ATLAS Search for ttH Production in Multi-Lepton Final States

Jürgen Kroseberg
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ATLAS EXPERIMENT

ttH: Why Do We Care?

- **top quarks are** (or at least appear to be) **special**
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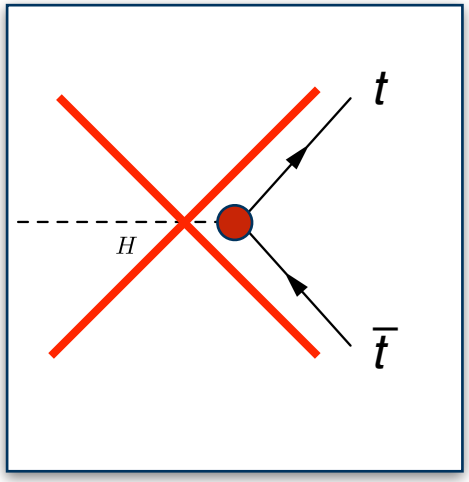

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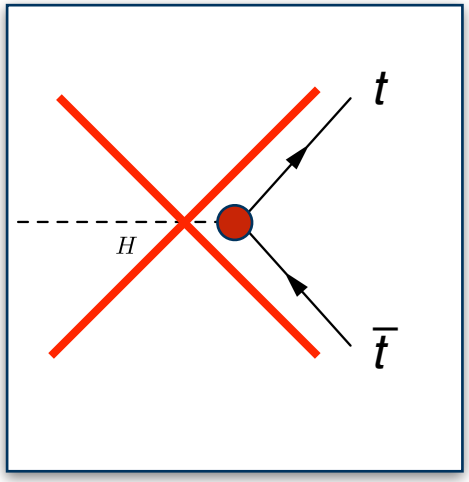

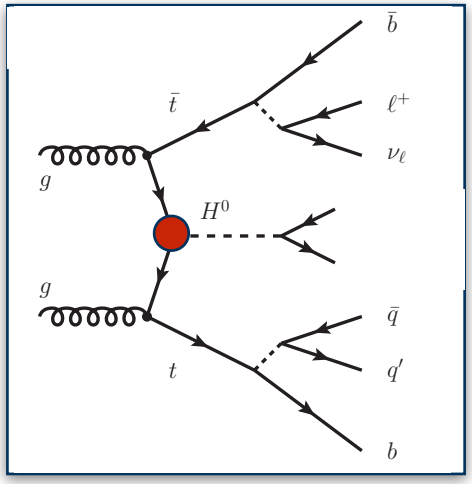

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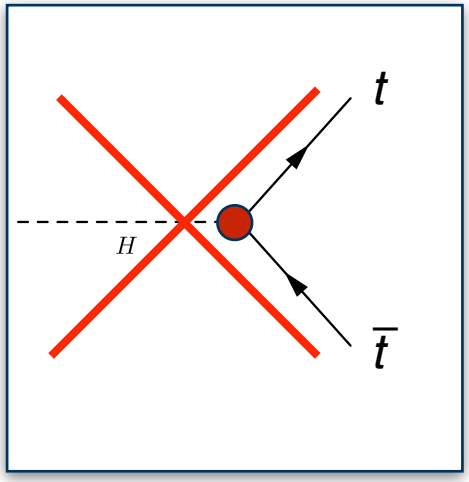
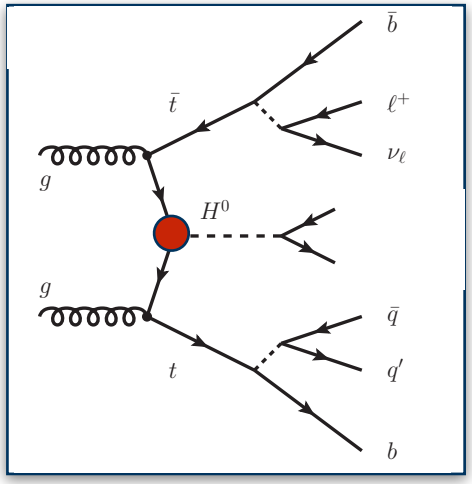
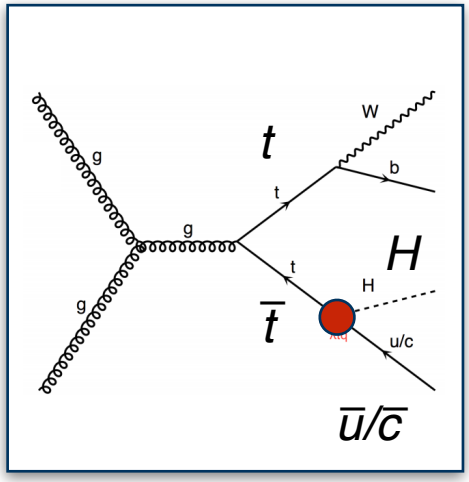
- sensitive to **BSM physics**







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- after all, successful Run1 **top** and **Higgs** physics program

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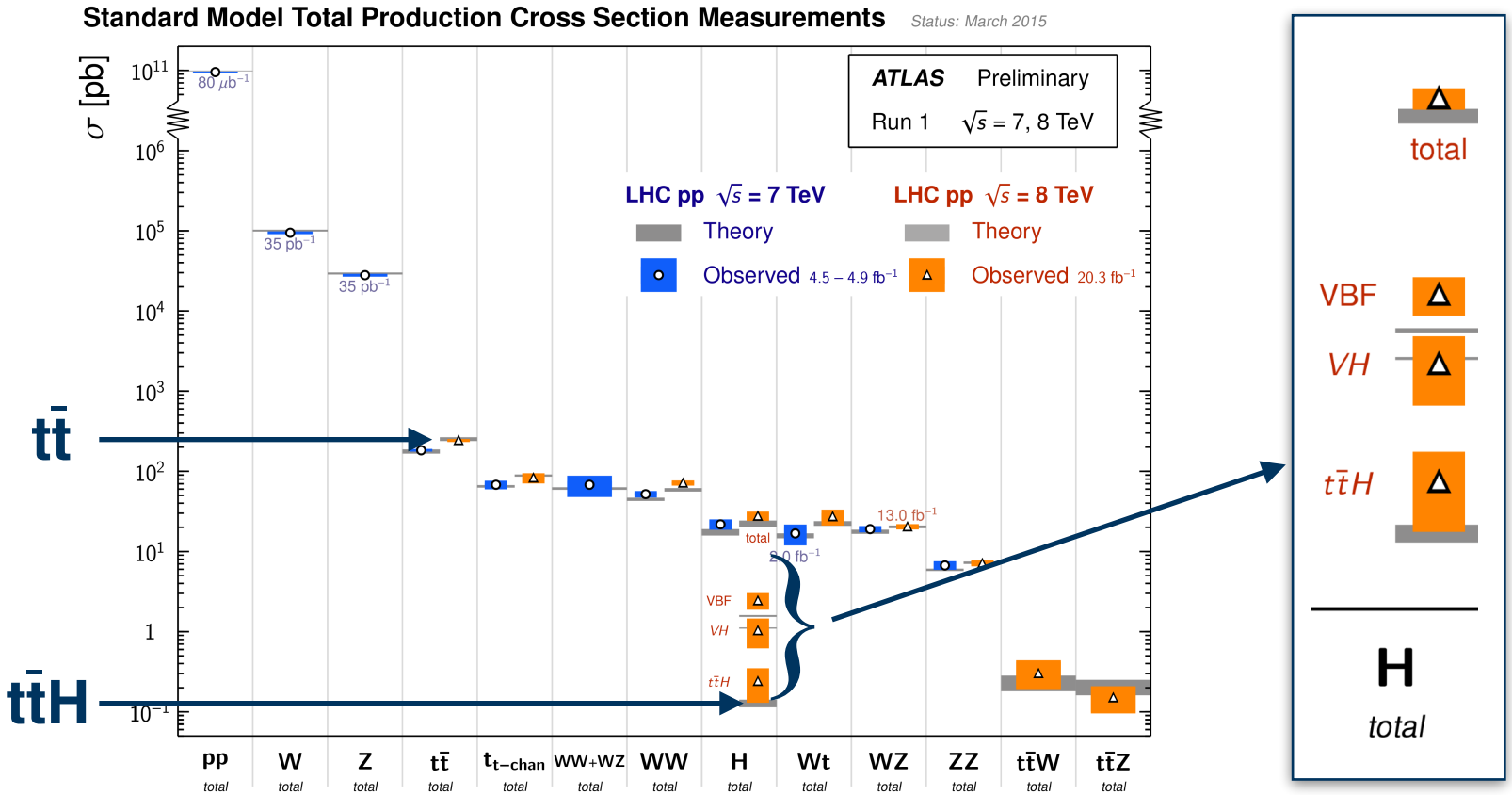


- small **cross section,** large **backgrounds** (+ complex signatures)

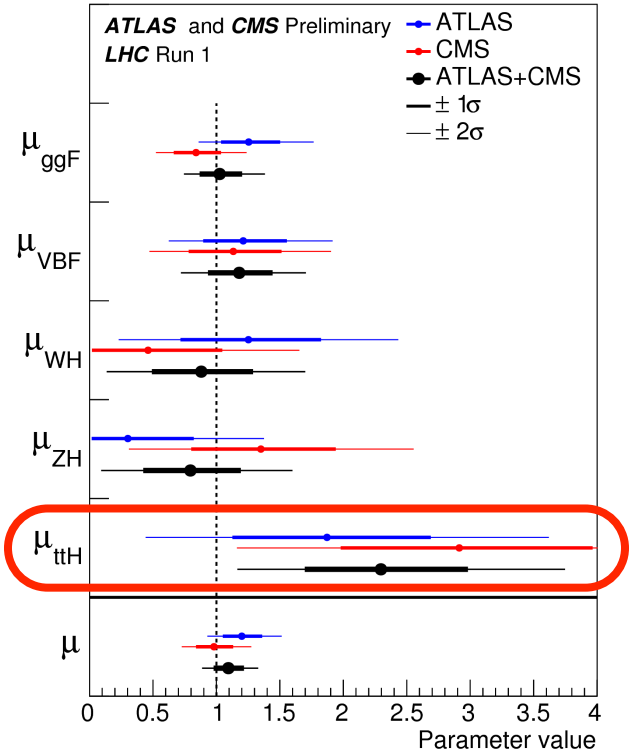
ttH: What Do We Know?

- preliminary combined **ATLAS+CMS** Higgs boson **coupling analysis**

  (ATLAS-CONF-2015-044, CMS-PAS-HIG-15-002)

⇒ ttH **signal strength**

	ATLAS+CMS	ATLAS	CMS
μ_{ttH}	$2.3^{+0.7}_{-0.6}$	$1.9^{+0.8}_{-0.7}$	$2.9^{+1.0}_{-0.9}$



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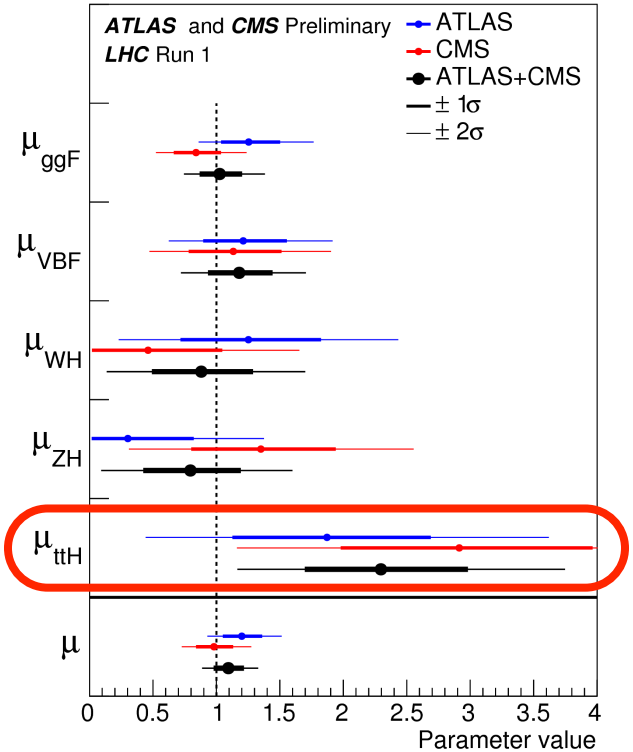
⇒ ttH **signal strength** and **significance**



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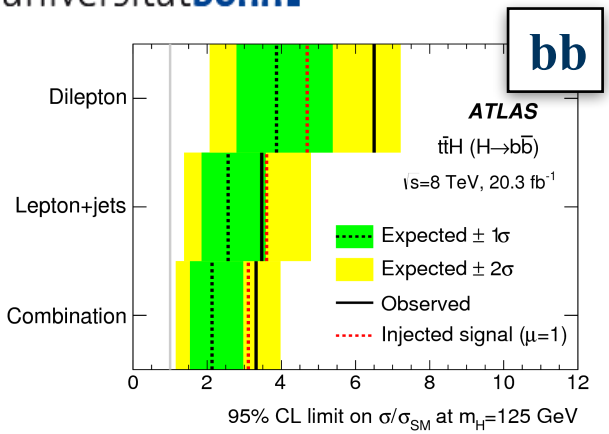
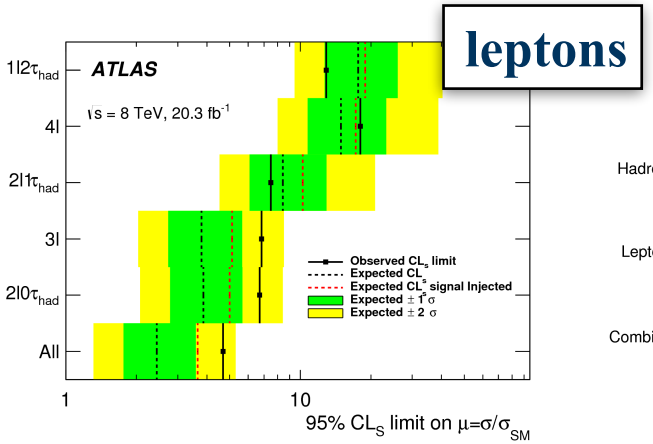
Production process	Measured significance (σ)	Expected significance (σ)
VBF	5.4	4.7
WH	2.4	2.7
ZH	2.3	2.9
VH	3.5	4.2
ttH	4.4	2.0

ttH: What Do We Know?



Eur. Phys. J. C (2015) 75:349



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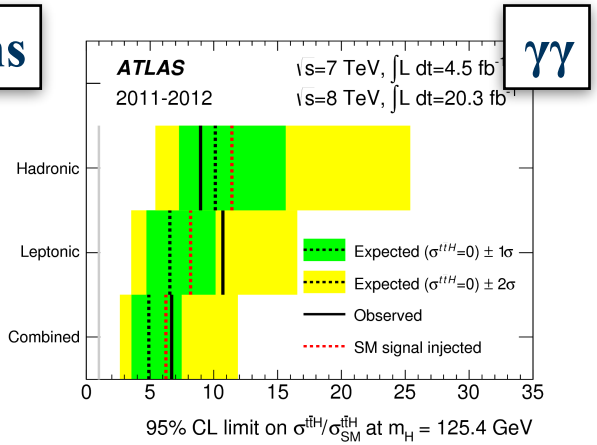

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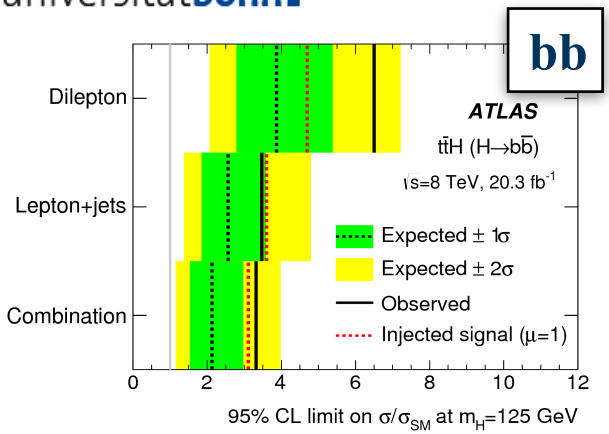

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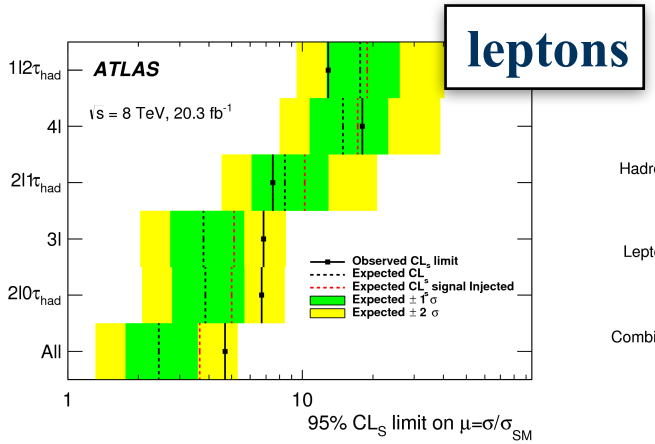

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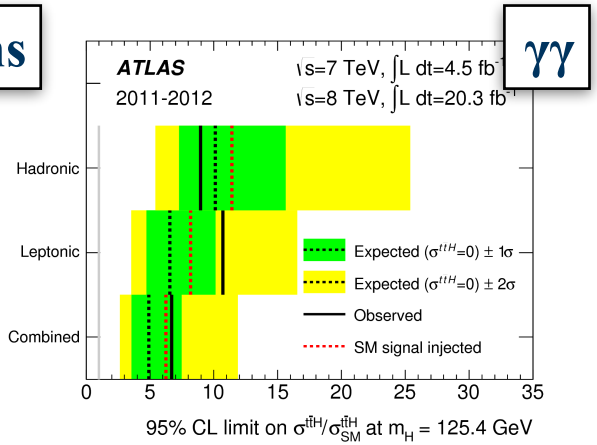

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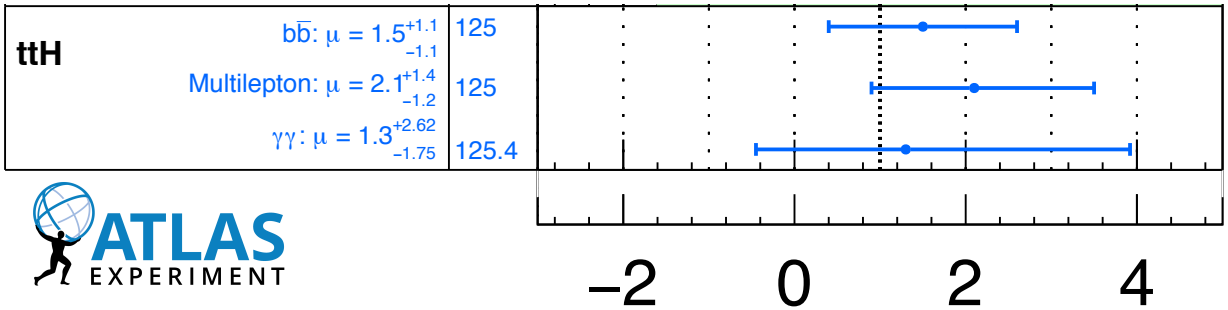
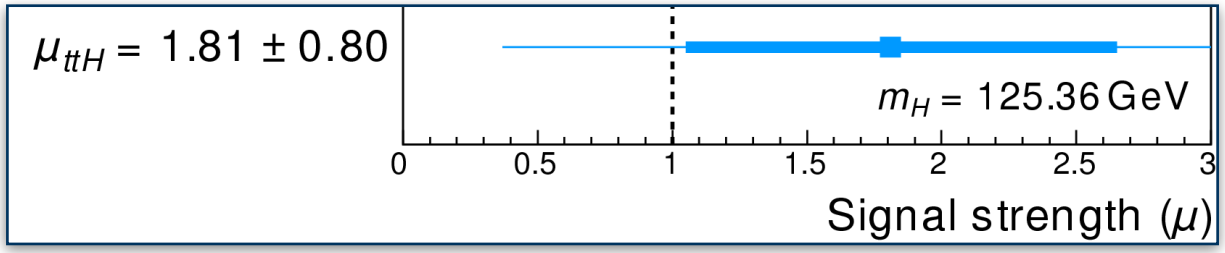


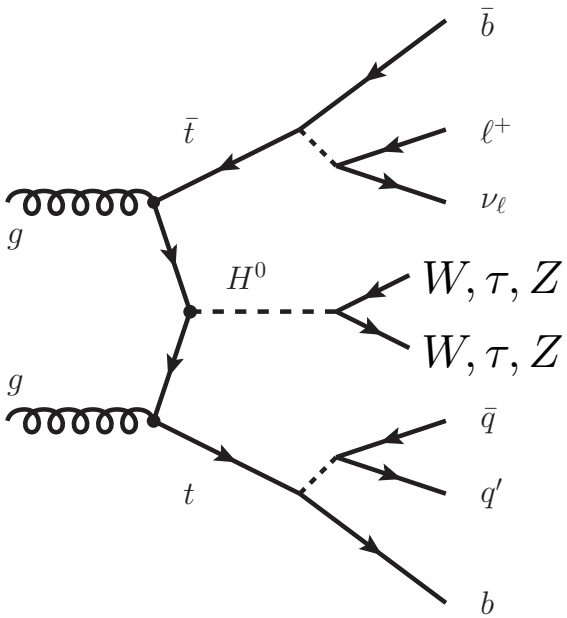


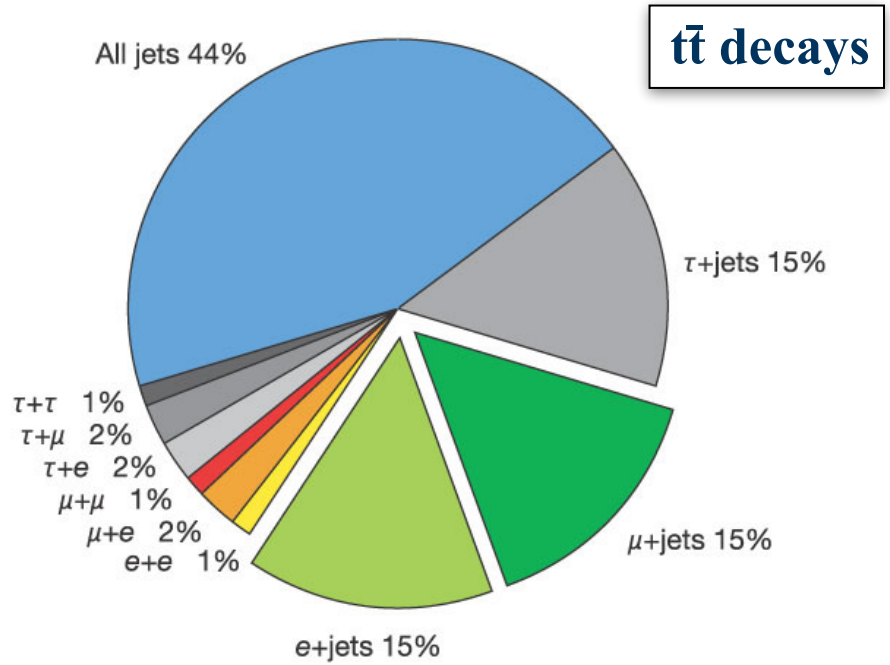
ATLAS combination:

- **significance**:
  2.5σ observed
  1.5σ expected
- upper **limit**:
  3.2xSM observed
  1.4xSM expected

arXiv:1507.04548; subm. to EPJC

ttH: “Multi-Lepton” Final States





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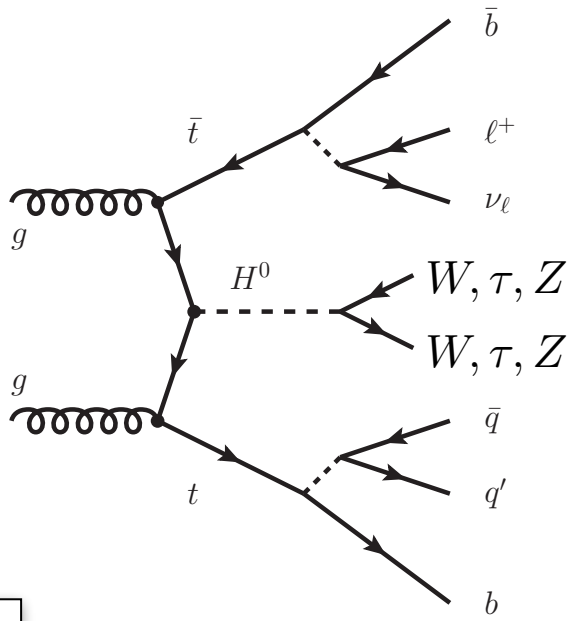
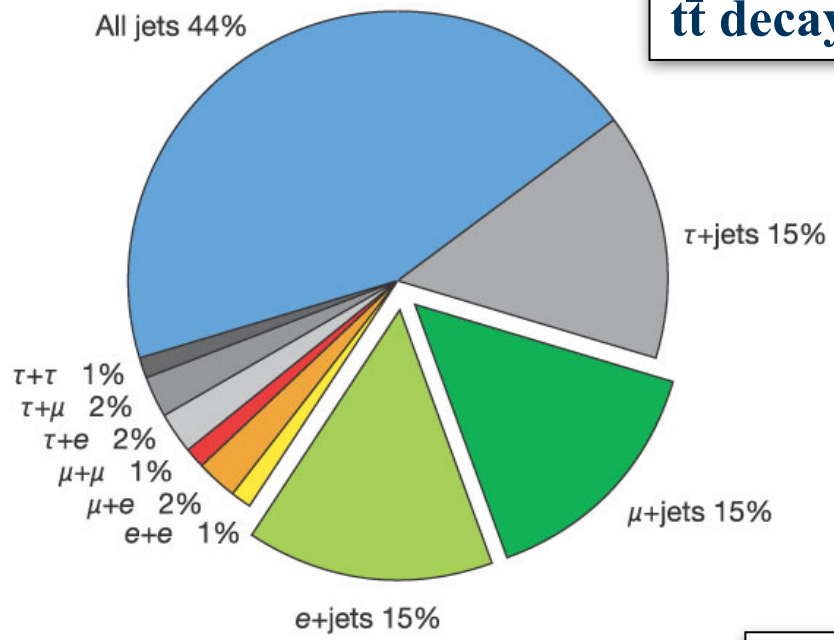
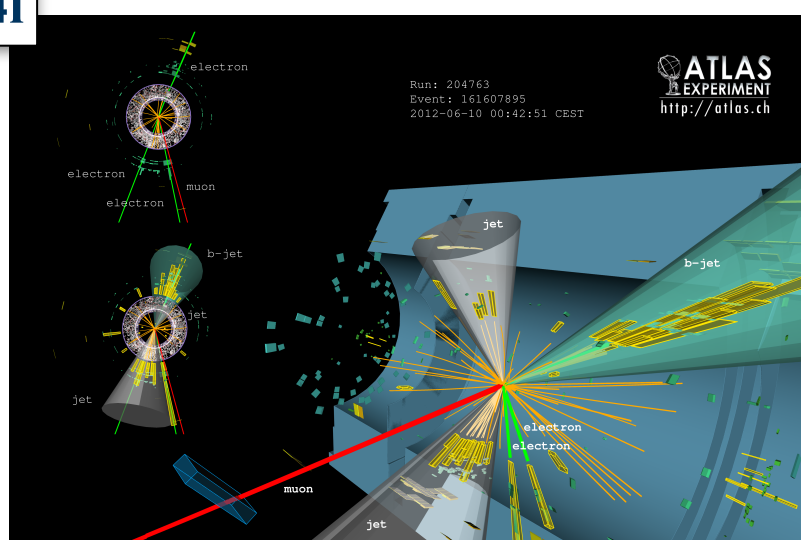


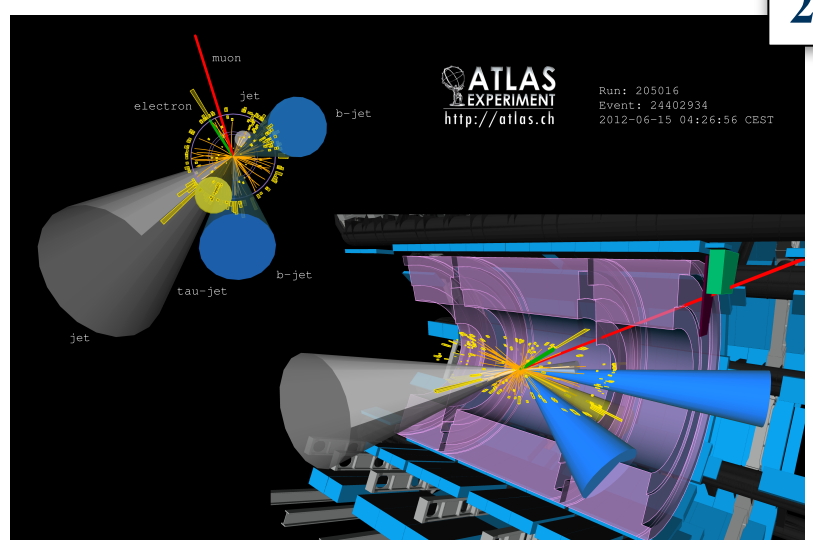
$t\bar{t}$ decays



4l

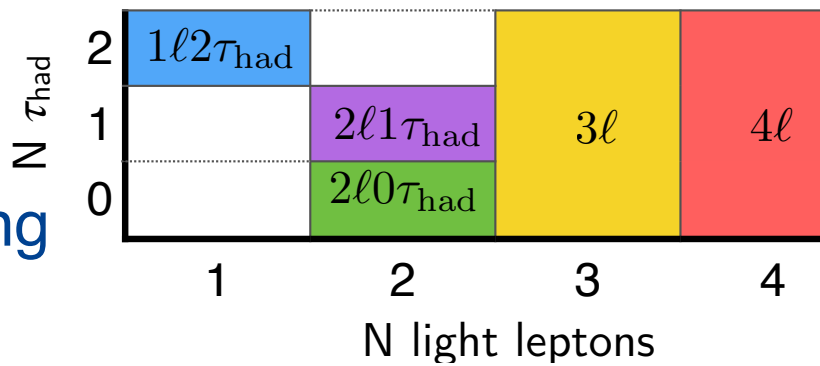


2l1τ



ttH→leptons: Selection + Categorisation

- **categorise** in terms of **number of** light-**lepton and hadronic τ cand.**
- avoid final states expected from $t\bar{t}$
- define **signal regions** also depending on **number of light and b jets**



Phys. Lett. B 749 (2015) 519

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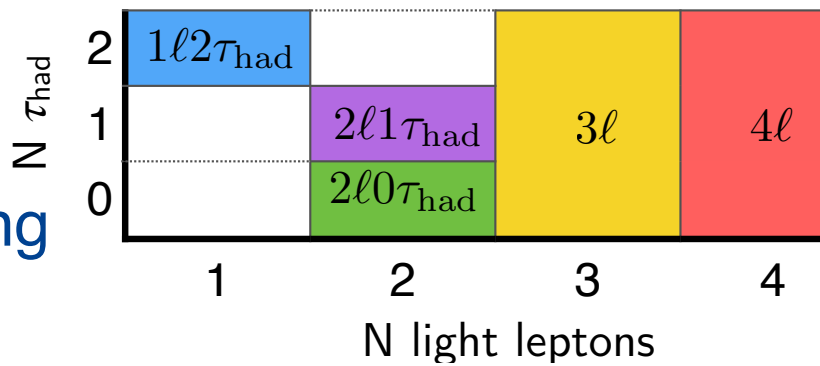

- **2l0τ$_{had}$:** 2 same-sign leptons; ≥4j, ≥1b
- **2l1τ$_{had}$:** 2 SS leptons; 1 OS τ; ≥4j, ≥1b
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- **3l:** Σq=1; Z veto; (≥4j,≥1b) v (3j,≥2b)
- **4l:** Σq=0; 100 GeV<m_{4l}<500 GeV; ≥2j, ≥1b

Phys. Lett. B 749 (2015) 519

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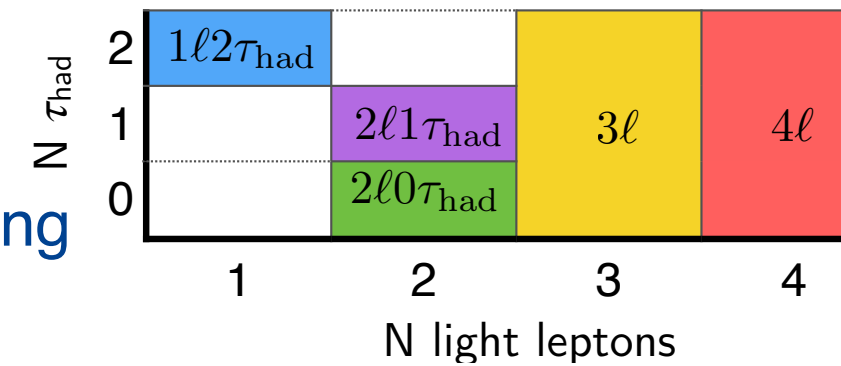

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	Higgs boson decay mode			
Category	WW^*	$\tau\tau$	ZZ^*	Other
$2\ell 0\tau_{had}$	80%	15%	3%	2%
3ℓ	74%	15%	7%	4%
$2\ell 1\tau_{had}$	35%	62%	2%	1%
4ℓ	69%	14%	14%	4%
$1\ell 2\tau_{had}$	4%	93%	0%	3%

- **mixture of Higgs decays**; mainly WW and ττ

Phys. Lett. B 749 (2015) 519

ttH→leptons: Background Estimation

non-prompt leptons*, charge flip

data-driven

$t\bar{t} + \text{jets}$

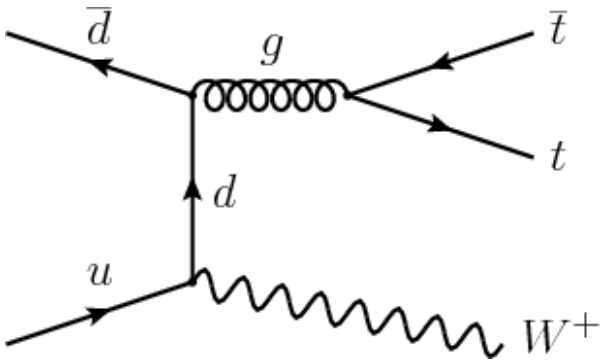
VV, tttt, ttWW, tH, tZ, VVV

MC

others

irreducible, charge asymmetry

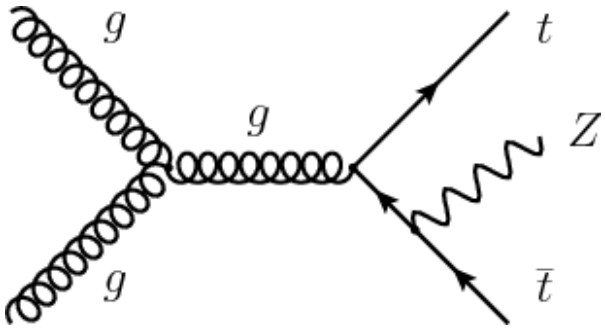
MC



$t\bar{t}W$

irreducible

MC



$t\bar{t}Z$

* "non-prompt" leptons from B decays and jets

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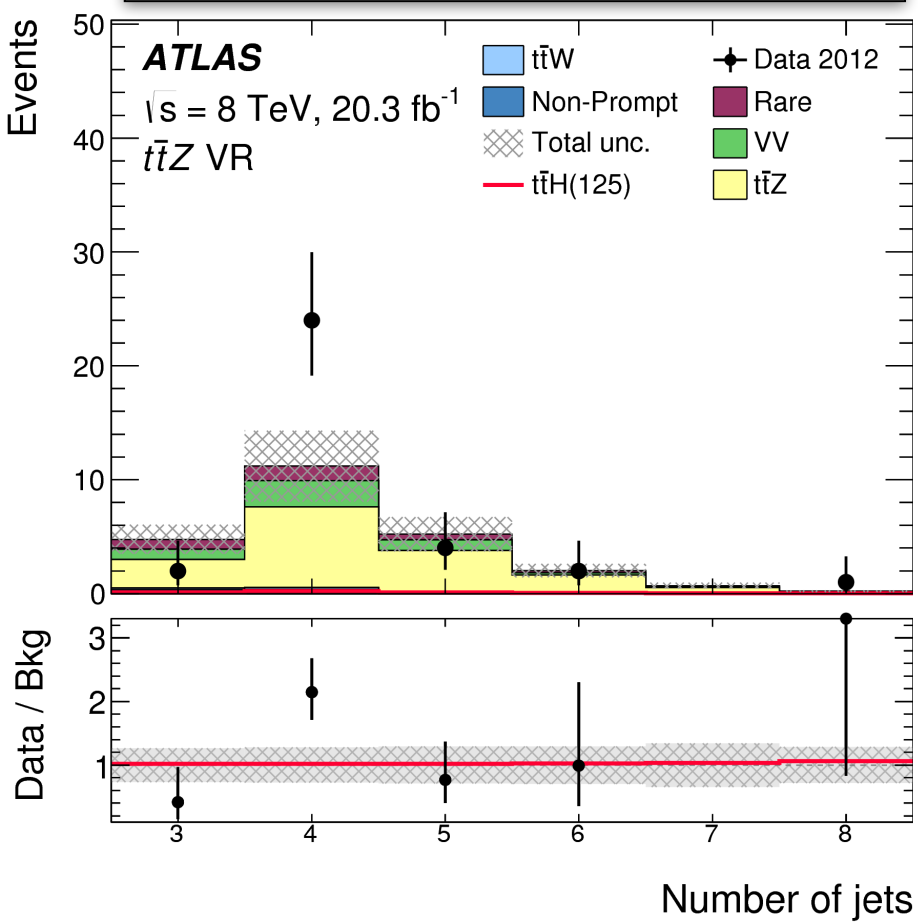
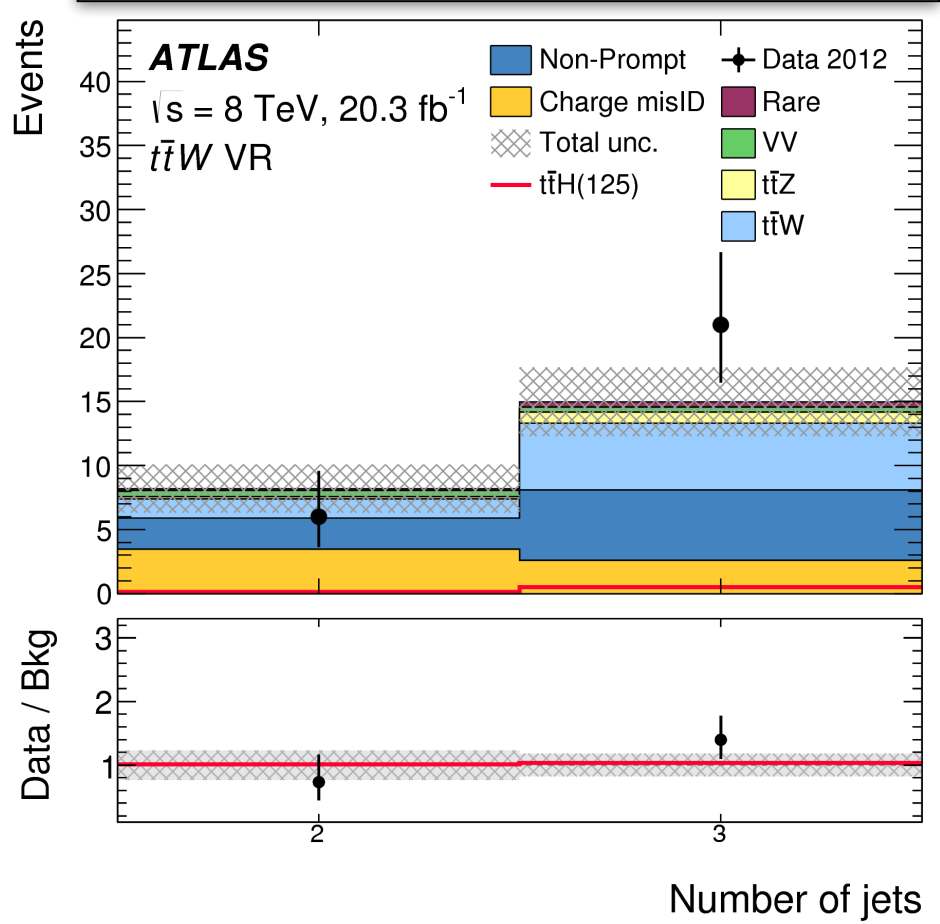
ttH→leptons: Background Estimation

- validate **MC predictions** with dedicated data regions, e.g.:

ttZ validation region (3l, Z peak)



ttW validation region (2l SS, 2-3jets)



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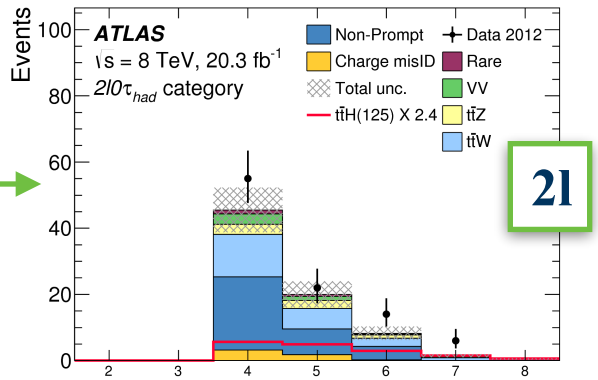
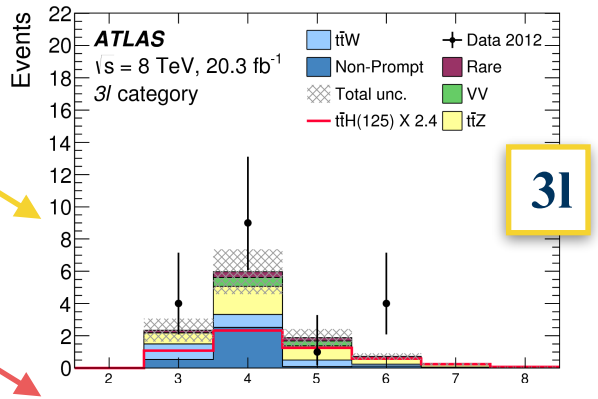
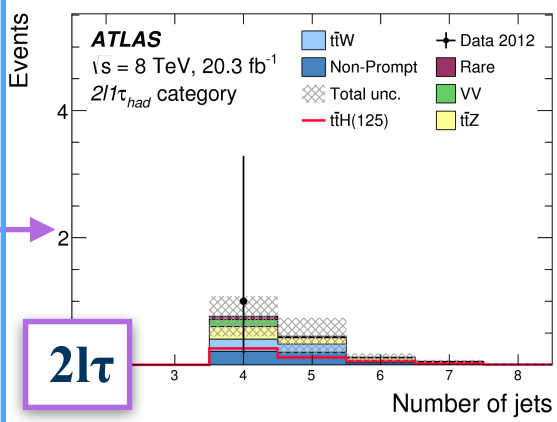
ttH→leptons: Event Yields

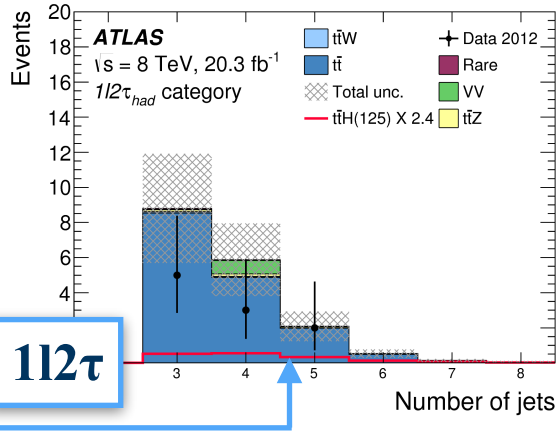
Category	Expected bkg.	$t\bar{t}H$ ($\mu = 1$)	Observed
$ee + \geq 5j$	6.5 ± 1.8	0.73 ± 0.14	10
$e\mu + \geq 5j$	15 ± 3	2.13 ± 0.41	22
$\mu\mu + \geq 5j$	8.6 ± 2.2	1.41 ± 0.28	11
$ee + 4j$	9.1 ± 2.1	0.44 ± 0.06	9
$e\mu + 4j$	24 ± 5	1.16 ± 0.14	26
$\mu\mu + 4j$	12.7 ± 2.9	0.74 ± 0.10	20
3ℓ	11.4 ± 2.3	2.34 ± 0.35	18
$2\ell 1\tau_{\text{had}}$	1.4 ± 0.6	0.47 ± 0.08	1
$1\ell 2\tau_{\text{had}}$	16 ± 5	0.68 ± 0.13	10
4ℓ Z-enr.	0.55 ± 0.15	0.17 ± 0.02	1
4ℓ Z-dep.	0.007 ± 0.005	0.025 ± 0.003	0

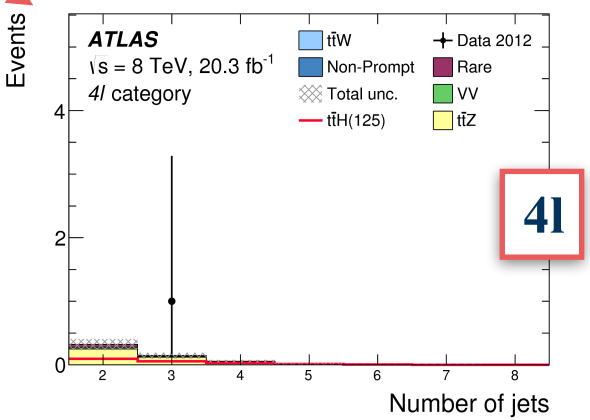
- yields are input to likelihood fit
- shape information note used









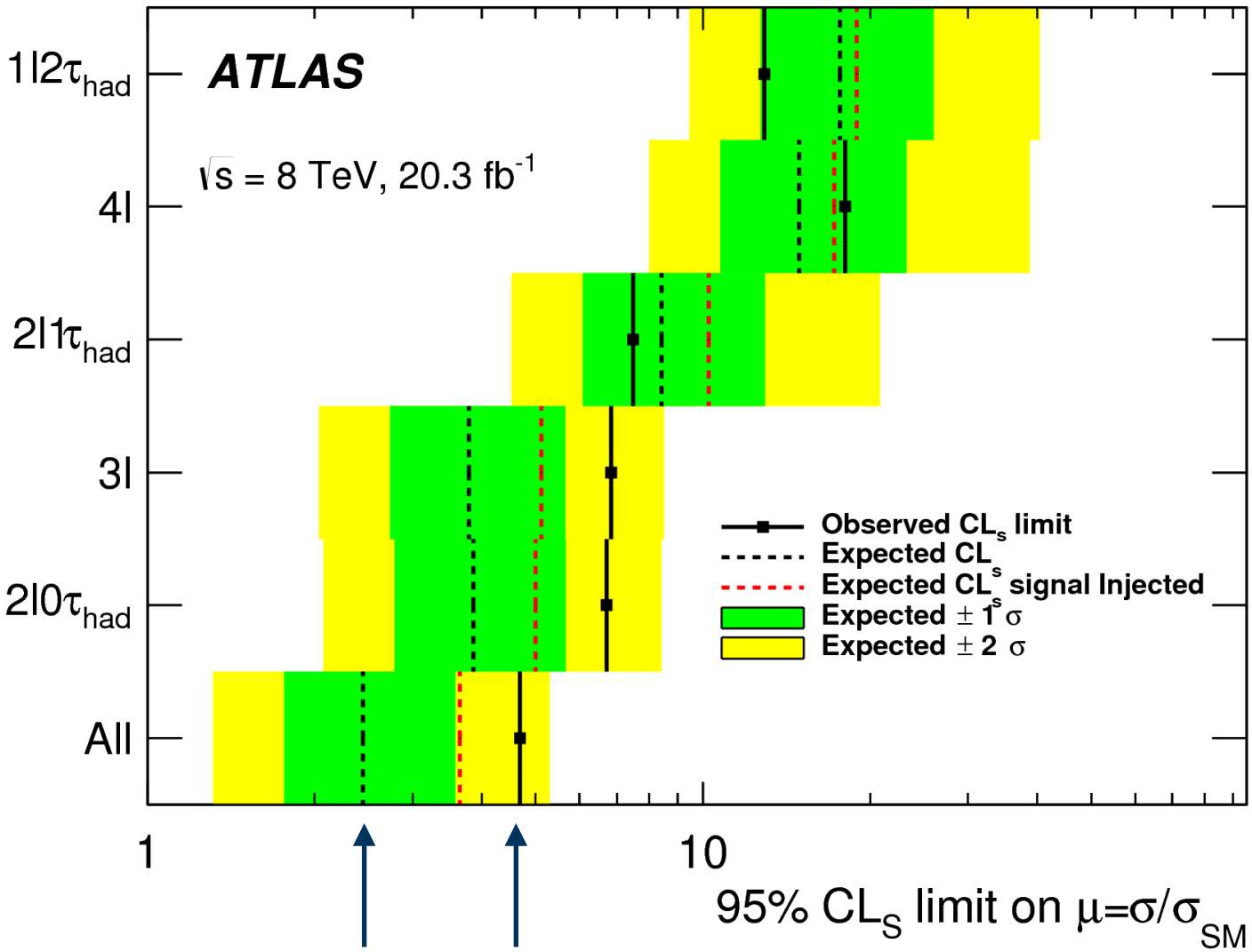


ttH→leptons: Systematic Uncertainties

Source	$\Delta\mu$	
$2\ell 0\tau_{\text{had}}$ non-prompt muon transfer factor	$+0.38$	-0.35
$t\bar{t}W$ acceptance	$+0.26$	-0.21
$t\bar{t}H$ inclusive cross section	$+0.28$	-0.15
Jet energy scale	$+0.24$	-0.18
$2\ell 0\tau_{\text{had}}$ non-prompt electron transfer factor	$+0.26$	-0.16
$t\bar{t}H$ acceptance	$+0.22$	-0.15
$t\bar{t}Z$ inclusive cross section	$+0.19$	-0.17
$t\bar{t}W$ inclusive cross section	$+0.18$	-0.15
Muon isolation efficiency	$+0.19$	-0.14
Luminosity	$+0.18$	-0.14

Phys. Lett. B 749 (2015) 519

ttH→leptons: Results



2.4 (obs.) 4.7 (exp.)

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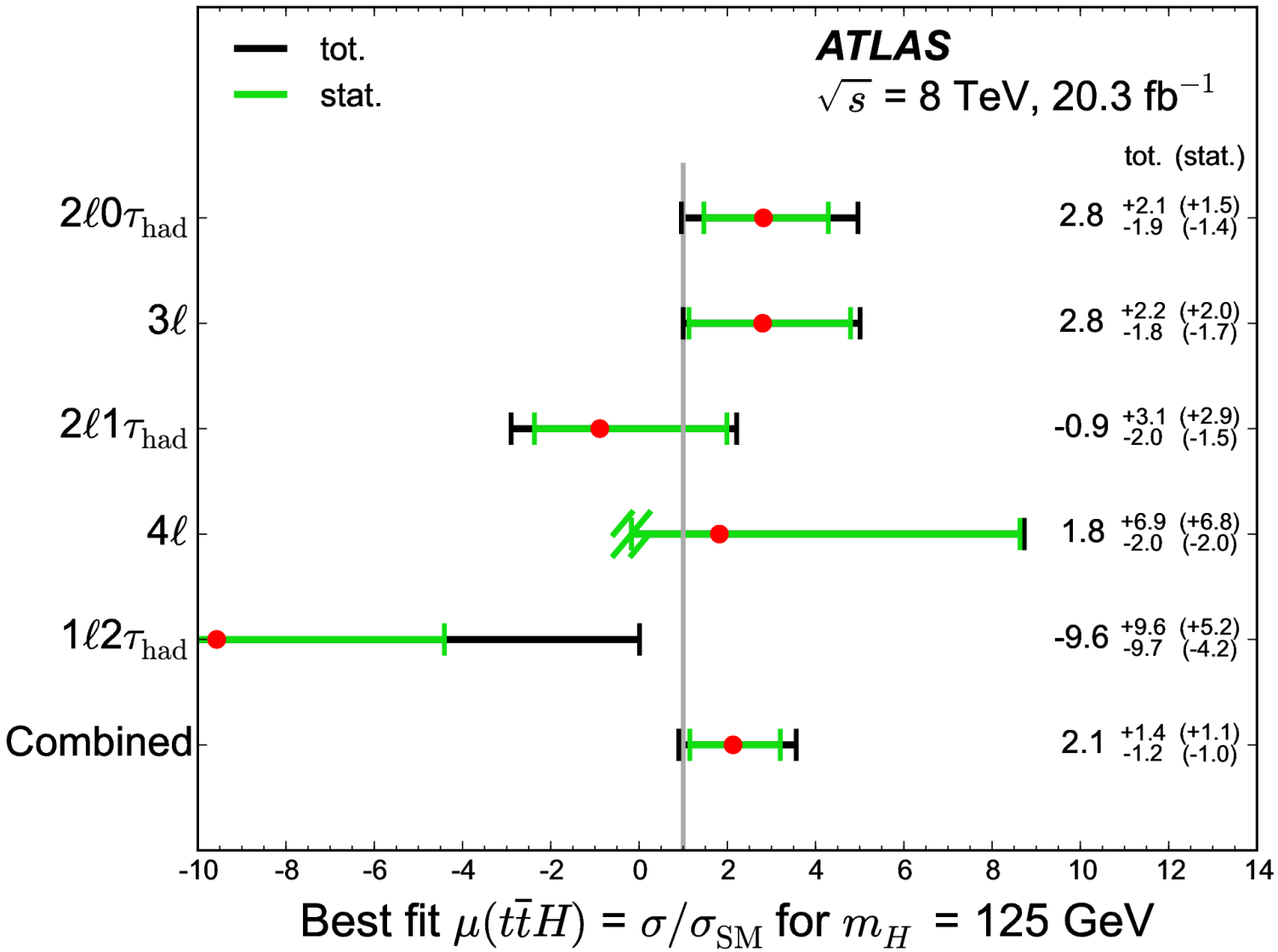
ttH→leptons: Results



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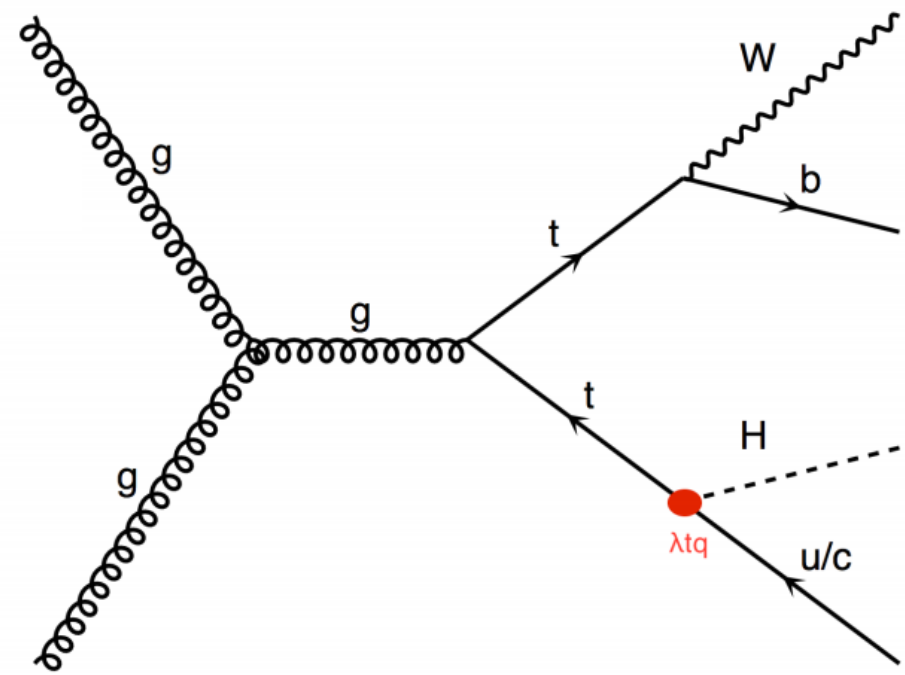
ttH→leptons: BSM Re-Interpretation

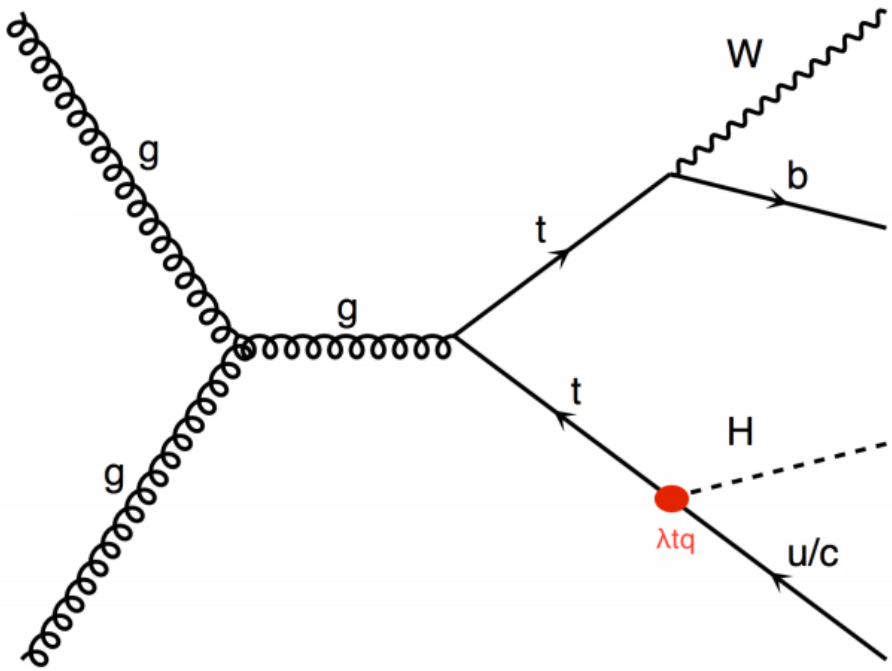
- **search for** flavour-changing Higgs-quark interactions; **FCNC** top quark decays **t→uH, t→cH**
- produces same final states as SM ttH→leptons processes

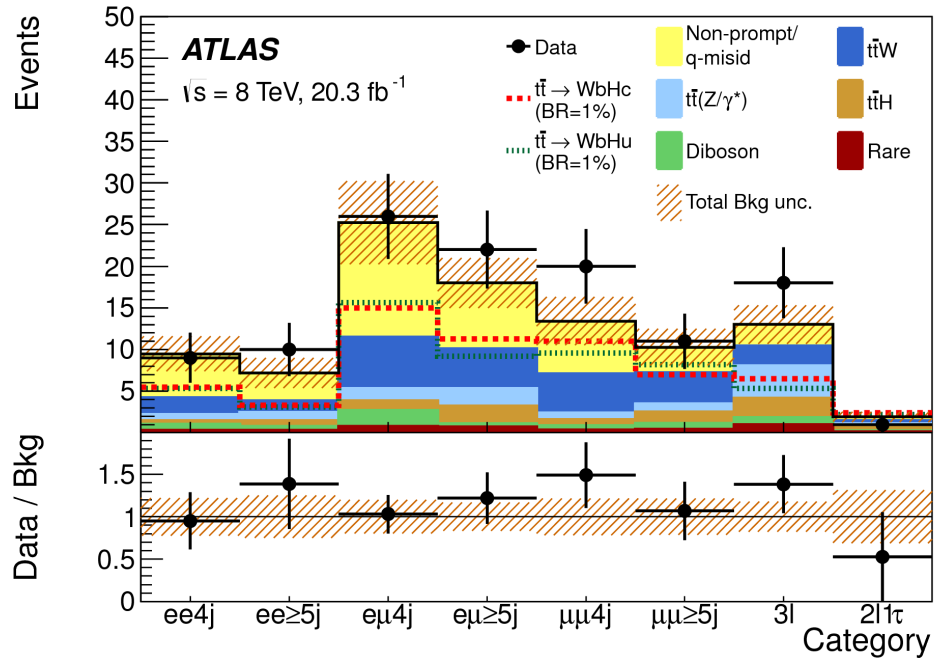


arXiv:1507.04548; subm. to EPJC

ttH→leptons: BSM Re-Interpretation

- **search for** flavour-changing Higgs-quark interactions; **FCNC** top quark decays **t→uH, t→cH**
- produces same final states as SM ttH→leptons processes
- use the **same** event **selection and categorisation**; include ttH production as background process





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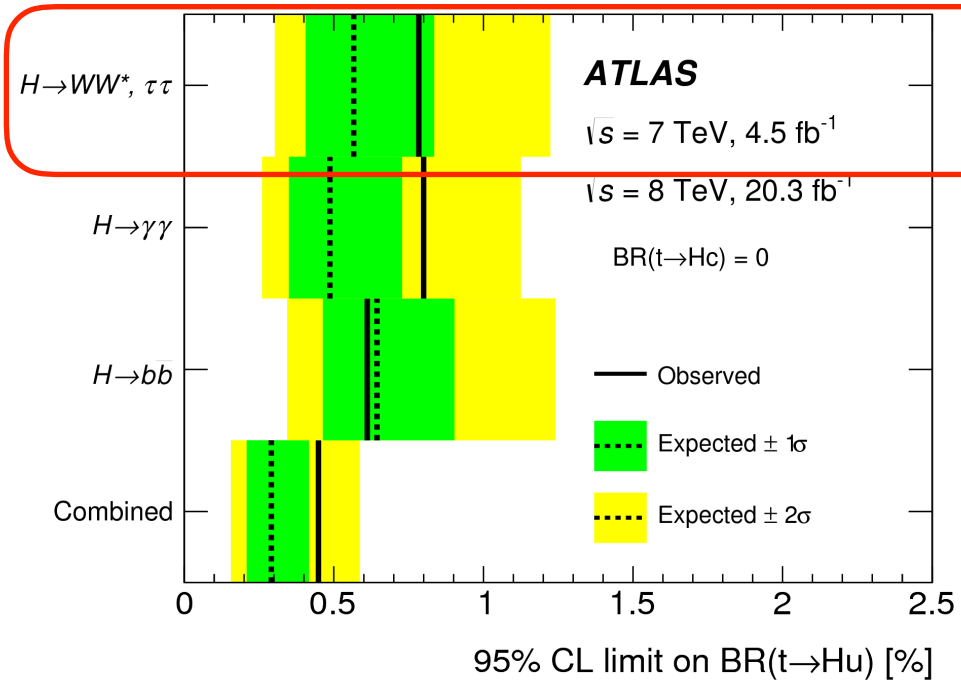
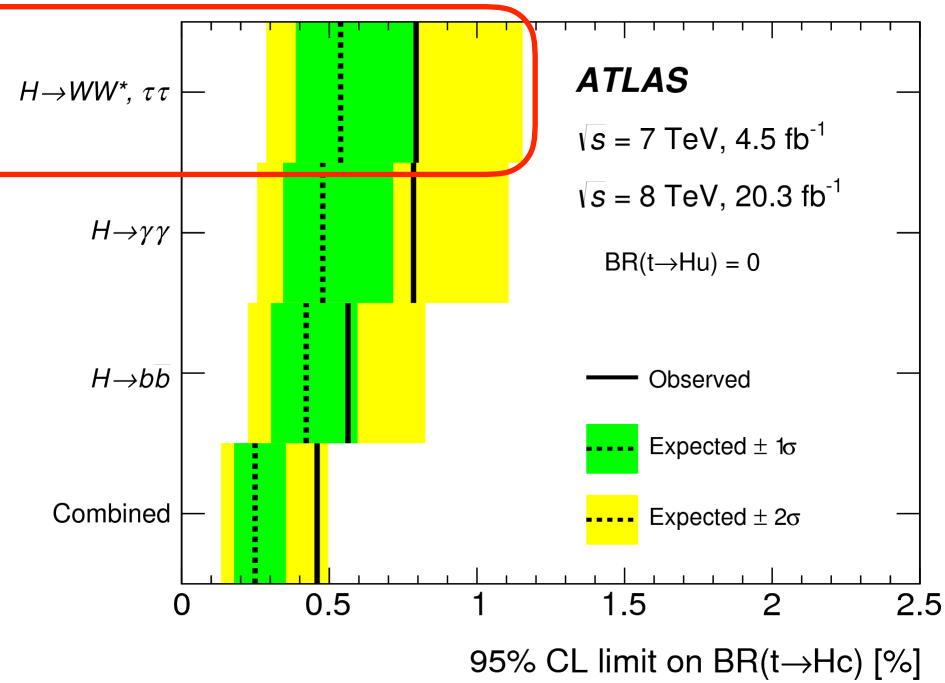
ttH→leptons: BSM Re-Interpretation Results

- **no excess** over SM expectation found
- set **limits on BR(t→Hq)**
- **combine with** searches in **other Higgs decay modes**

t→Hu



t→Hc



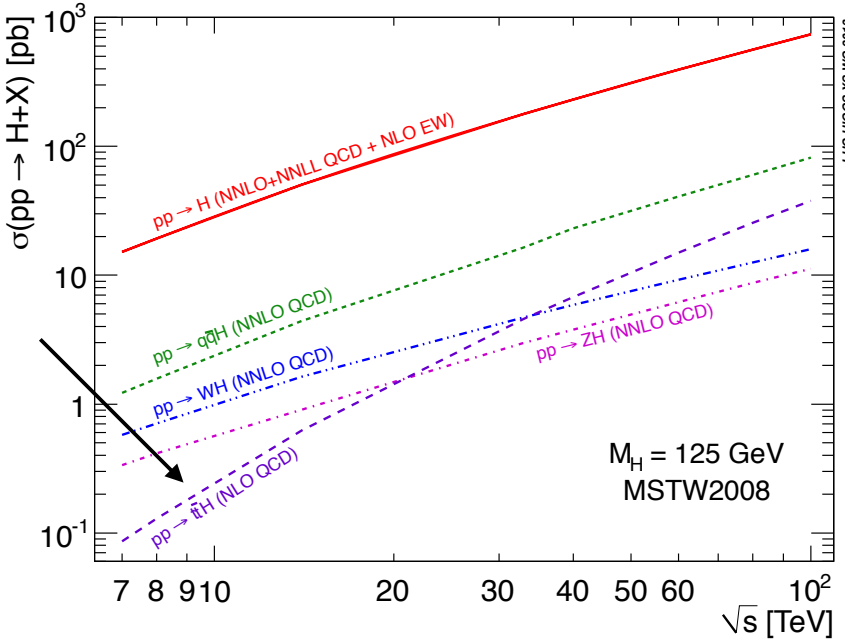
arXiv:1507.04548; subm. to EPJC

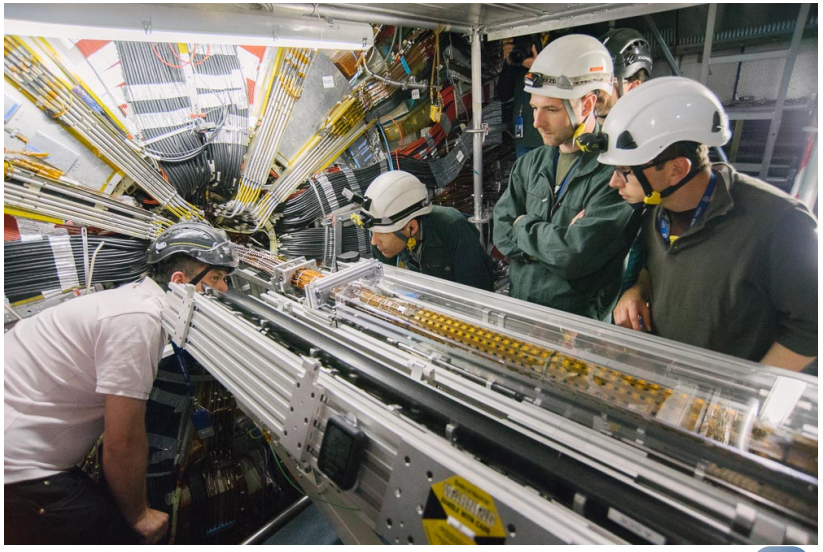
Run1→Run2: ttH

- much larger signal **cross section** (increase by about factor 4)
- somewhat better **S/B** (top pair production increases by ≈3.3)
- better **detector** (IBL)
- **improved** reconstruction and ID **algorithms**
- more data (eventually)

⇓

SM **ttH signal within reach** (and high priority)





Run1→Run2 Example(!): ttH→ττ

Eventually, will want/need to apply **more sophisticated** experimental **methods**. Could try to **learn from**

(a) "**inclusive**" SM **H→ττ** Run1 **analyses**, e.g.:

- use reconstructed **ττ mass** (shape)? Full reconstruction ("MMC")?
- focus on **specific phase space** regions ("boosted" Higgs regime)?
- use **multivariate** analysis **techniques** (BDT)?
- more/refined **data-driven background** estimation ("fake factors")?

(b) Run1 top analyses, e.g.:

- exploit mass constraints? **Kinematic fit** of top system / full event?

Aside: Any merit in optimising (even) more specifically for ttH→ττ?

Summary

- **ttH production** provides **direct access to top-Higgs** Yukawa **coupling**
- broad spectrum of ATLAS **Run1 searches**
- **no significant signal** yet: significance 2.5σ (1.5σ) obs. (exp.)
- **multi-lepton final states** are **important** ingredient to these searches
- relevant **within and beyond the SM**

Summary

- **ttH production** provides **direct access to top-Higgs** Yukawa **coupling**
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- **Run2** prospects are bright
- expect **definitive answer** on SM ttH prediction
- exploiting full potential will **require** further **improved experimental methods**