Electron efficiencies at the ATLAS detector. Search for flavor-changing neutral currents in t->Hq (q=u,c) decays with the ATLAS detector

Grigore Tarna
Supervisors: Calin Alexa(IFIN-HH), Pascal Pralavorio(CPPM)

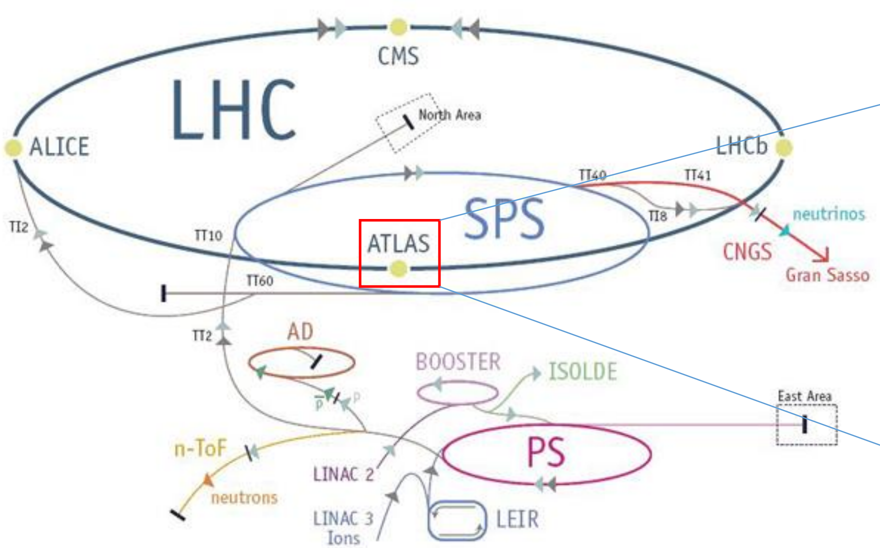
Sesiunea Tinerilor Cercetatori din IFIN-HH, IFIN-HH, 19-Dec-2017

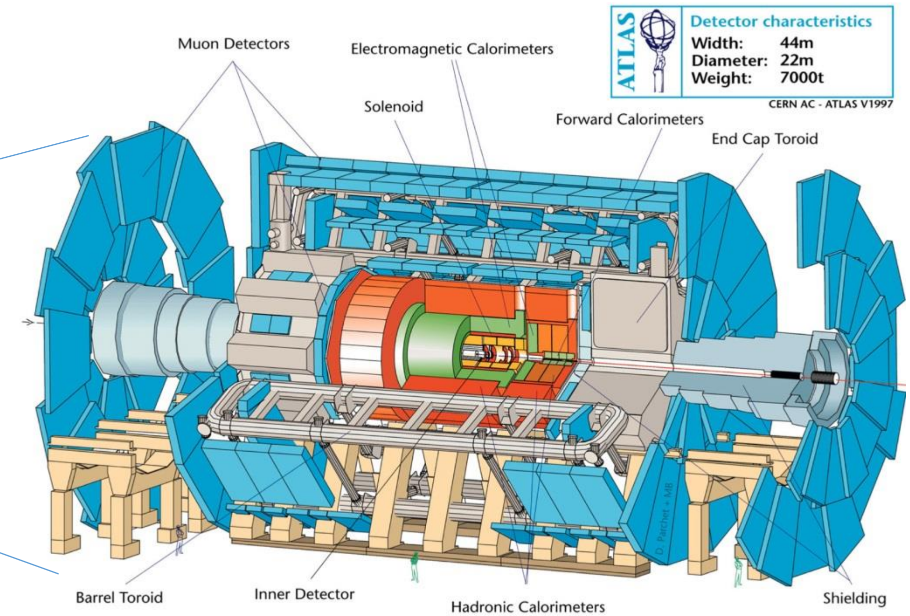
Introduction

- Joint PhD 2016-2019 : University of Bucharest and Aix-Marseille University
- Labs: IFIN-HH (DFPE) and CPPM

- *ATLAS* collaboration (~3000 physicists, 183 institutions, 38 countries)
- Become *ATLAS* author -> authorship qualification task: "Electron reconstruction efficiency measurement with $Z \rightarrow ee$ Tag and Probe method"
- Physics analysis for the thesis :
  "Search for flavor-changing neutral currents in t->Hq (q=u,c) decays with the ATLAS detector"

LHC and ATLAS

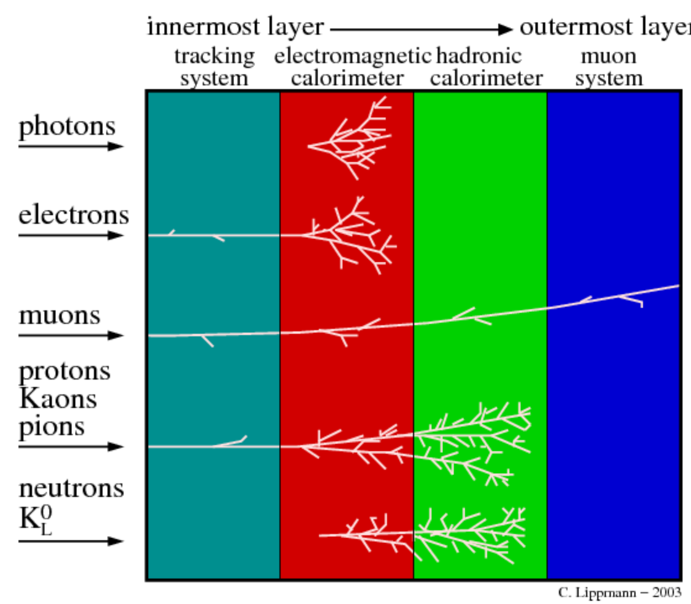




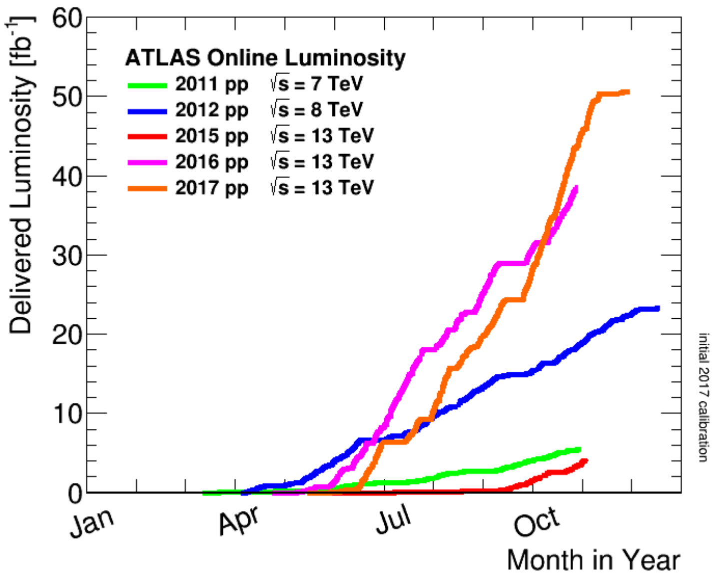
- The Large Hadron Collider (LHC):
  - proton-proton accelerator, $\sqrt{s} = 14^{**}$ TeV
- *Linac2 →Booster →PS →SPS →LHC*

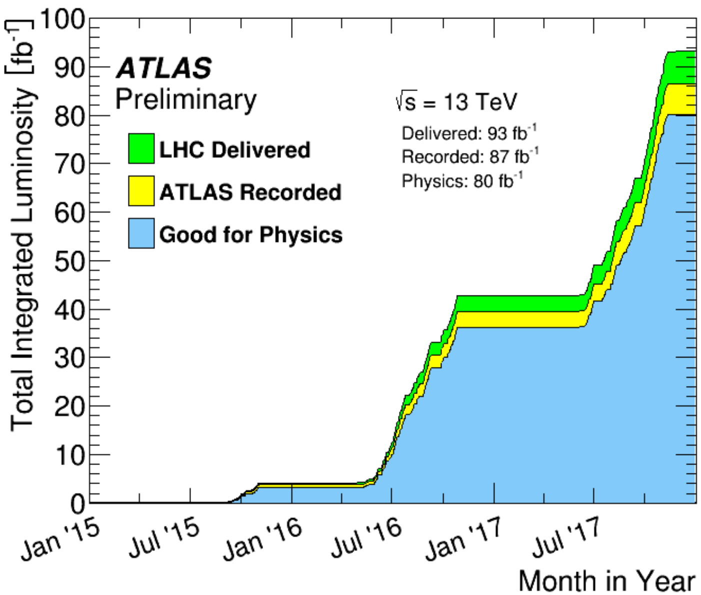
Run #	Period	$\sqrt{s}$ [TeV]	integrated luminosity $[fb^{-1}]$
Run 1	2010-2011	7	6.1
	2012-2013	8	23.3
Run 2*	2015	13	4.22
	2016	13	38.9
	2017	13	50.4

*2015-2018, integrated luminosity $\sim 100\ \mathrm{fb}^{-1}$ **designed



LHC and ATLAS: Data taking in 2017



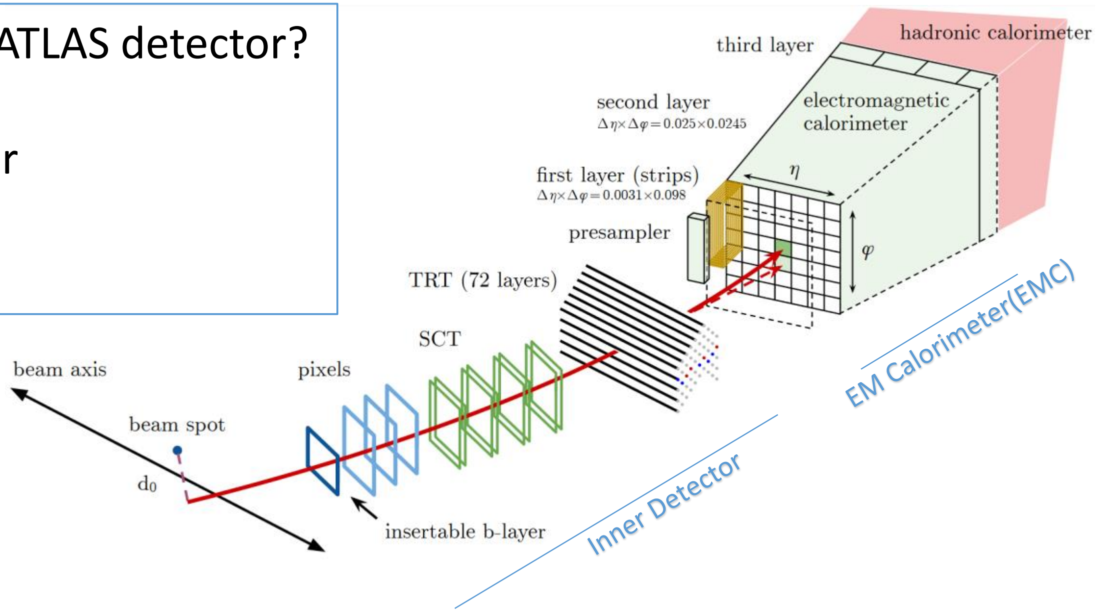


- A great year for the LHC:
  - Expected 45 fb^{-1}, delivered >50fb^{-1}
  - Reached x2 designed luminosity
- My contribution to detector operation and Data Quality(DQ)*:*
  ***7 weeks** of LAr DQ shifts*
  - after a run ends, 48h for DQ assessment (calibration loop)
  - mask noise before the bulk of data is processed

Electron reconstruction efficiency
Intro

- What is an electron in the ATLAS detector? *(reconstruction level)*
  - Track in Inner Detector
    +
  - Shower in EMC

How well are electrons reconstructed?



- We want our simulations to reproduce detector performance as well as possible
- Electron reconstruction efficiency is measured in both Data and MC: $\varepsilon_{reco}^{Data}$, ε_{reco}^{MC}
- To take into account the differences a scale factor is introduced

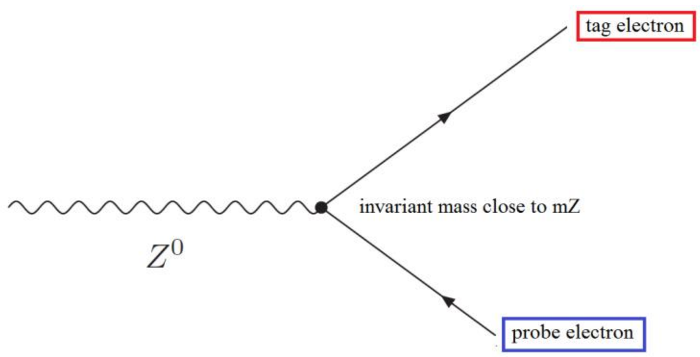
$$sf = \frac{\varepsilon_{reco}^{Data}}{\varepsilon_{reco}^{MC}}, \quad \text{such that } MC_{scaled} = sf \cdot MC$$

- ε_{reco} uncertainty for precision measurements has non negligible impact (Ex: W/Z cross-section, W mass)

Electron reconstruction efficiency

Tag and Probe Method

- Need an enriched, clean sample of electrons: $Z \rightarrow ee$
  - Signal: $Z \rightarrow ee$
  - Background: jets faking *e*, photon conversion, *e* from heavy flavor decay …



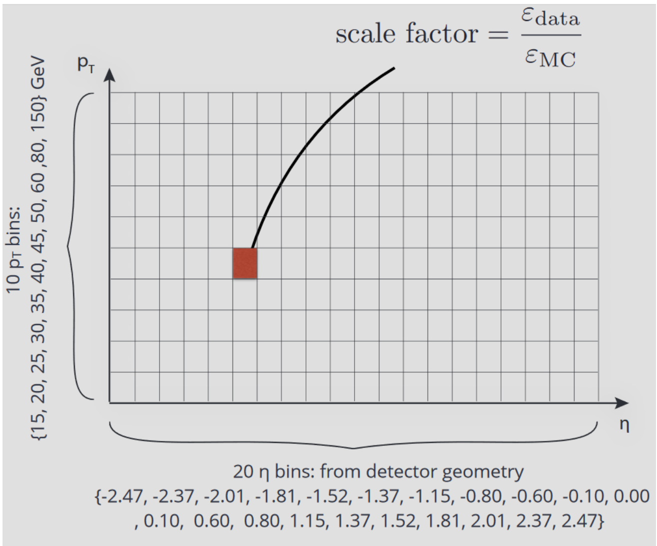
- Tight cuts
- pT>25 GeV
- Out of "crack" region ($1.37 < |\eta| < 1.52$)

- Mee in Z mass window
- pT>15 GeV

- Only the "probes" used in the measurement
- Reco efficiency

$$\varepsilon_{reco} = \frac{N_{passTrackQ}}{N_{passTrackQ} + N_{failTrackQ} + N_{noTrack}}$$

- SFs are provided to physics analysis as "recommendations" by the Egamma CP group

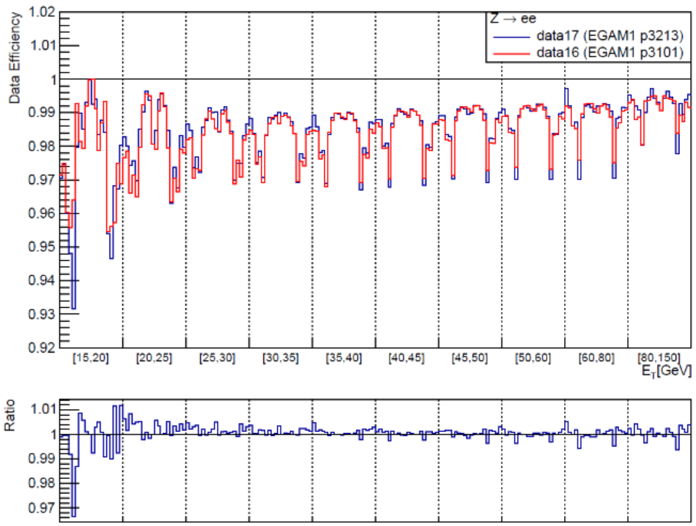


The recommendations are used by almost all physics analyses!

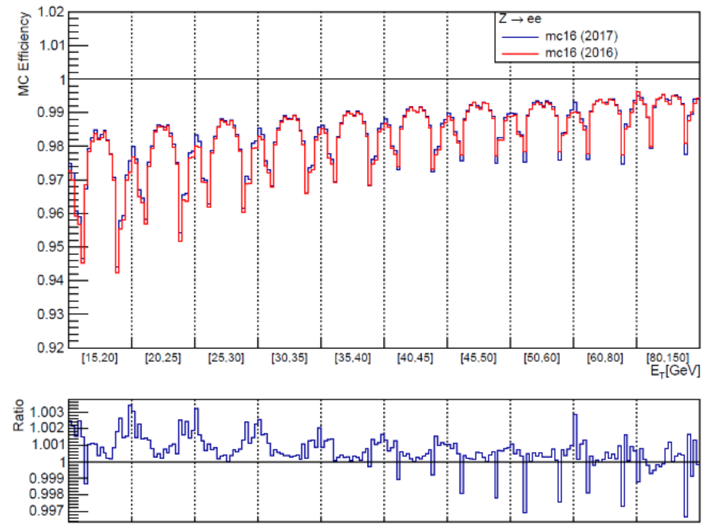
Electron reconstruction efficiency

Results: dependency on $E_T \times \eta$

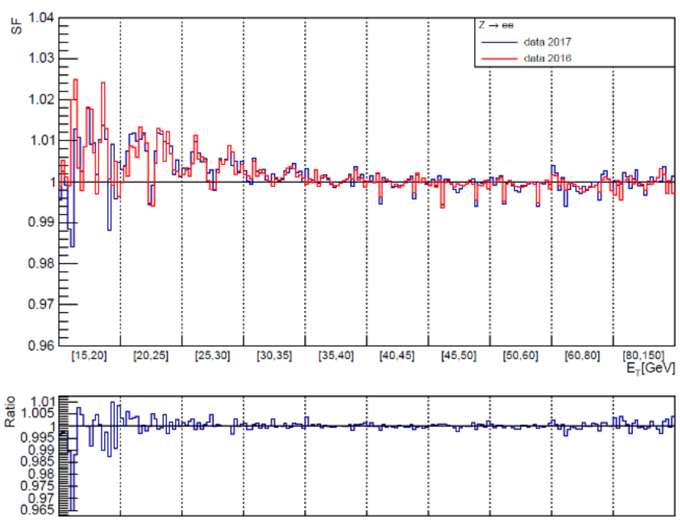
Data16(red) vs Data17(blue)



MC16(red) vs MC17(blue)



SF16(red) vs SF17(blue)

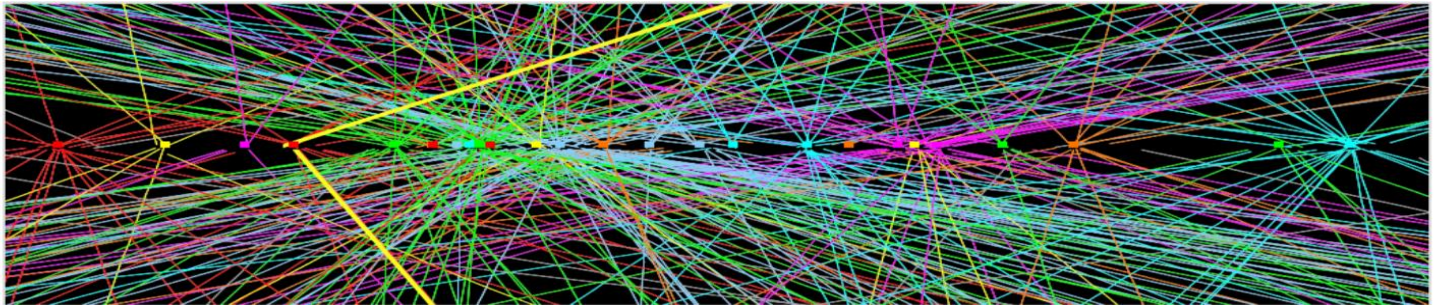


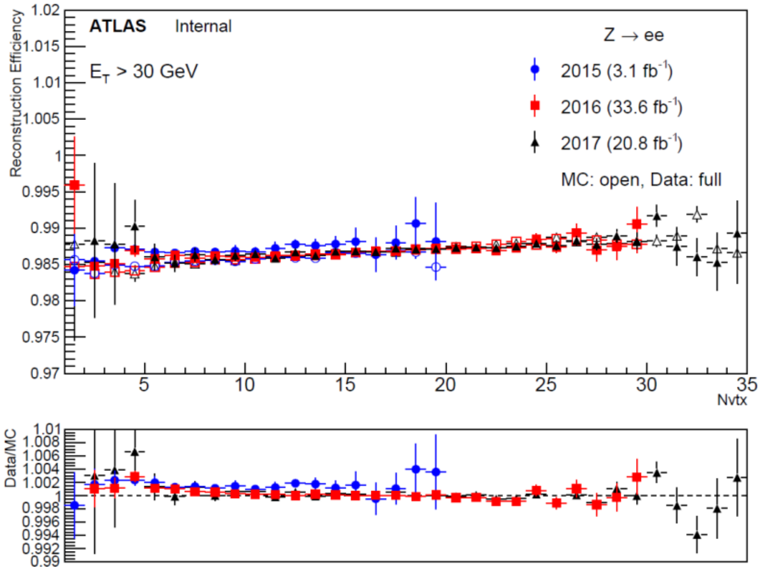
- Each E_T bin contains 20 η bins [-2.47,2.47]
- High efficiency for both Data and MC
- Drop in efficiency in the “crack” region
- SFs generally close to 1 (within 2% for extreme cases)
- SF uncertainty typically at per-mile level (~2% at low E_T)

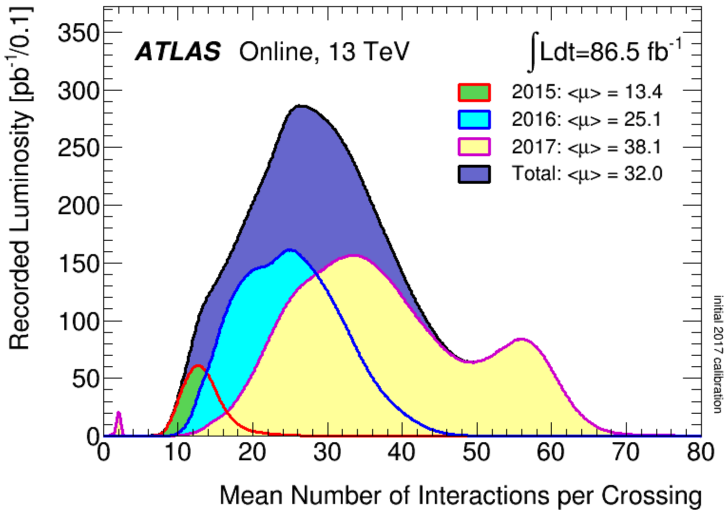
Electron reconstruction efficiency

Results: dependency on pileup

- More than one p-p collision happens in the same bunch crossing → pileup







- Slight increase in efficiency with pileup (higher chance of random track-cluster match)
- Minimal dependency on pileup for the SFs

Electron reconstruction efficiency
Results:

- Poster at EPS-HEP 2017 on “Electron identification with the ATLAS detector ” (with proceedings)

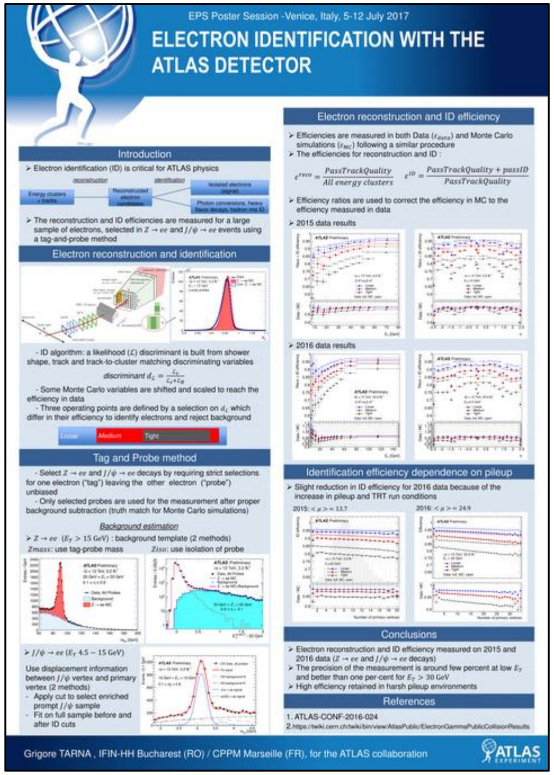
- All previous results were presented at the Egamma workshop (5-9 Nov 2017)

- I am editor of Internal Note for the electron reconstruction efficiency part
  - **paper** in preparation

- important efforts were dedicated to a software transition (Athena rel20.7->rel21)

Qualified as ATLAS author as of 10 sept 2017!

- Will continue to work on the topic



Isolation efficiency

- Some physics analysis with low cross-section suffer of significant non-prompt lepton background (ex. ttH→ multileptons)

- Cut based isolation not efficient enough -> multivariate analysis (MVA)

$$\varepsilon_{\text{total}} = \varepsilon_{\text{reconstruction}} \times \varepsilon_{\text{identification}} \times \boxed{\varepsilon_{\text{isolation}}} \times \varepsilon_{\text{trigger}}$$

- I adapted the official framework for efficiencies measurements to measure the efficiency of this non-standard isolation working point

- Detailed talk given in the Egamma workshop

- CONF note already public and **paper** draft is in the final stage of approval inside ATLAS

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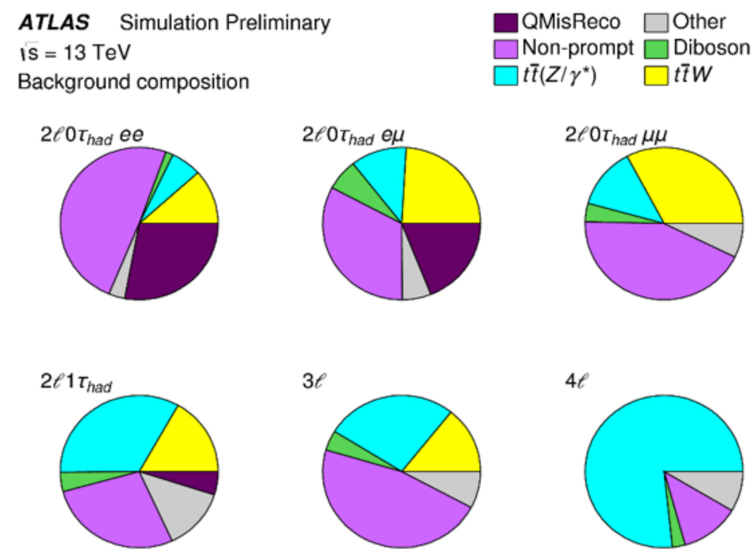

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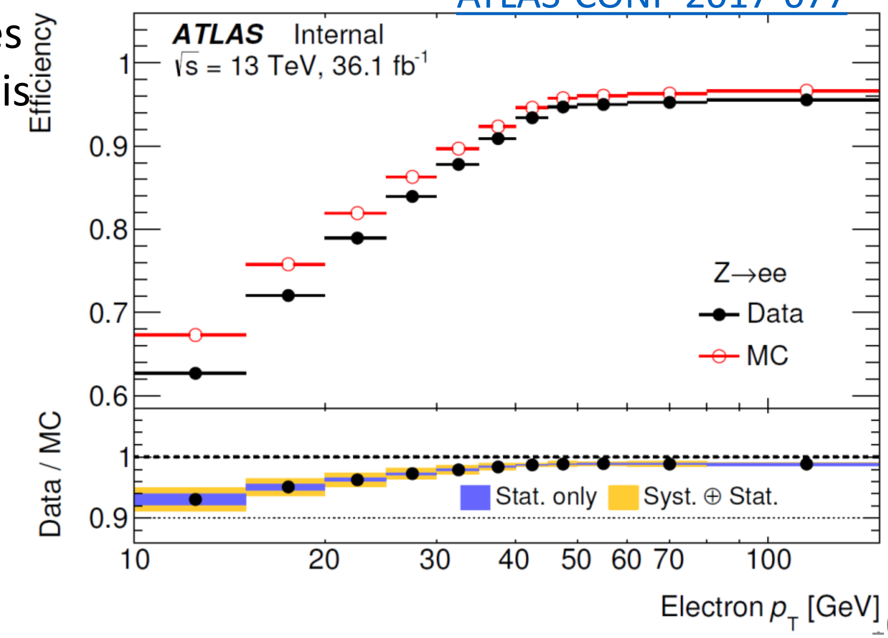
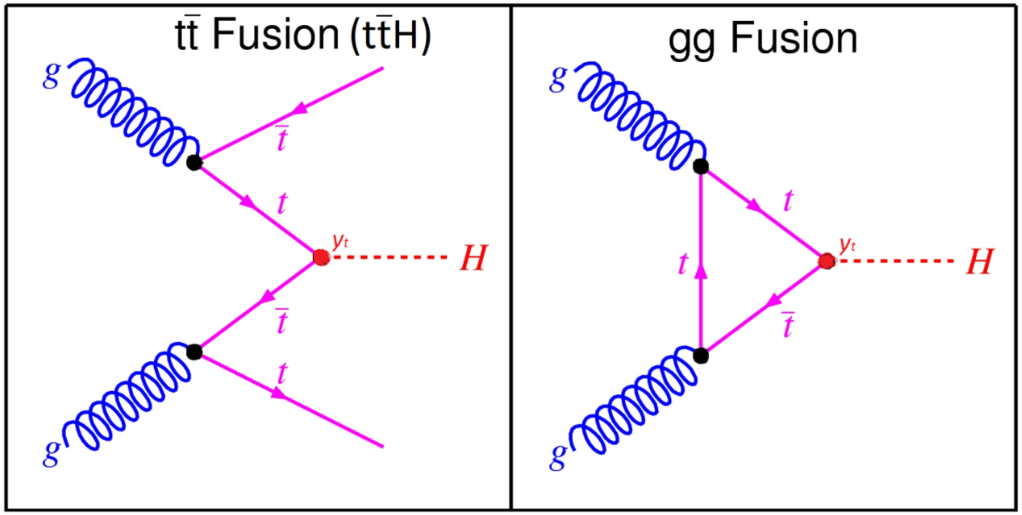


$t\bar{t}H$ production

Important(!):

- precision measurement of Top Yukawa coupling (y_t) will allow to check if the Higgs particle is the SM one
- comparison with indirect measurements can give hints about New Physics

Process	ttH	ggF
σ(8 TeV) [pb]	0.13	19.3
σ(13 TeV)[pb]	0.51	43.9



- σ(ttH) << σ(ggF)
- ggF ~90% H production

The *signal strength* is measured:

$$\mu_{t\bar{t}H} = \frac{\sigma_m(pp \to t\bar{t}H)}{\sigma_{SM}(pp \to t\bar{t}H)}$$

The fit is performed on:

$$data = \mu \cdot\ signal + background$$

$$\boxed{y_t^2 \sim \mu_{t\bar{t}H}}$$

Latest ttH results

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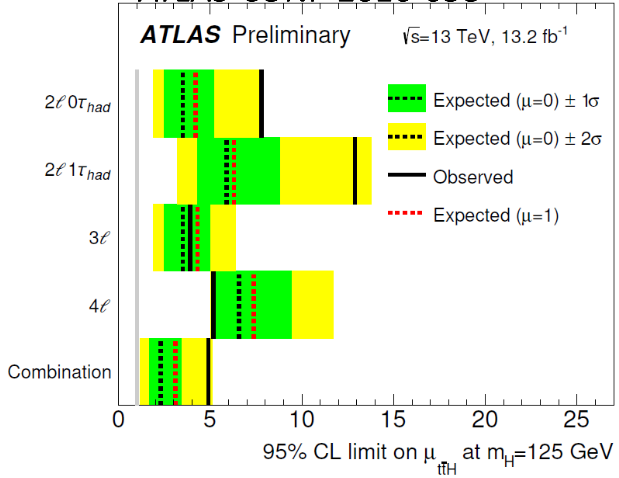

Statistical significance: **1.6 σ**

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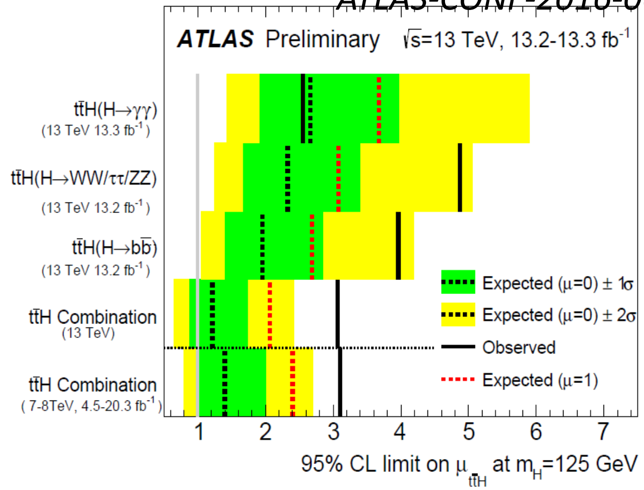
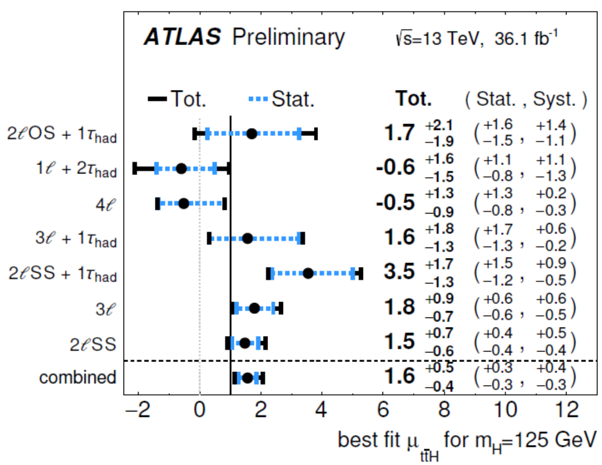


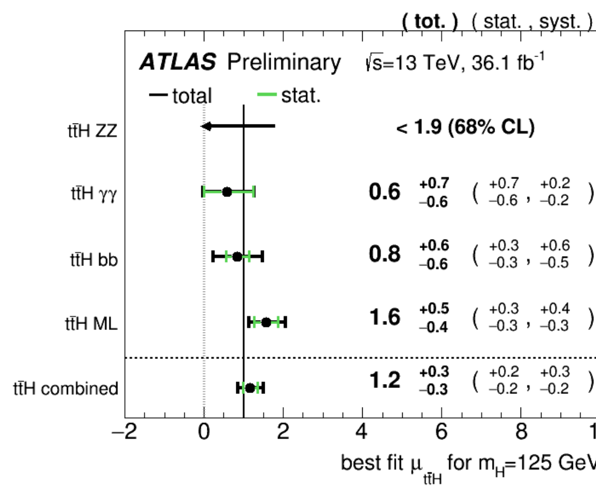
Statistical significance: **2.9 σ**

<u>2016</u> :

- Cut and count
- 13.2 fb



Statistical significance: **4.1 σ**



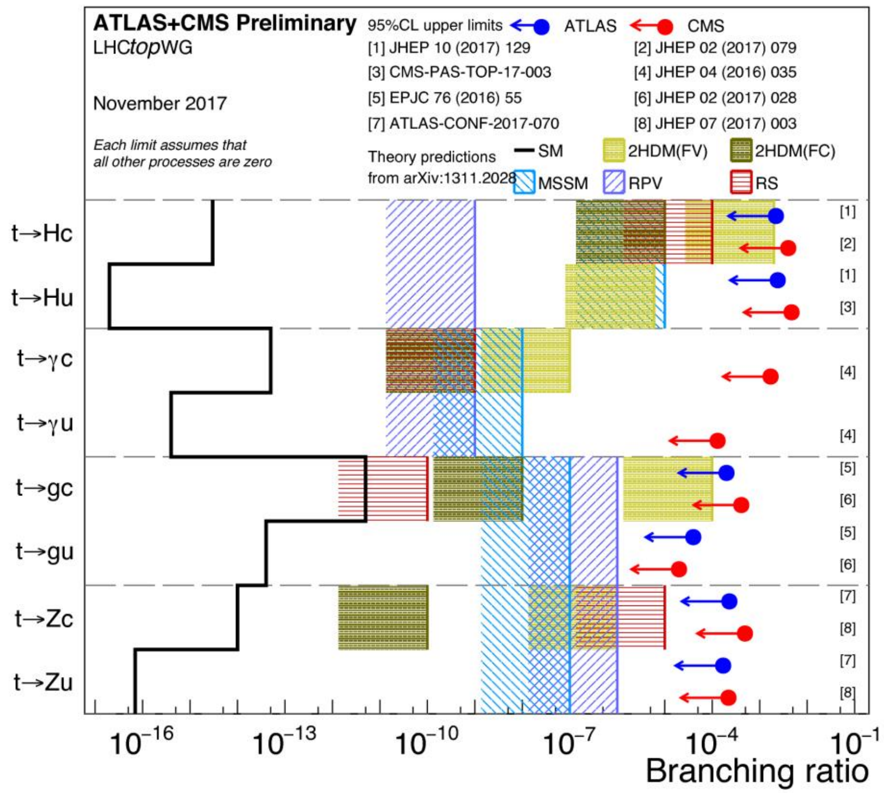
Statistical significance: **4.2 σ**

<u>2017</u>:

- MVAs based
- More channels
- 36.1 fb (x2.7)
- Evidence!

Hope to reach **5σ** by end of Run 2

Flavor-changing neutral currents (FCNC)



- FCNC forbidden at tree level and strongly suppressed at higher order in SM

  $t \rightarrow Xq$, q=u,c and X neutral boson

- Some beyond standard model (BSM) predict non-negligible branching ratios for top FCNC that could be probed at LHC

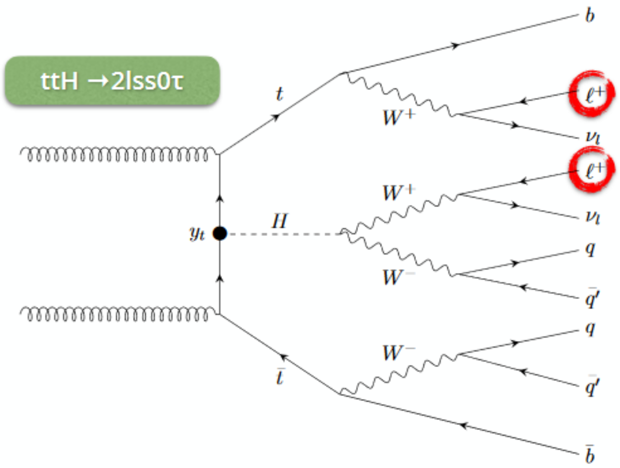
- In this analysis ($t \rightarrow Hq$) we exploit the similarity of the final states with the ttH (multilepton) process and use the complex developments fully validated and approved for the ttH analysis

Flavor-changing neutral currents (FCNC)

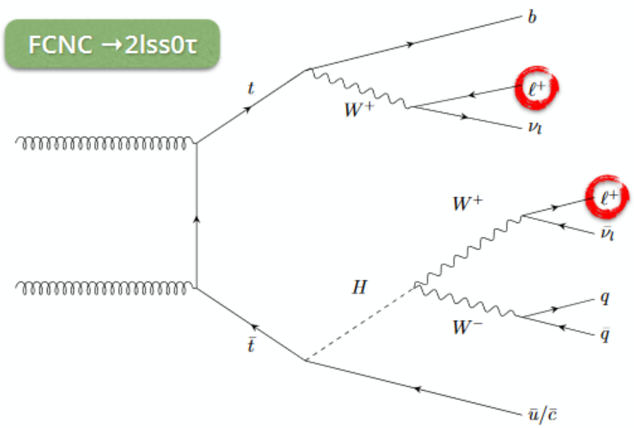
- Signal ttH vs top FCNC

$t\bar{t}H \to 4W + 2b \to$ **6j (inc. 2b) +2ℓSS +$E_{\mathrm{T}}^{\mathrm{miss}}$** or **4j (inc. 2b)+3$\ell$ +$E_{\mathrm{T}}^{\mathrm{miss}}$**

$t\bar{t} \to WbHq \to 3W + b + q \to$ **4j (inc. 1b) +2ℓSS +$E_{\mathrm{T}}^{\mathrm{miss}}$** or **2j(inc. 1b)+3$\ell$ +$E_{\mathrm{T}}^{\mathrm{miss}}$**



- Backgrounds are the same
  - ttH becomes background for top FCNC search



- 95% CL Upper Limit on B(t→Hu)

Run 1 ttHML	Simple ttHML reinterpretation	H-> yy	tHu*
0.54%	0.29%	0.20%	~0.15%

** Preliminary results. Work in progress*

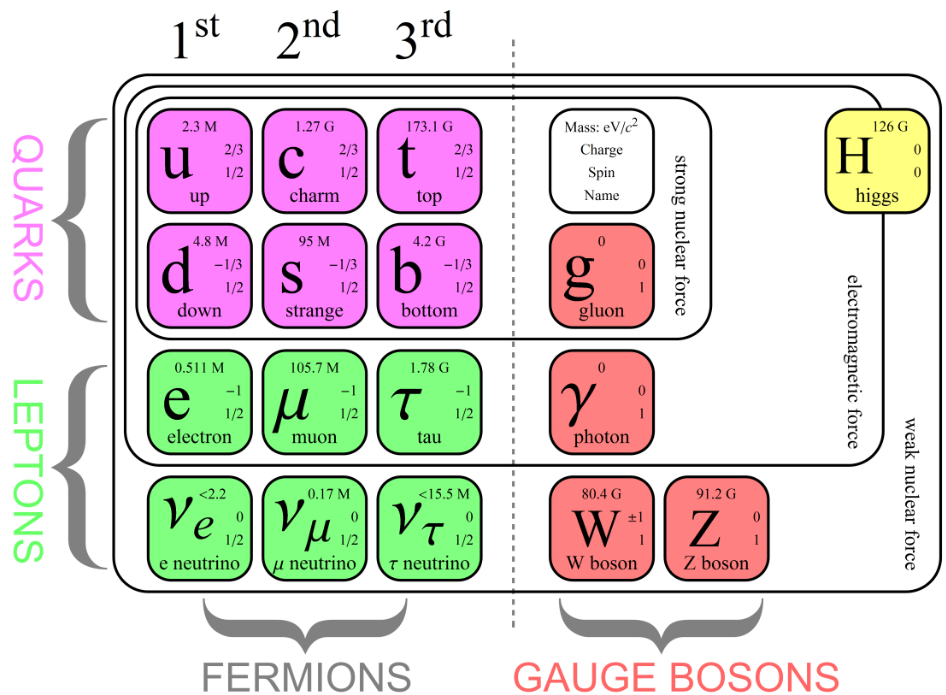
- Pre-approval presentation for t->Hq FCNC analysis this Thursday
- Aim for **publication** with 36.1 fb (2015+2016 data)

Results summary

- Authorship qualification task completed successfully
- **Paper** for electron efficiencies in preparation
- CONF note publicly available and **paper** draft in final stage of final approval for $t\bar{t}H$ analysis
- Top FCNC analysis in good shape, aim for a **paper** until spring
- Poster at EPS-HEP2017 and talk at Egamma workshop
- More than 20 internal presentation in CERN groups

backup

SM



- The Standard Model – the best theory for particle physics up to date

scalar
fermion
coupling

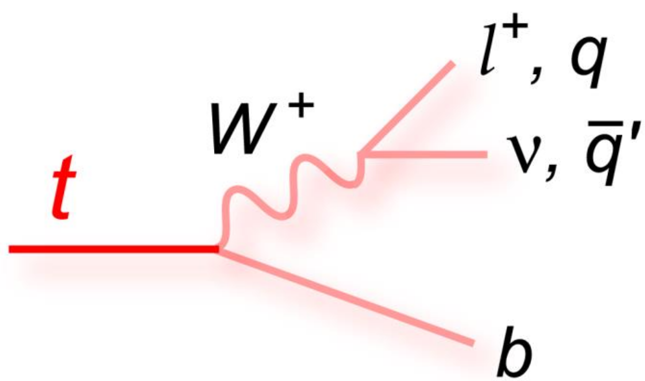
- Yukawa coupling: $\mathcal{L}_{Yukawa}(\phi,\psi) = -y\bar{\psi}\phi\psi$
- t quark (heaviest fermion) → largest coupling
- y_t <u>direct</u> measurement possible via ttH production

$$\boxed{y_t = \frac{\sqrt{2}\mathrm{m_t}}{\mathrm{v}} \sim 1}$$

Top and Higgs

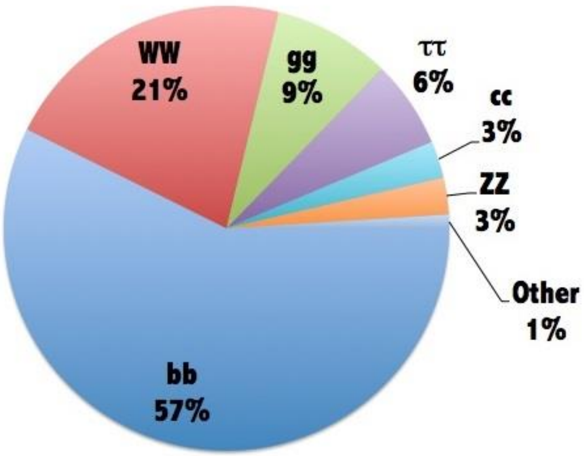
Top quark:

- Discovered: 1995 (Tevatron)
- Mass: 173 GeV
- $\tau \approx 5 \cdot 10^{-25}\ s$
- Does not hadronize
- Decays to W+b (99.8%)



Higgs boson:

- Discovered: 2012 (CERN)
- Mass: 125 GeV
- $\tau \approx 1.6 \cdot 10^{-22}\ s$
- Decays directly to pairs of massive particle-antiparticle



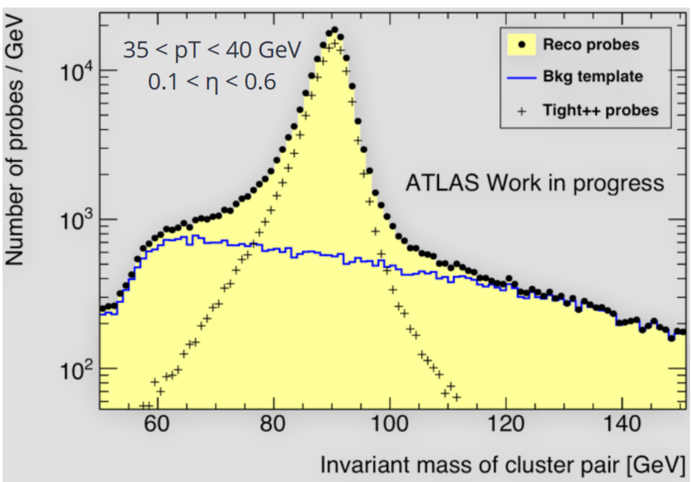
Electron reconstruction efficiency

Tag and Probe Method: Backgrounds

$$\varepsilon_{reco} = \frac{N^{sig}_{pass}}{N^{sig}_{pass} + N^{sig}_{fail}} = \frac{N^{QT} - B^{QT}}{(N^{QT} - B^{QT}) + (N^{NoQ} - B^{NoQ}) + (N^{NoT} - B^{NoT})}$$

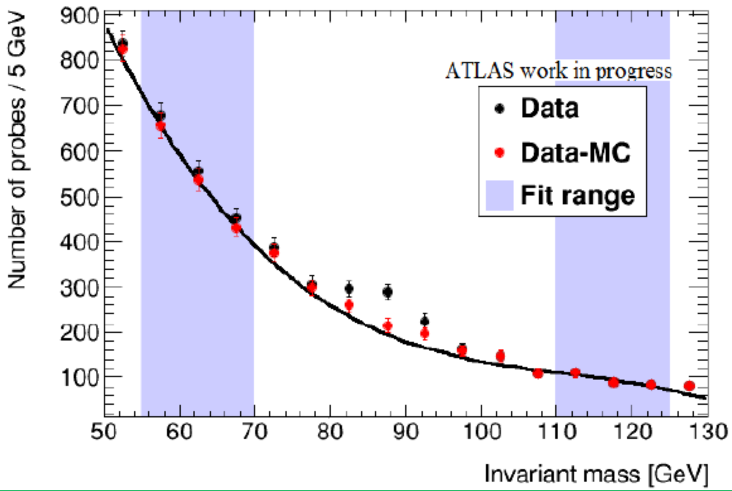
Background *e* with track:

1. Build template by inverting cuts and Iso
2. Normalize template in signal free region



Background *e* with no track:

1. Fit the tag-probe invariant mass with a 3rd order polynomial
2. Fit only in side bands



No nominal measurement! 72 variations for Data and 9 for MC

Tag and Probe Method: systematic uncertainties

-Statistical uncertainty

Statistical uncertainty is calculated by error propagation

-Systematical uncertainty

Sources of systematic uncertainties:

- Background shape
- Background origin
- Signal contamination
- …

systematic variations :

- Tag identifications: 3
- Z mass window: 3
- Electron background template: 2
- Sideband for eγ mass fit: 4

Total: 3x3x2x4 = 72 variations (for MC only 9)

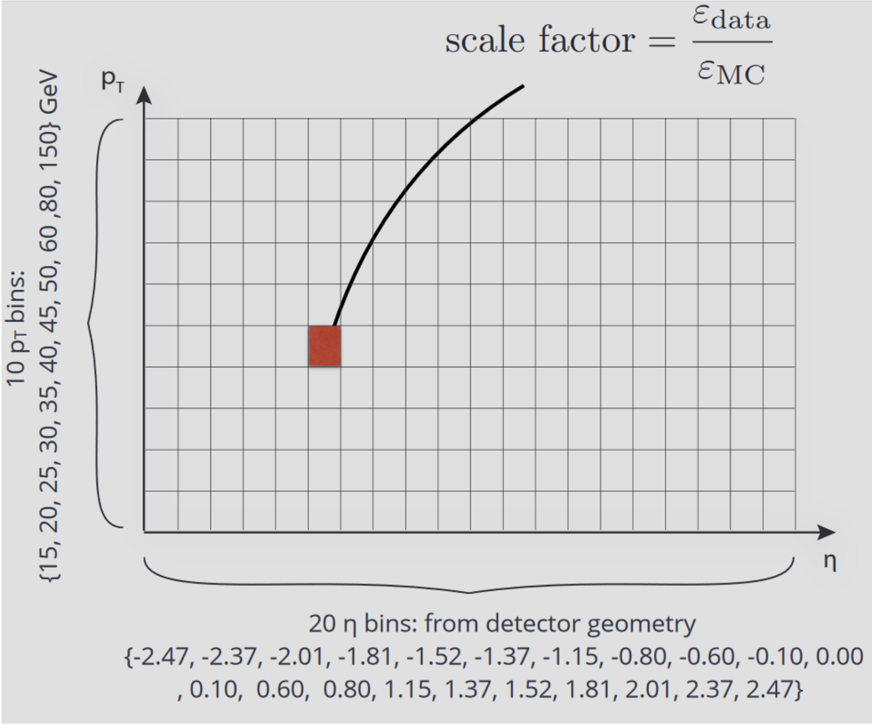
Tag identification variations	Z mass peak windows	Electron background template	Sideband for eγ mass fit
Tight LH	]80, 100[GeV	Variation 1	]70, 80[U]100, 110[GeV
Tight LH & TopoE$_T$cone40 < 5 GeV	]75, 105[GeV	Variation 2	]60, 80[U]100, 120[GeV
Medium LH & TopoE$_T$cone40 < 5 GeV	]85, 95[GeV		]50, 80[U]100, 130[GeV
			]55, 70[U]110, 125[GeV

Template	Cuts	p_T < 30 GeV	p_T >= 30 GeV
Variation 1	fail at least 2 loose+ + cuts	topoE$_T^{cone30}$/p_T > 0.02 $120 < m_{ee} < 250$ GeV	topoE$_T^{cone40}$/p_T > 0.05 $120 < m_{ee} < 250$ GeV
Variation 2	fail at least 2 loose+ + cuts	topoE$_T^{cone30}$/p_T > 0.02 $60 < m_{ee} < 70$ GeV	topoE$_T^{cone40}$/p_T > 0.20 $120 < m_{ee} < 250$ GeV

Electron reconstruction efficiency

Tag and Probe Method: Deliverables

- 2D maps with scale factors are delivered to the physics analyses (+ stat and syst uncertainties) (*recommendations*)



For each bin:

$$\varepsilon^{centrVal} = \frac{\sum_i^N \varepsilon_i^{centrVal}}{N}$$

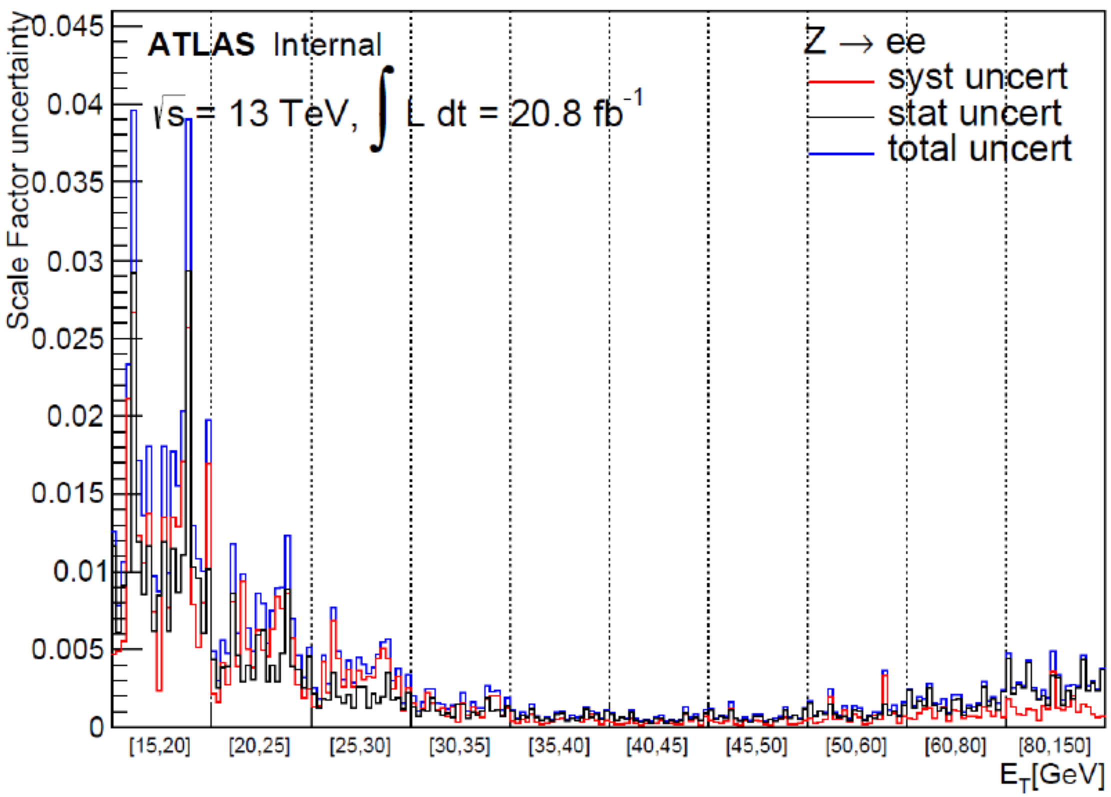
$$\Delta\varepsilon^{stat} = \frac{\sum_i^N \varepsilon_i^{stat}}{N}$$

$$\Delta\varepsilon^{syst} = \sqrt{\frac{\sum_i^N \left(\varepsilon_i^{stat} - \varepsilon^{centrVal}\right)^2}{N}}$$

In parallel, I am working on bringing improvements to the current methodology

The recommendations are used by almost all physics analyses!

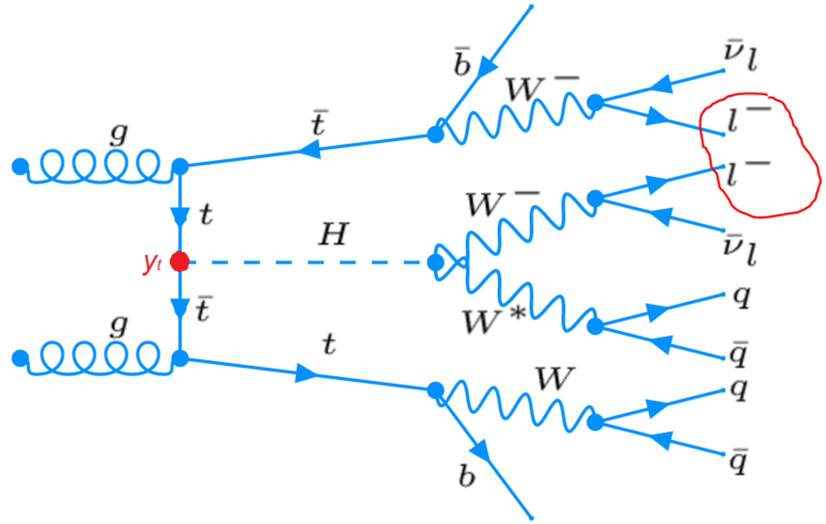
Reco SF uncertainty (2017)



Two lepton same sign channel

- $t\bar{t}H$ final states depends on H decay

	Higgs boson decay mode			
Category	WW^*	$\tau\tau$	ZZ^*	Other
2ℓss	77%	17%	3%	3%



- $t\bar{t}H$ →2 leptons same sign (2lss)
  - ➢ low backgrounds and relatively well controlled
  - ➢ high efficiency lepton triggering
  - ➢ low production (1 % of $t\bar{t}H$, ~5 events/fb^{-1})

luminosity

$$N_{ev}^{x} = \sigma_x \underbrace{\int \mathcal{L}\, dt}_{\text{integrated luminosity}}$$

Signal signature:

- 2 leptons of same sign
- 6 jets in total
  - 2 b-jets
  - 4 non b-jets
- missing transverse energy (neutrinos are not detected)

up to date results: *ICHEP 2016*

The *signal strength* is measured:

$$\mu_{t\bar{t}H} = \frac{\sigma_m(pp \to t\bar{t}H)}{\sigma_{SM}(pp \to t\bar{t}H)}$$

The fit is performed on:

$$data = \mu \cdot\ signal + background$$

$$\boxed{y_t^2 \sim \mu_{t\bar{t}H}}$$

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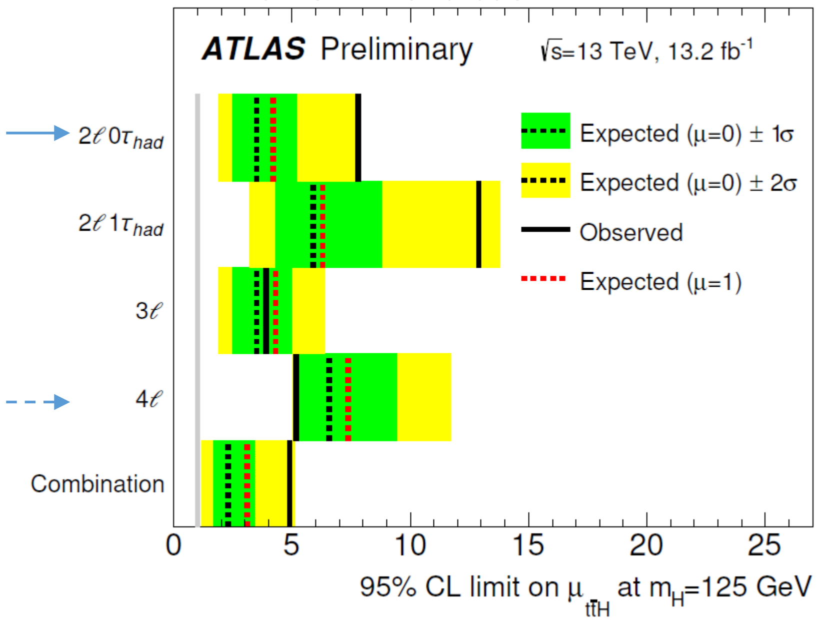

Statistical significance: **1.6 σ**

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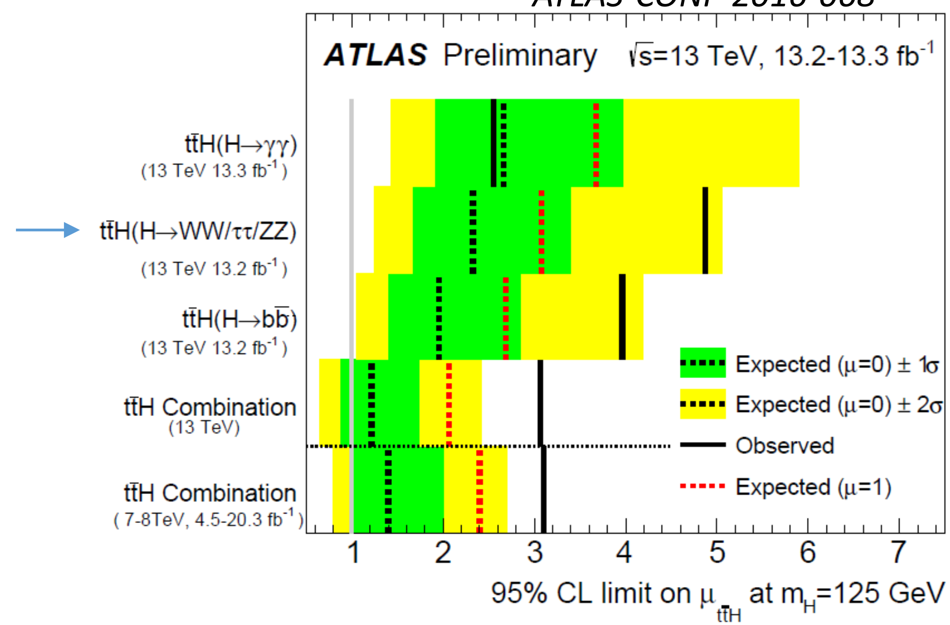

Statistical significance(13TeV): **2.9 σ**

More data is expected (x 7-8)!