1. Data taking with the Liquid Argon Demonstrator for the Phase-I trigger readout electronics upgrade of the ATLAS experiment
2. Studies on associated Higgs boson production with top quark pair

Journées de Rencontre des Jeunes Chercheurs 2016

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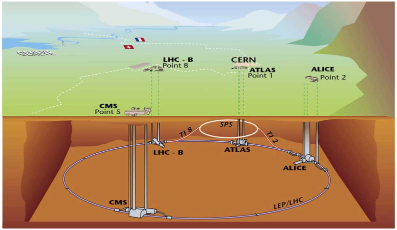
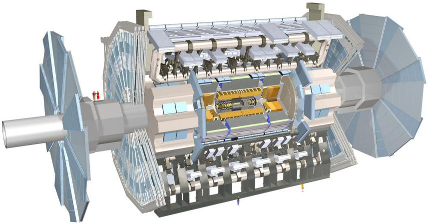
The LHC, the ATLAS experiment and my PhD

- the LHC (Large Hadron Collider)

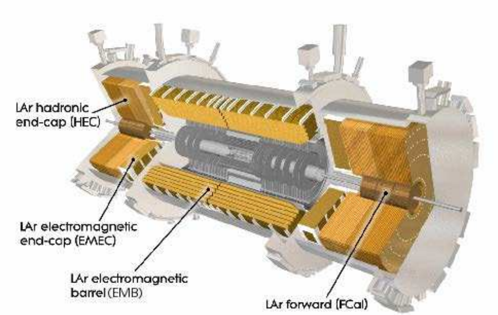


- the ATLAS experiment

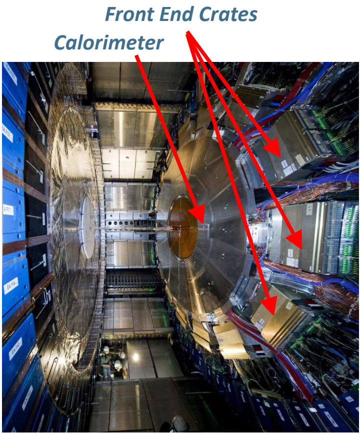


- discovery of the Higgs boson in 2012
- since 2015 proton-proton collisions with increased energy & luminosity (Run 2)
  - → precisely study properties of Higgs boson
  - → search for new physics
- PhD in ATLAS group of CPPM (Marseille) under supervision of Cristinel Diaconu and Emmanuel Monnier
  - → upgrade of the Liquid Argon Calorimeter (LAr) trigger readout (1st part)
  - → analysis $t\bar{t}H \to$ leptons (2nd part)

The ATLAS Liquid Argon Calorimeter (LAr)



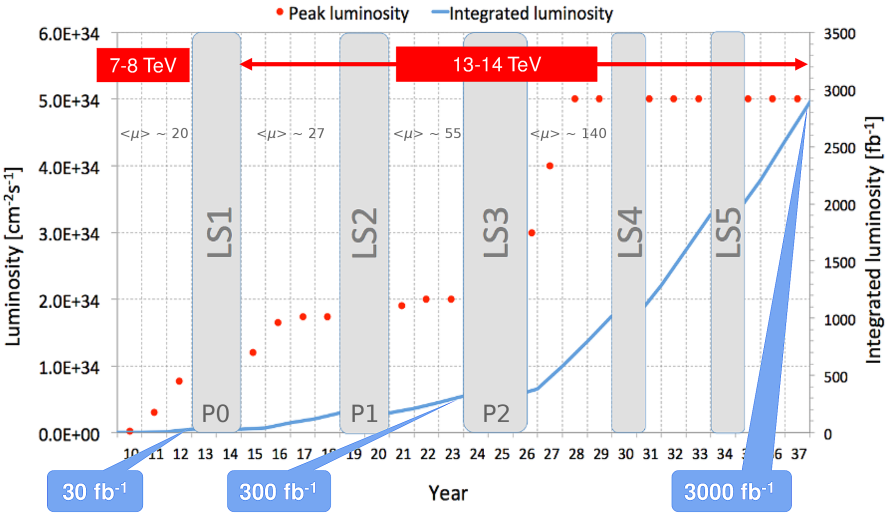
- **LAr calorimeter : 182k channels**
- **Front End : 1600 Front End Boards**
- **Back End : 200 Readout Out Driver boards**



Between Electromagnetic barrel and end-cap

- measures precisely energy and position of electrons and photons

The LHC Forecast



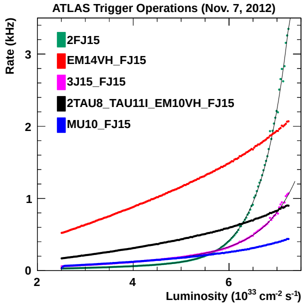
- increase of pile-up $< \mu >$ and luminosity
- higher particle flux through detector

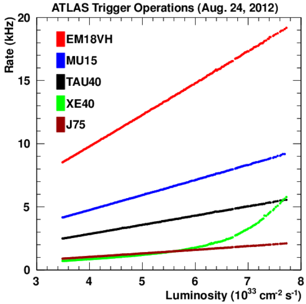
Why does the trigger needs an upgrade?

- collisions with rate of 40 MHz
- limited level 1 trigger rate of $\sim$ 20 kHz
- lepton trigger rates increase linearly with luminosity
- forward-jet and missing E_{T} trigger rates increase logarithmically

→ increase trigger threshold
  - cuts out interesting physics!

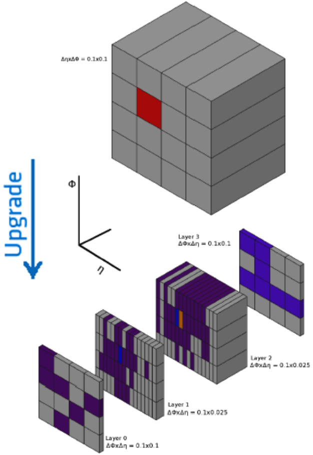
→ improve trigger
  - e.g. higher granularity in LAr Calorimeter readout

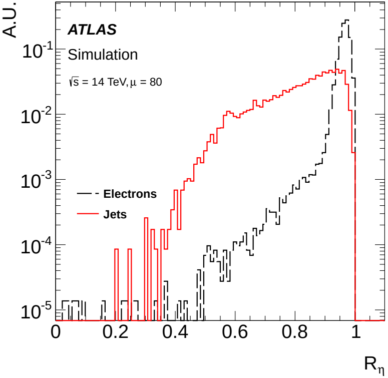




Upgrade of the Liquid Argon Calorimeter

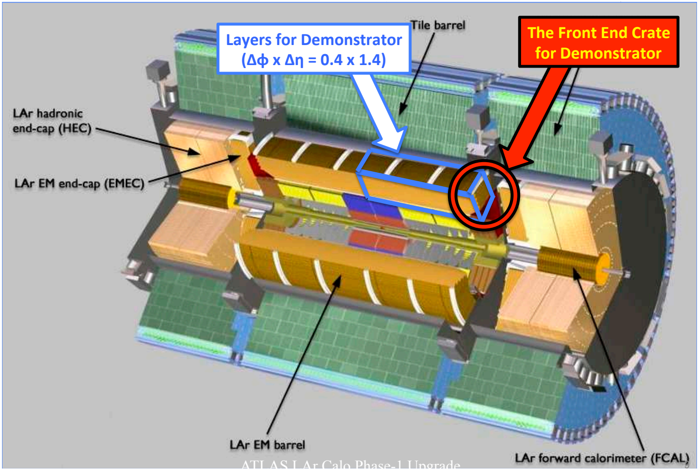
- Liquid Argon Calorimeter upgrade (Phase-I, during 2019/20):
  - increase of granularity in readout by factor 10 → super cells
  - add longitudinal shower information to the level 1 trigger input → layers





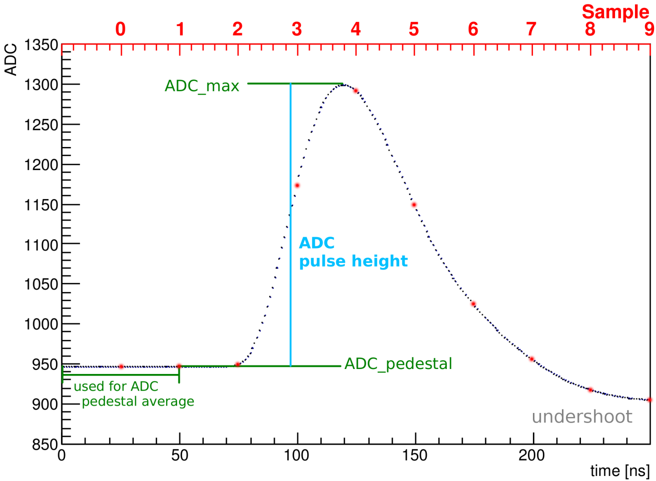
→ new discriminant variables like R_η

The LAr Demonstrator



- installed in June 2014, covering a small area of the detector
  - → no disturbance of current system
  - digitisation of supercell pulses with 40 MHz
  - 2 digital boards, waiting for trigger level 1 accept to readout super cells
  - calibration and data-taking in 2015 and 2016

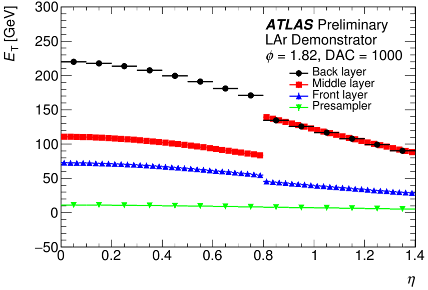
ADC pulse measurement at the LAr Demonstrator



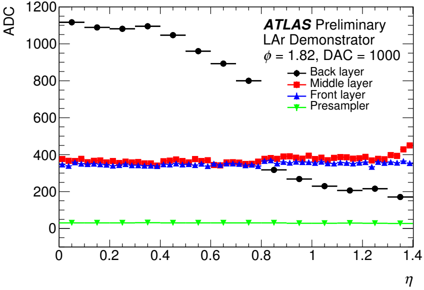
- measured quantity is ADC, digitized electronic signals
- readout only every 25 ns $\rightarrow$ red points
- measure points in between by delaying readout by steps of 1 ns

Calibration of the LAr Demonstrator

predicted energy for the super cells

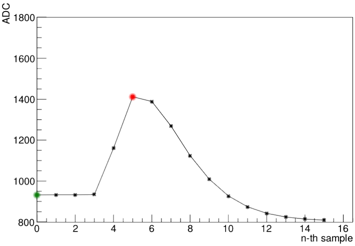


measured pulse heights in ADC



- pulses and noise in calibration have been measured
- ADC differences by estimation:

$$\mathrm{ADC}^{\mathrm{meas.}} = \mathrm{ADC}_{\mathrm{max}} - \mathrm{ADC}_{\mathrm{pedestal}}$$

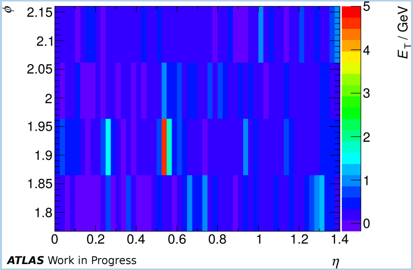
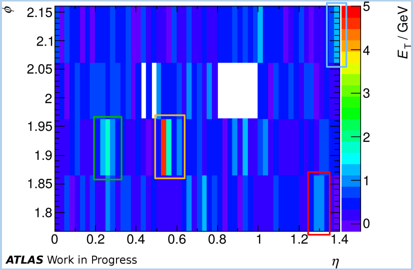


- transverse energies from calibration:

$$E_T^{\mathrm{meas.}} = \frac{E_T^{\mathrm{calib.}}}{\mathrm{ADC}^{\mathrm{calib.}}} \cdot \mathrm{ADC}^{\mathrm{meas.}}$$

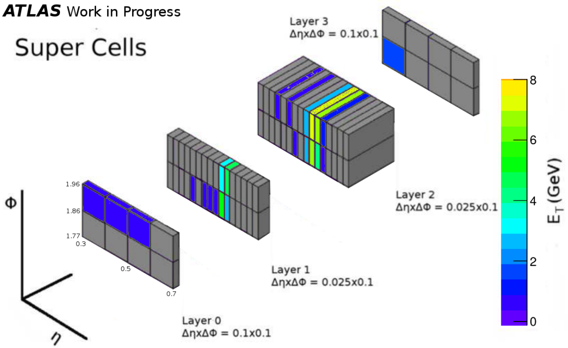
LAr Demonstrator data taking in physics collisions

- data taking with proton-proton and heavy-ion collisions since 2015
  - see if there is any wrong behaviour
- collect data triggered in LAr Demonstrator region
- compare LAr Demonstrator readout and ATLAS main readout
  - matching of events uses L1ID, BCID and trigger type
- check comparison in event signature (E_T distribution):

ATLAS main readout	LAr Demonstrator readout
	

- matched reconstructed objects in corresponding ATLAS event:
  - electrons (11.0, 5.6, 6.7 GeV)
  - photons (6.3, 4.8 GeV)

The LAr Demonstrator



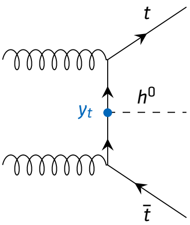
- pulses measured in calibration and collisions
- first data taking promising
- plan to use optimal filtering constants in calibration and E_T measurement
- plan for early 2018 to have final prototype installed and running in end of Run 2

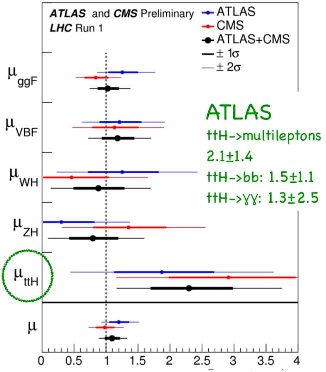
$t\bar{t}H$ with leptons in final state

- direct measurement of top Yukawa coupling to Higgs boson (y_t) via associated Higgs production with top quark pair
  - any deviation might be hint for new physics
- four main channels for final state targeting mainly $H \to WW^*$ decay:
  - 2 same-sign light leptons, τ veto (2ℓ**ss**)
  - 2 same-sign light leptons + 1 opposite-sign τ (2ℓ**ss**$+1\tau$)
  - 3 light leptons with total charge ±1 (3ℓ)
  - 4 light leptons with total charge 0 (4ℓ)
- cross sections increase from $\sqrt{s} = 8$ to 13 TeV

	$t\bar{t}H$	VV	$t\bar{t}W$	$t\bar{t}Z$	$t\bar{t}$
$\sigma^{8\text{ TeV}}$	130 fb	8220 fb	232 fb	206 fb	253 pb
$\sigma^{13\text{ TeV}}$	507 fb	14200 fb	601 fb	839 fb	831 pb
$f_{\sqrt{s}}$	3.9	1.7	2.6	4.1	3.3

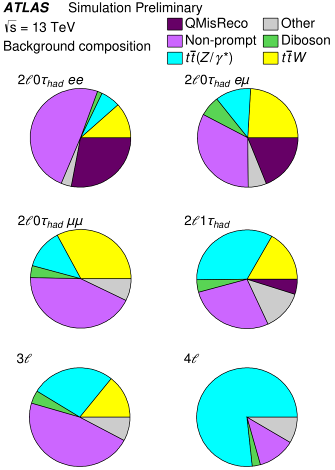
- contribute to data preparation, validation and final fit





Backgrounds

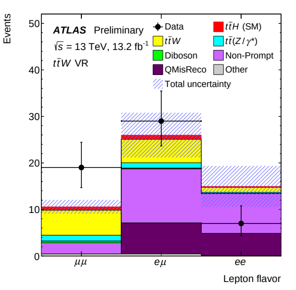
- Irreducible backgrounds (prompt light leptons):
  - mainly $t\bar{t}W$, $t\bar{t}Z$, VV (di-boson) production
  - rely on Monte Carlo (MC) simulation and theoretical uncertainties
- Reducible backgrounds:
  - have at least one lepton to be non-prompt or charge mis-reconstructed
  - non-prompt leptons from $t\bar{t}$, single-top, tW processes
  - based on data-driven estimates
- Rare backgrounds:
  - $t\bar{t}WW$, tH, tZ, $t\bar{t}t\bar{t}$, VVV, WtZ
  - rely on MC estimates and theoretical uncertainties



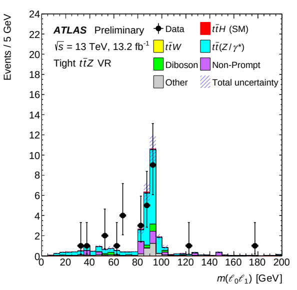
Validation regions for irreducible backgrounds

- validate, that relying on MC simulation is appropriate
- therefore construct validation regions close to signal regions

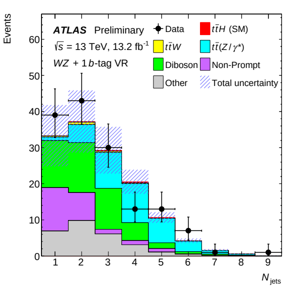
lepton flavor in $t\bar{t}W$ (2ℓss)



invariant lepton pair mass in $t\bar{t}Z$ (3ℓ)



number of jets in $WZ + 1b$-tag (3ℓ)

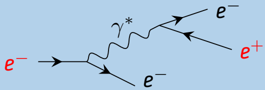


- good agreement, but poor statistics with 13.2 fb^{-1}
- in 2015 + 2016 total collected 36.5 fb^{-1} $\rightarrow$ almost factor 3

Reducible backgrounds, data-driven estimates

Electron charge mis-reconstruction

- two main sources:
  - Hard Bremsstrahlung
    ($e^{-} \rightarrow e^{-}\gamma^{*} \rightarrow e^{+}e^{-}e^{-}$)
  - slightly curved track for high-p_{T} electrons



- Probability estimated from $e^{\pm}$ of Z boson decay using Likelihood method

Non-prompt leptons background

- estimated using transfer factors

$$\theta_\ell = \frac{A}{B} = \frac{N_{\ell\ell}^{\text{Data}} - N_{\ell\ell}^{\text{Prompt}} - N_{\ell\ell}^{\text{QMisId}}}{N_{\ell\not\ell}^{\text{Data}} - N_{\ell\not\ell}^{\text{Prompt}} - N_{\ell\not\ell}^{\text{QMisId MC}}}$$

	$\ell\not\ell$	$\ell\ell$
≤ 4 jets	B	A
> 4 jets	CR	SR

$$N^{\text{Non-prompt}}(SR) = \theta_\ell \cdot N(CR)$$

Systematic uncertainties

theoretical uncertainties on prompt backgrounds

- on cross sections of signal ($t\bar{t}H$) and prompt backgrounds $\sim 10\,\%$
- acceptance for QCD scale, PDF and shower variations from MC studies

uncertainties on data-driven background estimates

- charge mis-reconstruction uncertainty anti-correlated
- Non-prompt leptons uncertainties correlated among different channels
- combined statistical uncertainties (control region size) and systematic uncertainties from MC closure test and subtracted charge mis-reconstruction

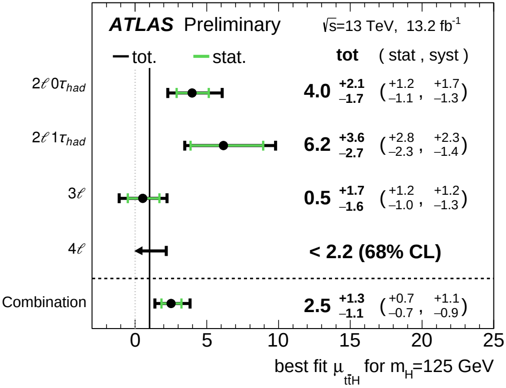
Systematic uncertainties

Detector retated uncertainties

- luminosity measurement (overall scale)
- pile-up modelling (MC to data discrepancy)
- lepton scalefactors for reconstruction, isolation and triggering (MC to data discrepancy)
- jet energy scale (19 nuisance parameters)
- jet vertex association
- jet b-tagging (24 nuisance parameters)

Fit in $t\bar{t}H \rightarrow$ leptons

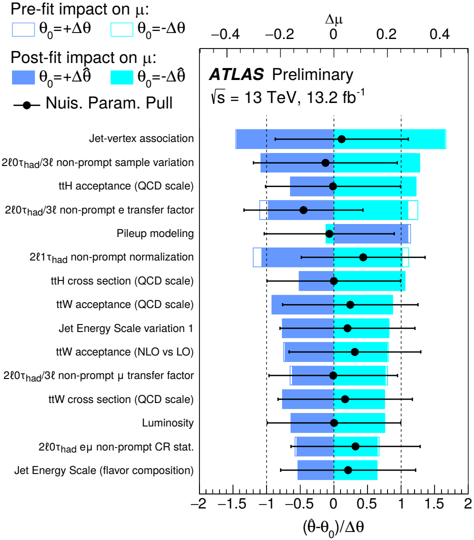
- profile likelihood ratio fit using RooFit
- parameter of interest (POI): signal strength $\mu = \frac{\text{data} - \text{SM backgrounds}}{\text{SM } t\bar{t}H \text{ prediction}}$
- nuisance parameters (NPs): theoretical and experimental systematics, systematics on data-driven fake estimates



- measured significance of ~ 2.2 (expected 1.0)

Systematic uncertainties after the fit to data

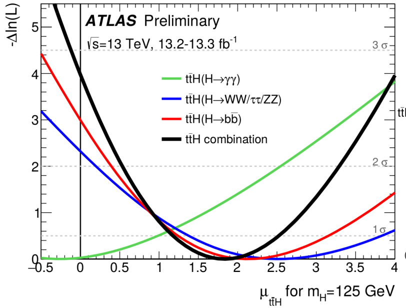
- dominating systematic uncertainties:

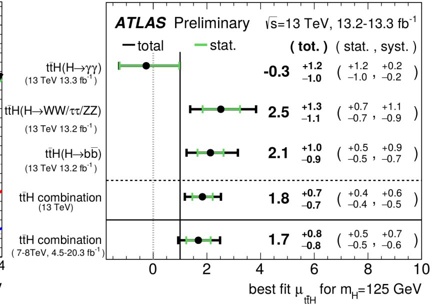


- detector-related:
  - 1 jet-vertex association
  - 5 pileup-modelling
  - 9,14 jet energy scale
  - 12 luminosity
- non-prompt estimates
  - 2 CR selection variation
  - 4,11 transfer factor for *e* and μ
  - 6 non-prompt estimate for $2\ell 1\tau_{\text{had}}$
- theoretical
  - 3 $t\bar{t}H$ scale acceptance
  - 7 $t\bar{t}H$ cross section
  - 8 $t\bar{t}W$ scale acceptance
  - 10 $t\bar{t}W$ cross section

$t\bar{t}H$ combination

- combination of $t\bar{t}H$ with $H \to b\bar{b}$, $H \to WW$ and $H \to \gamma\gamma$

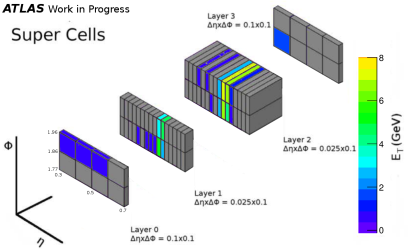




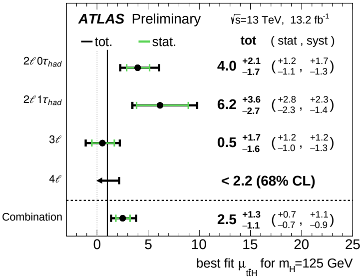
- measured significance of 2.8 (expected 1.8)

Conclusions and outlook

- successful data taking with Liquid Argon demonstrator in collisions of 2015 and 2016
  - plan to continue studying performance of future system
  - apply optimal filtering coefficients on physics pulses



- successful $t\bar{t}H \to$ multileptons analysis with published ICHEP conference note
- challenging next months:
  - improve fakes and charge mis-reconstruction measurements (MM, MVA)
  - MVA for event selection
  - shape fits?, signal region splitting?, control regions?
  - planned paper in summer 2017 with full 2015+2016 dataset



- Huge effort to find evidence for $t\bar{t}H$ production (in combination)