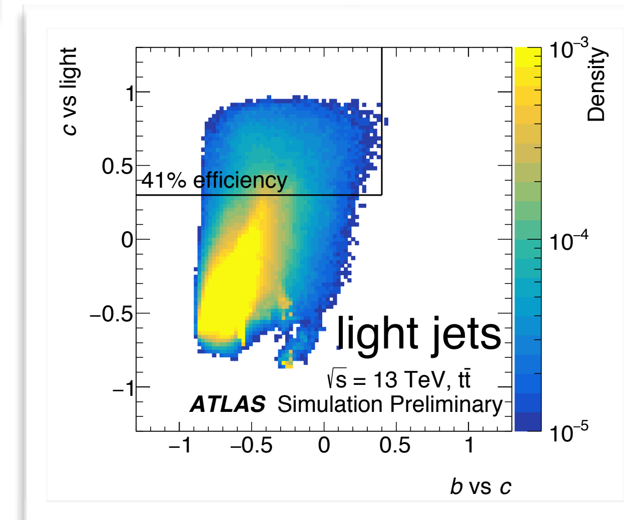
PRL 120 (2018) 211802

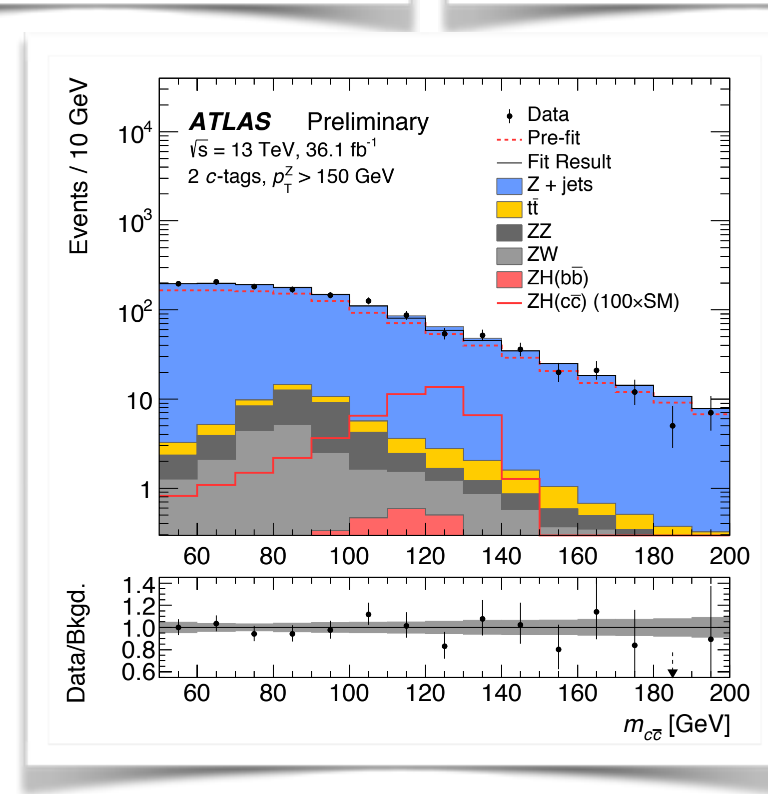
- We've observed the coupling of the Higgs to third generation quarks only
  - Rich flavour structure
- Can we probe the second generation quark coupling using charm?
- Analogous strategy to VH(bb)
  - Only 2-lepton; fit dijet invariant mass
- Crucial element
  - Efficient charm tagging
  - Exploit capabilities of IBL
- Obtain limit of ~100x SM
  - Strongest direct limit on charm
  - HL-LHC projection: ~6 x SM



- c-tag: 40%
- b-rej: 4x
- l-rej: 20x







Conclusion

- An exciting ten years since the start of the LHC and six years since the Higgs discovery
- Excellent detector and software performance has been key to many of our important physics results
- This summer we've observed the coupling of the Higgs to quarks via its interactions with both top and bottom quarks
- So far, these results (and the Higgs sector in general) are compatible with the Standard Model but observation is only the beginning
  - What will we learn about nature from future LHC data ?

Many thanks to all my collaborators