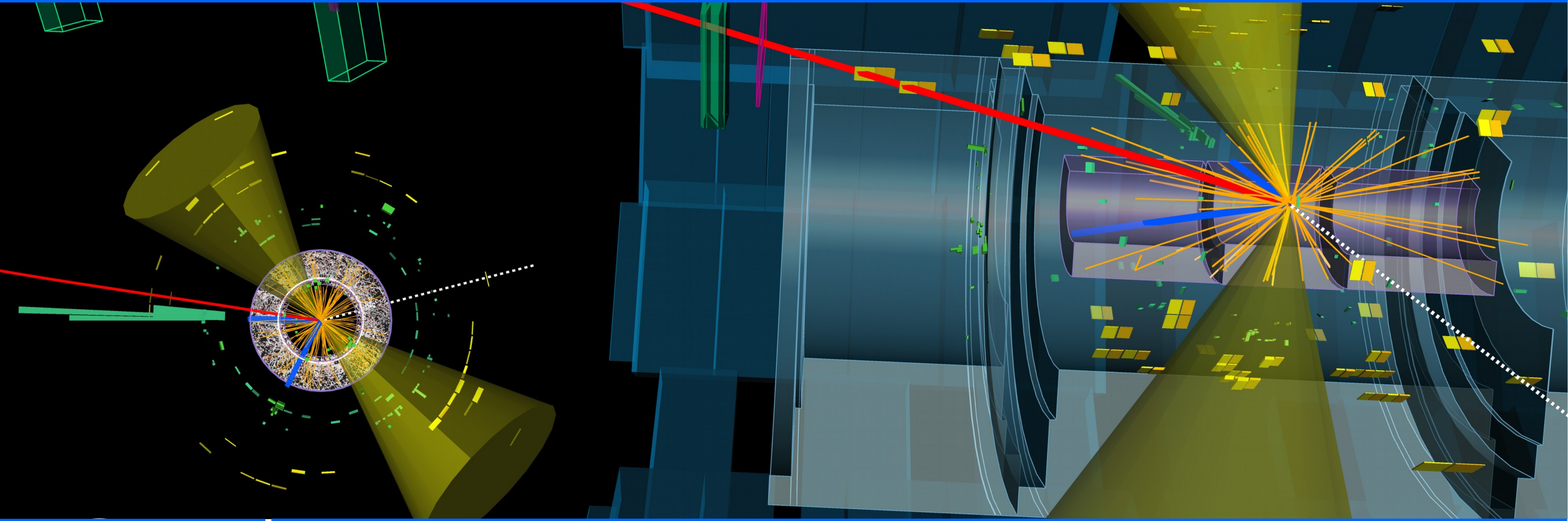
Georgian contributions in ATLAS experiment

Archil Durglishvili (HEPI TSU, Tbilisi, Georgia)
on behalf of "Tbilisi" team at ATLAS experiment



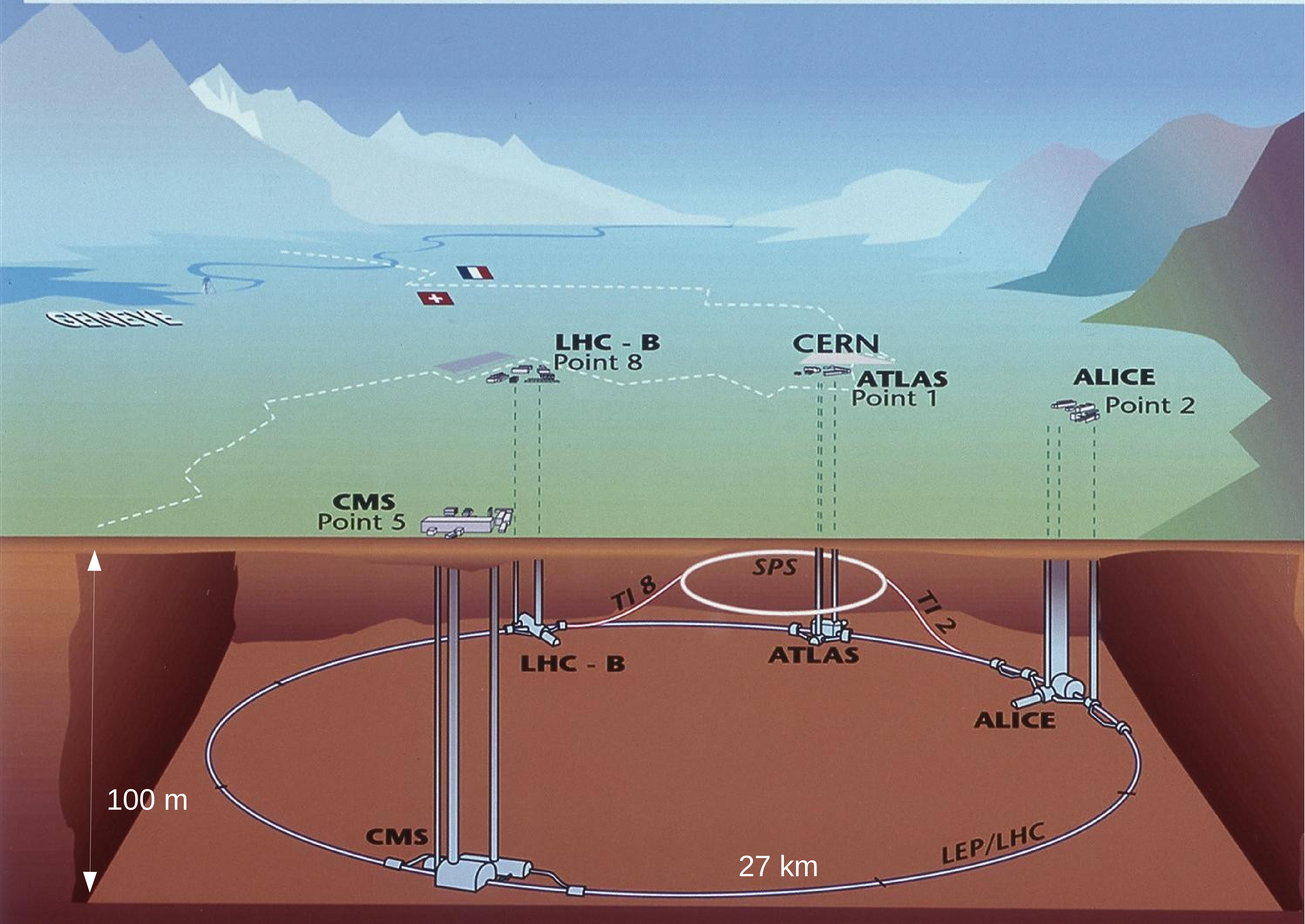
Outline

- LHC and ATLAS experiment
- Georgian contributions in ATLAS exp.
  - Tile Calorimeter
  - Top quark rare decays

LHC

Large Hadron Collider
Lake of Geneva
CMS
LHCb
Airport
ALICE
ATLAS

Overall view of the LHC experiments.



ATLAS physics program

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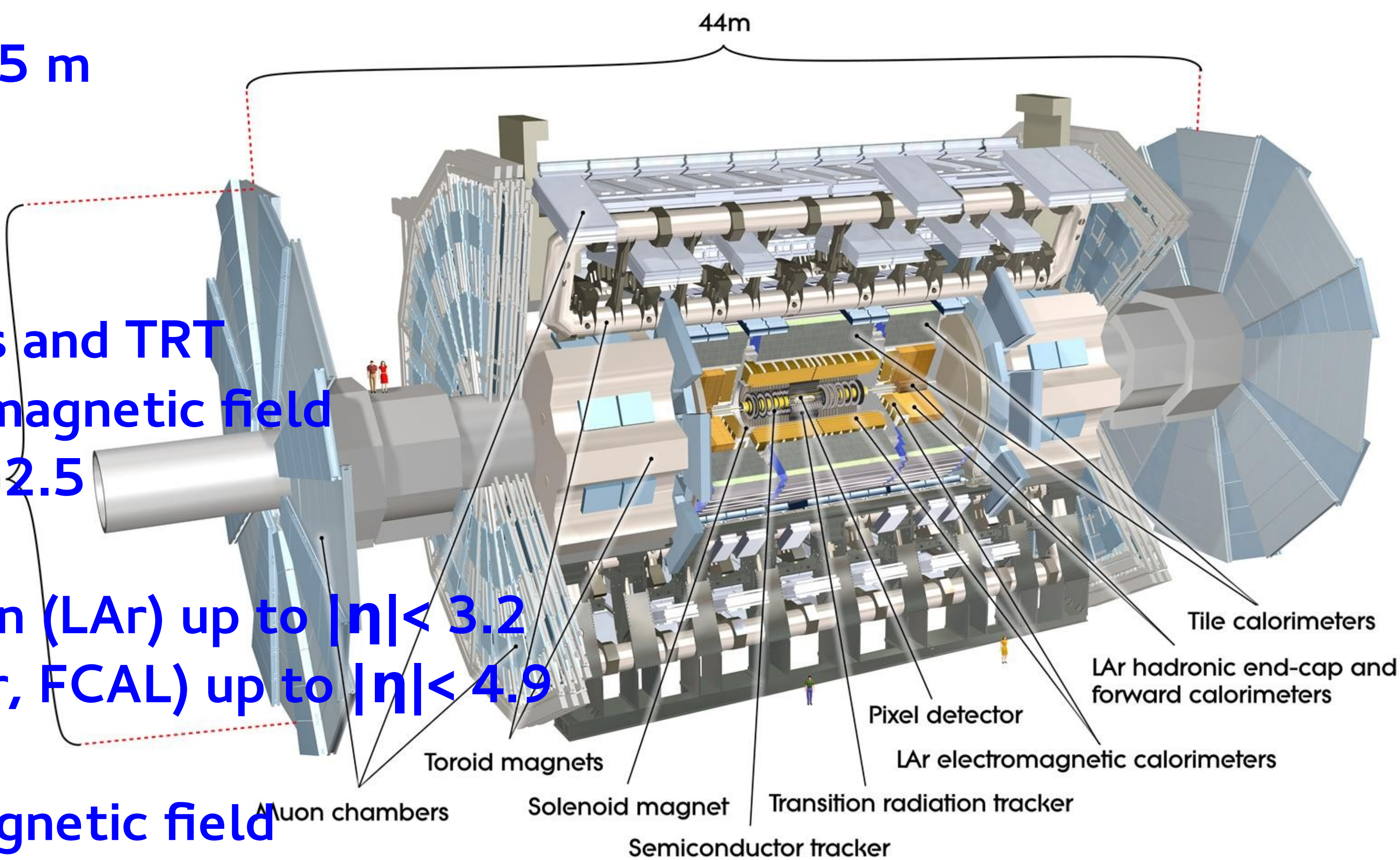
ATLAS EXPERIMENT

- Higgs Bosons
- Supersymmetric Particles
- Detailed studies of the top quark
- Compositeness of the fermions
- The investigations of CP-violation in B- decays
- Search and discovery of Extra Dimensions (ADD Theory)
- Black Holes

ATLAS detector



Properties
- L ~ 46 m, d ~ 25 m
- 7000 tons
- 5000 persons

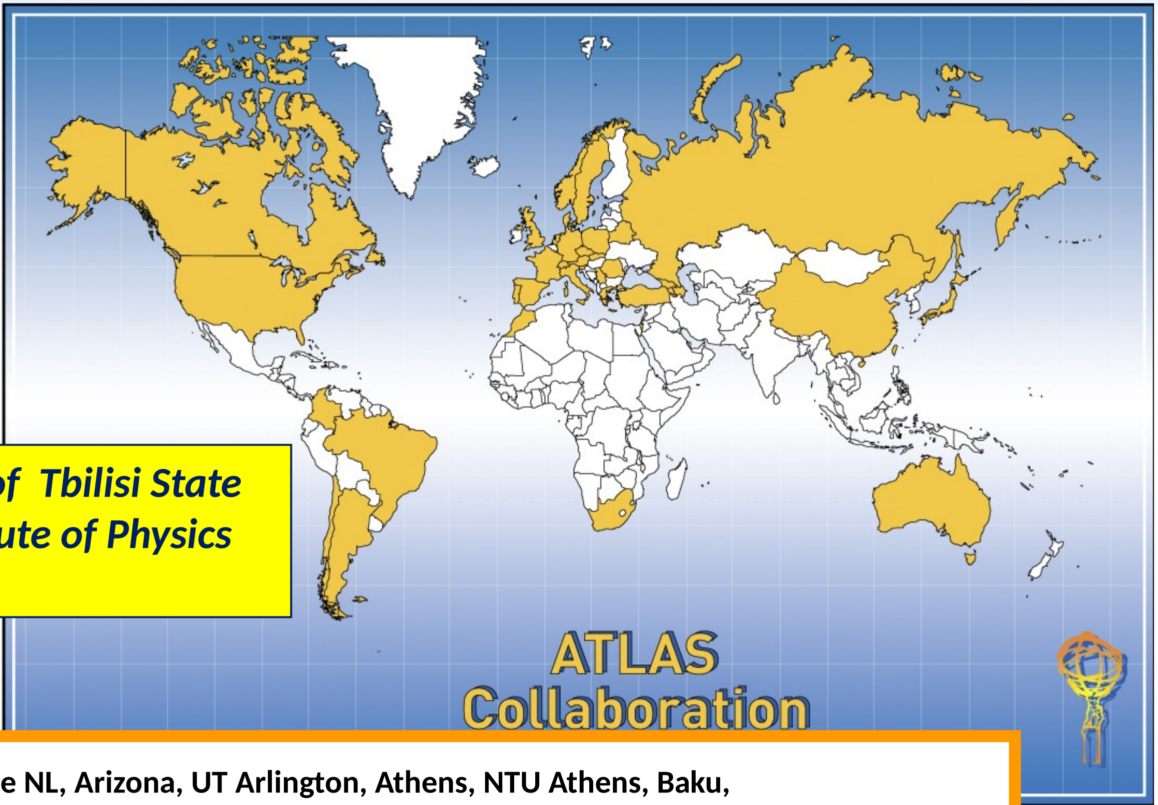
Inner Detector
- Pixels, Si strips and TRT
- 2T solenoidal magnetic field
- Coverage $|\eta| < 2.5$

Calorimeter
- EM Liquid argon (LAr) up to $|\eta| < 3.2$
- Had. (Tiles, LAr, FCAL) up to $|\eta| < 4.9$

Muon System
- 4T toroidal magnetic field
- Coverage $|\eta| < 2.7$

ATLAS Collaboration

38 Countries
175 Institutions
3000 Scientific participants total
(1000 Students)



The joint team from High Energy Physics Institute of Tbilisi State University (HEPI TSU) and E. Andronikashvili Institute of Physics became ATLAS member since 1994

Albany, Alberta, NIKHEF Amsterdam, Ankara, LAPP Annecy, Argonne NL, Arizona, UT Arlington, Athens, NTU Athens, Baku, IFAE Barcelona, Belgrade, Bergen, Berkeley LBL and UC, HU Berlin, Bern, Birmingham, UAN Bogota, Bologna, Bonn, Boston, Brandeis, Brasil Cluster, Bratislava/SAS Kosice, Brookhaven NL, Buenos Aires, Bucharest, Cambridge, Carleton, CERN, Chinese Cluster, Chicago, Chile, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza, AGH UST Cracow, IFJ PAN Cracow, SMU Dallas, UT Dallas, DESY, Dortmund, TU Dresden, JINR Dubna, Duke, Edinburgh, Frascati, Freiburg, Geneva, Genoa, Giessen, Glasgow, Göttingen, LPSC Grenoble, Technion Haifa, Hampton, Harvard, Heidelberg, Hiroshima IT, Indiana, Innsbruck, Iowa SU, Iowa, UC Irvine, Istanbul Bogazici, KEK, Kobe, Kyoto, Kyoto UE, Lancaster, UN La Plata, Lecce, Lisbon LIP, Liverpool, Ljubljana, QMW London, RHBNC London, UC London, Lund, UA Madrid, Mainz, Manchester, CPPM Marseille, Massachusetts, MIT, Melbourne, Michigan, Michigan SU, Milano, Minsk NAS, Minsk NCPHEP, Montreal, McGill Montreal, RUPHE Morocco, FIAN Moscow, ITEP Moscow, MEPhI Moscow, MSU Moscow, Munich LMU, MPI Munich, Nagasaki IAS, Nagoya, Naples, New Mexico, New York, Nijmegen, BINP Novosibirsk, Ohio SU, Okayama, Oklahoma, Oklahoma SU, Olomouc, Oregon, LAL Orsay, Osaka, Oslo, Oxford, Paris VI and VII, Pavia, Pennsylvania, Pisa, Pittsburgh, CAS Prague, CU Prague, TU Prague, IHEP Protvino, Regina, Rome I, Rome II, Rome III, Rutherford Appleton Laboratory, DAPNIA Saclay, Santa Cruz UC, Sheffield, Shinshu, Siegen, Simon Fraser Burnaby, SLAC, NPI Petersburg, Stockholm, KTH Stockholm, Stony Brook, Sydney, Sussex, AS Taipei, Tbilisi, Tel Aviv, Thessaloniki, Tokyo ICEPP, Tokyo MU, Tokyo Tech, Toronto, TRIUMF, Tsukuba, Tufts, Udine/ICTP, Uppsala, UI Urbana, Valencia, UBC Vancouver, Victoria, Waseda, Washington, Weizmann Rehovot, FH Wiener Neustadt, Wisconsin, Wuppertal, Würzburg, Yale, Yerevan

Georgian Joint Group "Tbilisi" in ATLAS

Team Leader Prof. J. Khubua
Team contact person at CERN Dr. I. Minashvili

1	Jemal Khubua	(HEPI TSU)
2	Tamar Djobava	(HEPI TSU)
3	Irakli Minashvili	(JINR/HEPI TSU)
4	Maia Mosidze	(HEPI TSU)
5	Nugzar Mosulishvili	(HEPI TSU)
6	Edisher Tskhadadze	(E. Andronikashvili Institute of Physics of TSU)
7	Juansher Jejelava	(E. Andronikashvili Institute of Physics of TSU)
8	Archil Durglishvili	(PhD Student, HEPI TSU)
9	Tamar Zaqareishvili	(Masters program student, TSU)
10	Bakar Chargeishvili	(Bachelor program student, TSU)

Activities of Georgian physicists before start-up of ATLAS

E. Andronikashvili Institute of Physics of TSU

Muon Detector
Dubna – Tbilisi

- Drift tubes production and tests
- BMS station preparation for installation in the Barrel
- Muon chamber test in the Barrel

HEPI TSU

- Test beam and offline analysis
- Transition-Radiation Tracker (TRT)

- top-quark rare decays ($t \to Zq$, $t \to Hq$)
- SUSY-like signal from two gluinos gg→ğğ

Dubna – Tbilisi

Tile Calorimeter
Dubna – Tbilisi

- ATLAS CALORIMETER Hadronic Calibration
- Jet/E_T (missed) reconstruction
- Tile Calorimeter Cells e/γ calibration
- DAQ software
- Tile Calorimeter simulation in GEANT 4
- Data Control System of TileCal (DCS)

Current activities of HEPI at ATLAS

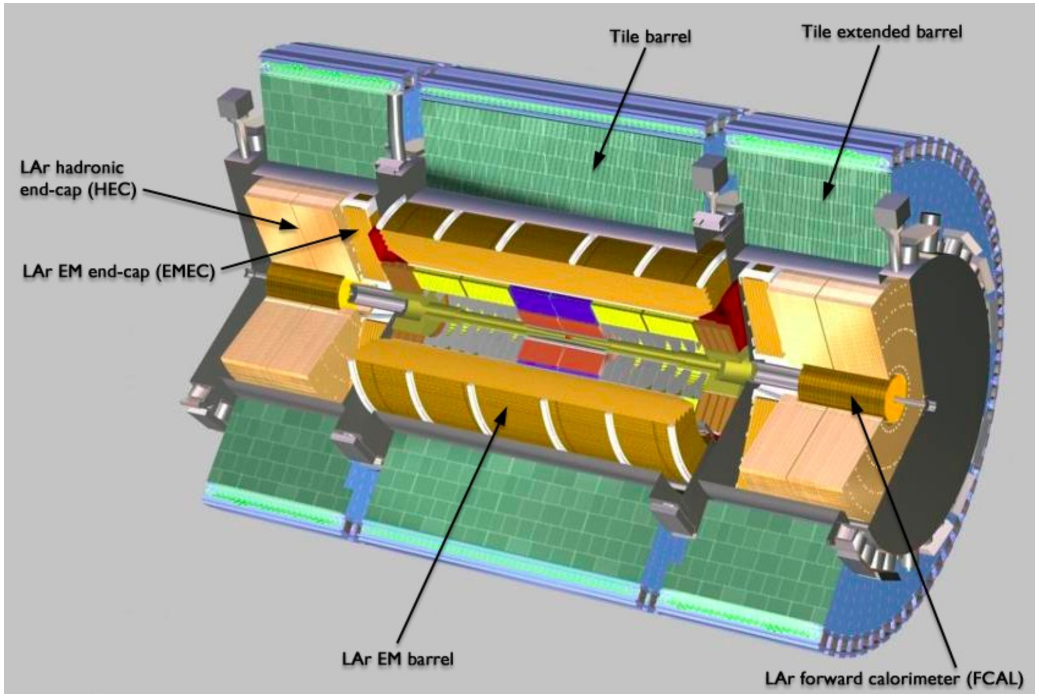
The current activities of HEPI at ATLAS experiment includes the following directions:

- <u>Tile calorimeter</u>
  - Maintenance and consolidation works.
  - Operation (ACR shifts, Tile Calorimeter Data Quality Leader and Validator shifts).
  - Tile Calorimeter Demonstrator Test Beam shifts and recorded data analysis.
  - Understand the role of Tile Calorimeter E4 crack scintillators in the physics objects performance and try to improve it.
    - Jets performance (work in progress)
    - E/gamma performance (completed)
    - Propose an improved layout of gap/crack scintillators for Phase I upgrade
- <u>Top Quark Physics</u>
  - Study of Flavor Changing Neutral Current (FCNC) top quark decays $t \rightarrow Zq$ (q=u,c quarks)

Tile Calorimeter

The components of the ATLAS calorimetry system are:
the Liquid Argon (LAr) Calorimeter and the Tile Hadronic Calorimeter.

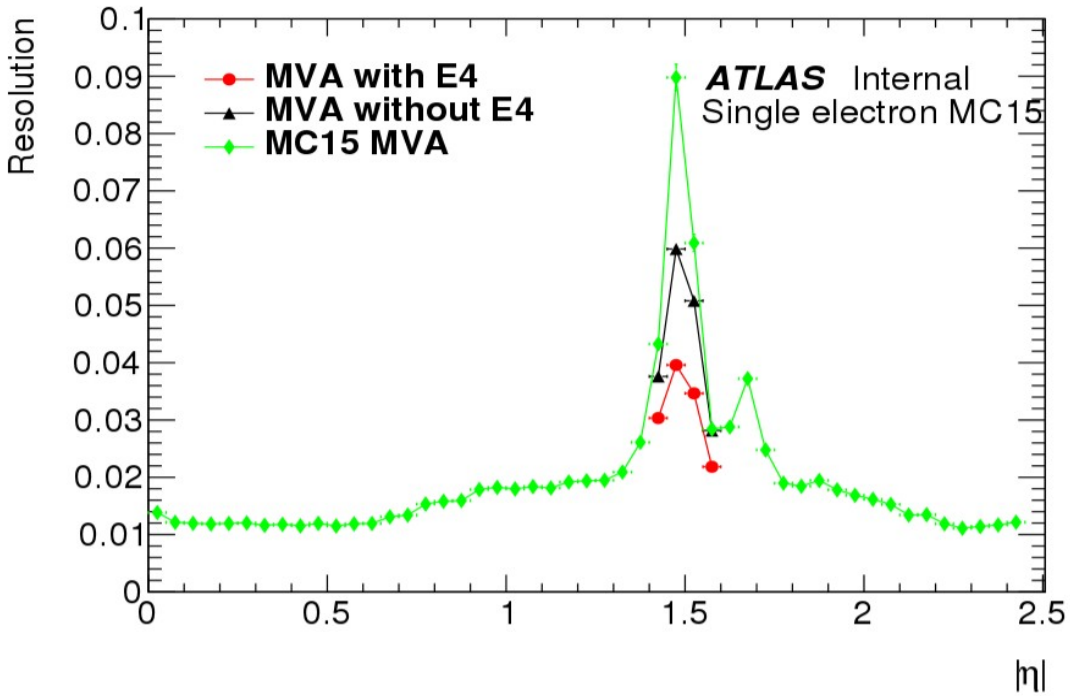
- Barrel made of 64 modules, each 5.6m long and 20 tonnes
- Each endcap has 64 modules, each 2.6m long and 16 tonnes
- 500,000 plastic scintillator tiles



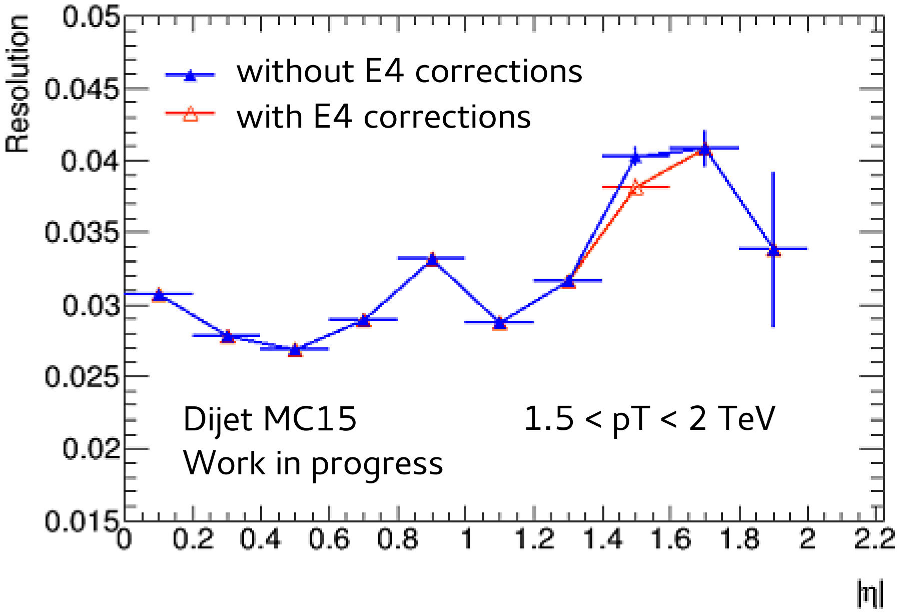
- In the gap between barrel and ext. barrel there are gap/crack scintillators (E-cells)
- E4 scintillators are between EM barrel and EM endcap

Study of Tile Calorimeter E4 crack scintillators

- E/gamma resolution and jets response degrades in the region eta ~1.5 where active-to-passive material ratio is low
  - We have proposed a new calibration based on Multivariate Analysis techniques that includes E4 crack scintillators
- E4 crack scintillators improve the e/g performance in the crack region $1.4 < |\eta| < 1.6$
- ATL-PHYS-INT-2016-008

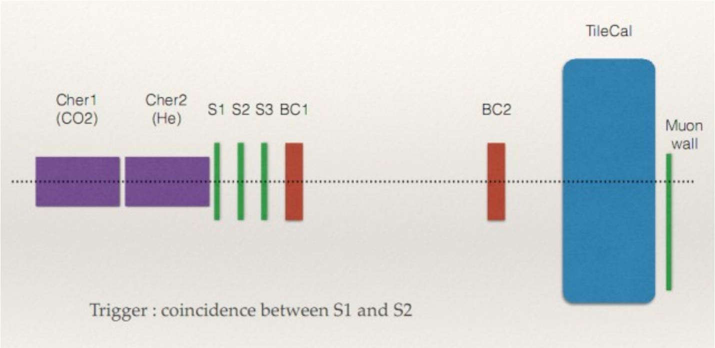


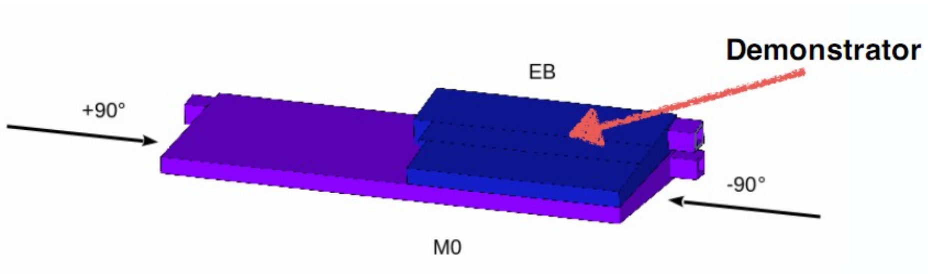
- Additional pT corrections based on E4 crack scintillators give a noticeable improvement in jet resolution (work in progress)



Tile Calorimeter Demonstrator Test Beam data analysis

- ATLAS Tile Calorimeter Demonstrator prototype have been developed for the Phase 2 Upgrade. It is a hybrid prototype associated to one TileCal module to be integrated into ATLAS for evaluation of the Phase 2 new electronics architecture. It provides digital trigger, but with the addition of backward compatible analog trigger cables to send the analog differential signal to the summing card so that it can be used in the current analog trigger but in Phase 2 upgrade this analog trigger will be removed.
- The Demonstrator has been tested with beams of different particles (π, e, μ) at different incident angles (20^{o}, 90^{o}, -90^{o}) and energies (50, 150, 180 GeV). The features to be studied are the hadronic energy response, resolution, linearity.





- Participating in the Test Beam data analysis:
  - **Inter-calibration of LBC (barrel) with 90^{o} muons (180 GeV)**
  - **Study of the muon response in Extended Barrel (180 GeV)**

Top quark rare decays

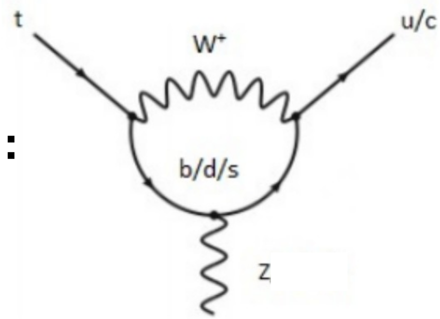
- The top quark has been discovered at the proton-antiproton collider Tevatron in 1995 by two collaborations CDF and D0
- The top quark is the heaviest elementary particle found so far with the mass ~173 GeV
- In the SM top quark **F**lavour **C**hanging **N**eutral **C**urrent (FCNC) decays are forbidden at tree level and have much smaller BR than the dominant decay mode (t→bW) at one loop level:

Process	SM	QS	2HDM	FC 2HDM	MSSM	$\not{R}$ SUSY	RS
$t \to qZ$	$\sim 10^{-14}$	$\sim 10^{-4}$	$\sim 10^{-6}$	$\sim 10^{-10}$	$\sim 10^{-7}$	$\sim 10^{-5}$	$\sim 10^{-5}$

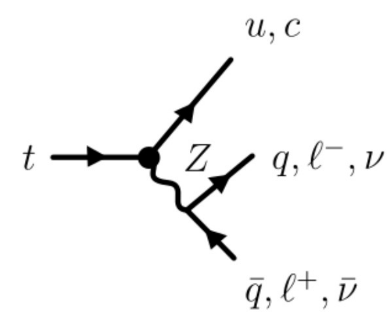
- A search for top quark **FCNC** decays in $t\bar{t}$ production
  - One top decays through FCNC (t→qZ) and other through SM dominant mode (t→bW)
  - Data collected by the ATLAS detector during 2012 from proton-proton (pp) collisions at the Large Hadron Collider at a centre-of-mass energy of √s=8 TeV, corresponding to an integrated luminosity of 20.3 fb^{-1}
- Considering dilepton channel
  - Leptonic decay Z bosons
  - Hadronic decay of W boson
  - Final state topology: 2 isolated leptons and at least 4 jets
- The Georgian ATLAS team has been working on study of top FCNC decays since many years: *Eur. Phys. J. C* 52 (2007) 999-1019

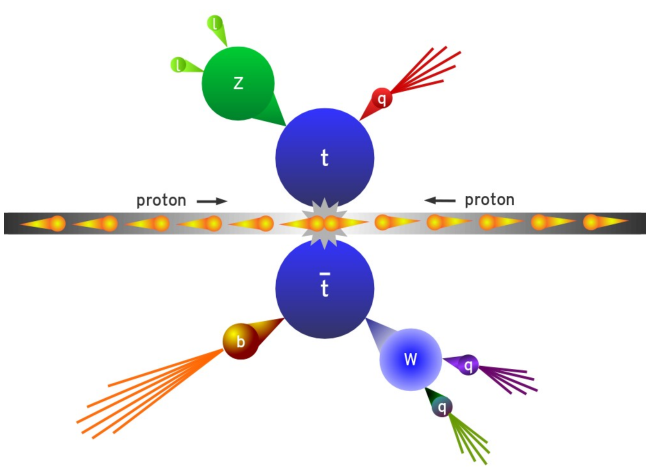
t→qZ FCNC

SM:



BSM:





Analysis strategy

- **Cut based selection**
- **Event reconstruction:**
  - χ^2 – minimization
- **Signal region:**
  - Arbitrary cuts on the reconstructed masses of the tops and W boson
- **Background evaluation:**
  - Backgrounds with real leptons were estimated using MC
  - Fake leptons background was estimated using Matrix Method
  - Dominant background (Z+jets) was normalized using the data
- **Optimization of $s/\sqrt{b}$:**
  - Multivariate discriminant was built and the cut was set
- **Estimation of systematic uncertainties:**
  - Bootstrap method was applied
- **Limit evaluation of the BR($t \to qZ$):**
  - 95% CL upper limit using CLs method as implemented in *RooStats*

Events selection

Preselection:

- GRL and corrupted events(data), LAr veto(both MC and data), BadJets(both MC and data)
- Trigger and trigger matching: electron or muon
- At least one primary vertex with 5 or more tracks
- Cosmics veto
- e/μ overlap removal
- One pair of same flavour and opposite charged leptons from the same vertex
- $|m_Z^{reco} - m_Z^{PDG}| < 10$ GeV
- At least one jet

Final selection:

- Exactly one b-tagged jet
- At least 4 jets with $p_T > 30$ GeV and $|\eta| < 2.5$ including b-tagged jet
- $|m_W^{reco} - 80.4| < 30$ GeV & $|m_{tops}^{reco} - 172.5| < 40$ GeV

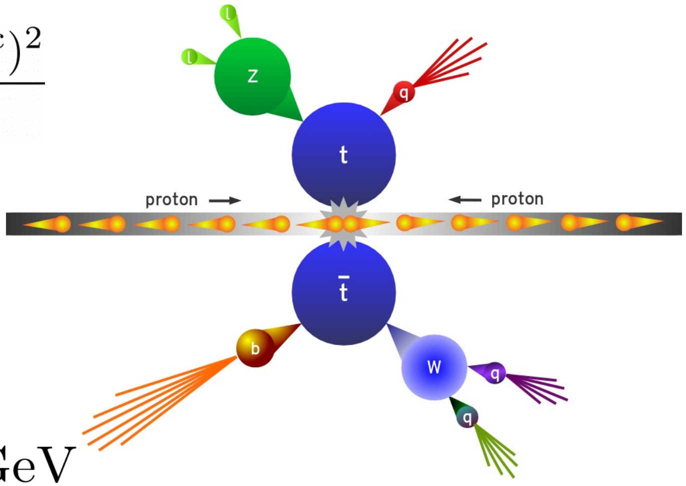
Event reconstruction

Event reconstruction

- Events are reconstructed using a χ² minimization over the jets combination

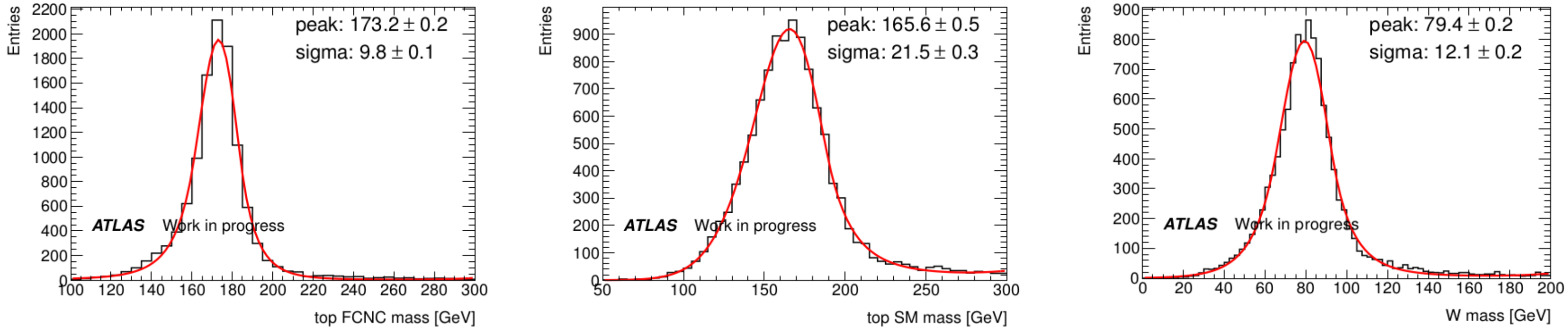
$$\chi^2 = \frac{(m_{\mathrm{t}} - m^{\mathrm{rec}}_{\mathrm{tFCNC}})^2}{\sigma^2_{\mathrm{tFCNC}}} + \frac{(m_{\mathrm{t}} - m^{\mathrm{rec}}_{\mathrm{tSM}})^2}{\sigma^2_{\mathrm{tSM}}} + \frac{(m_{\mathrm{W}} - m^{\mathrm{rec}}_{\mathrm{W}})^2}{\sigma^2_{\mathrm{W}}}$$

- b-quark is set to only b-tagged jet
- $m_{\mathrm{t}} = 172.5\ \mathrm{GeV};\ m_{\mathrm{W}} = 80.4\ \mathrm{GeV}$
- Values of sigmas are extracted from Bukin fit
- $\sigma_{\mathrm{tFCNC}} = 9.8\ \mathrm{GeV};\ \sigma_{\mathrm{tSM}} = 21.5\ \mathrm{GeV};\ \sigma_{\mathrm{W}} = 12.1\ \mathrm{GeV}$



Bukin fits

- Top quarks and W boson are reconstructed from the objects which are closest to the generated true particles



Background evaluation

Real leptons

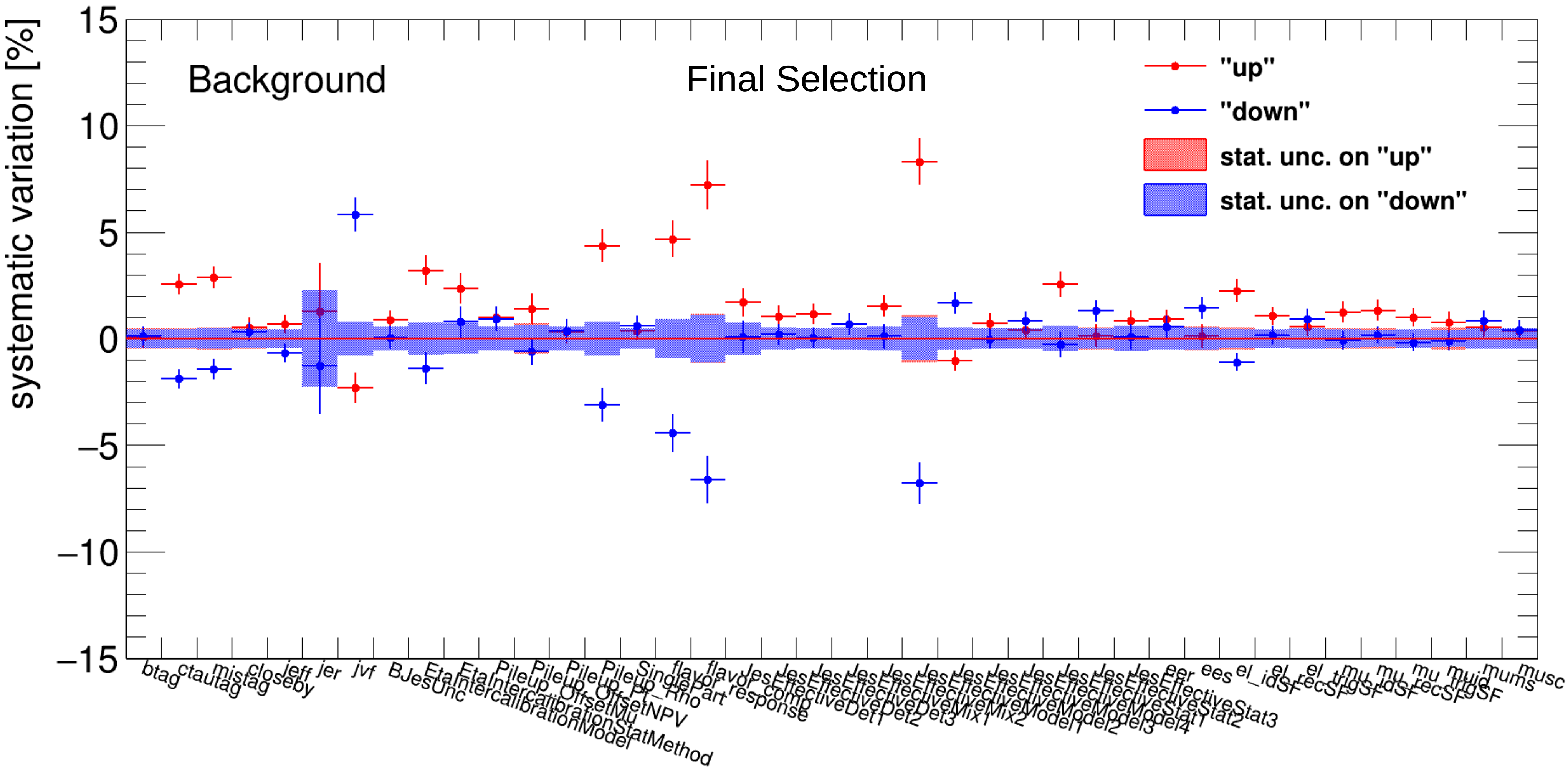
- All the processes with at least 2 isolated leptons in the signature could be the background for $t\bar{t} \to bWqZ$ ($W \to jj$, $Z \to ll$) events
- **Dominant background is from Z+jets production, its contribution is ~75%**
- Such a backgrounds were estimated using MC

Fake leptons

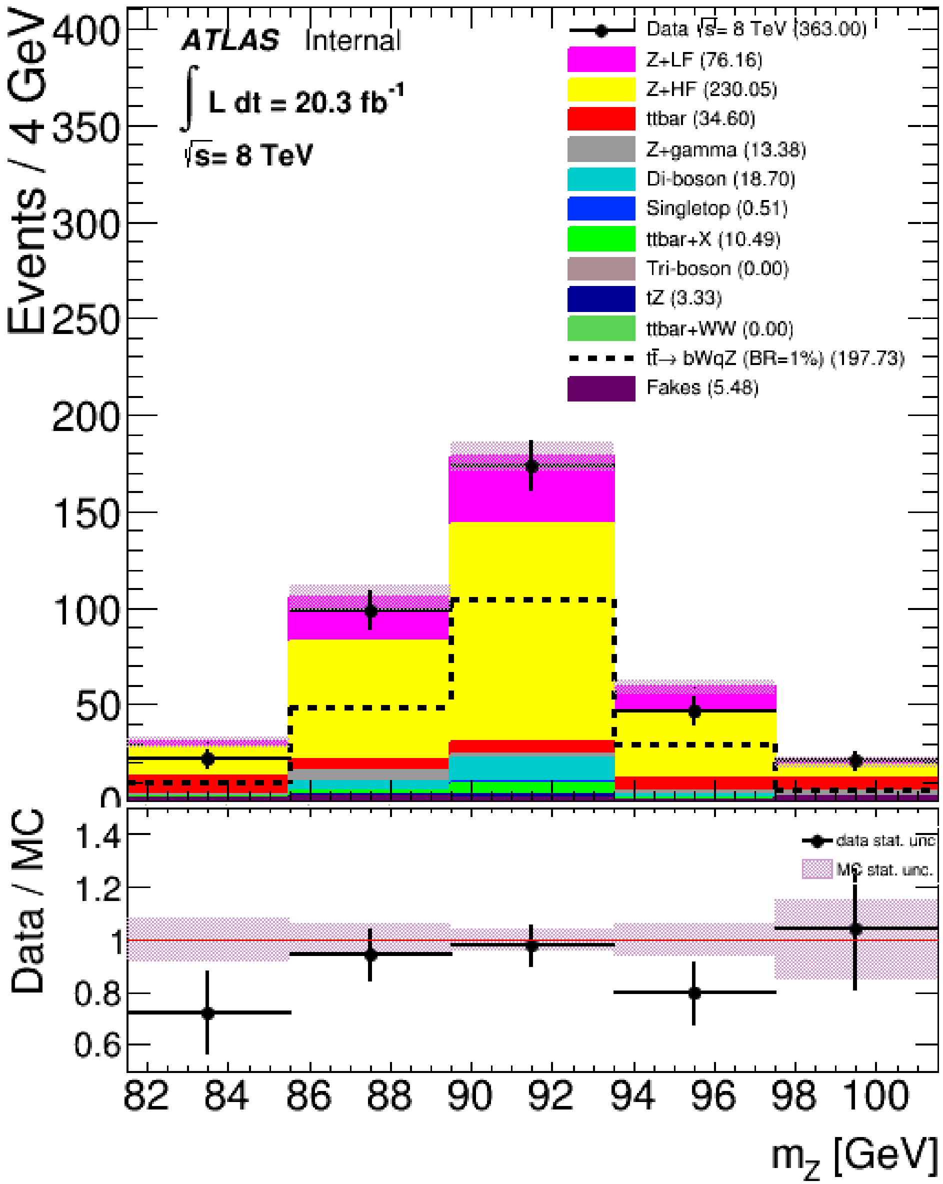
- Background coming from events with fake leptons is negligible, since we select the e^-e^+ and $\mu^-\mu^+$ events with the dilepton invariant mass within Z boson mass window: $|m_{ll}^{reco} - m_Z^{PDG}| < \mathbf{10}$ GeV
- Such a background was estimated using a Matrix Method

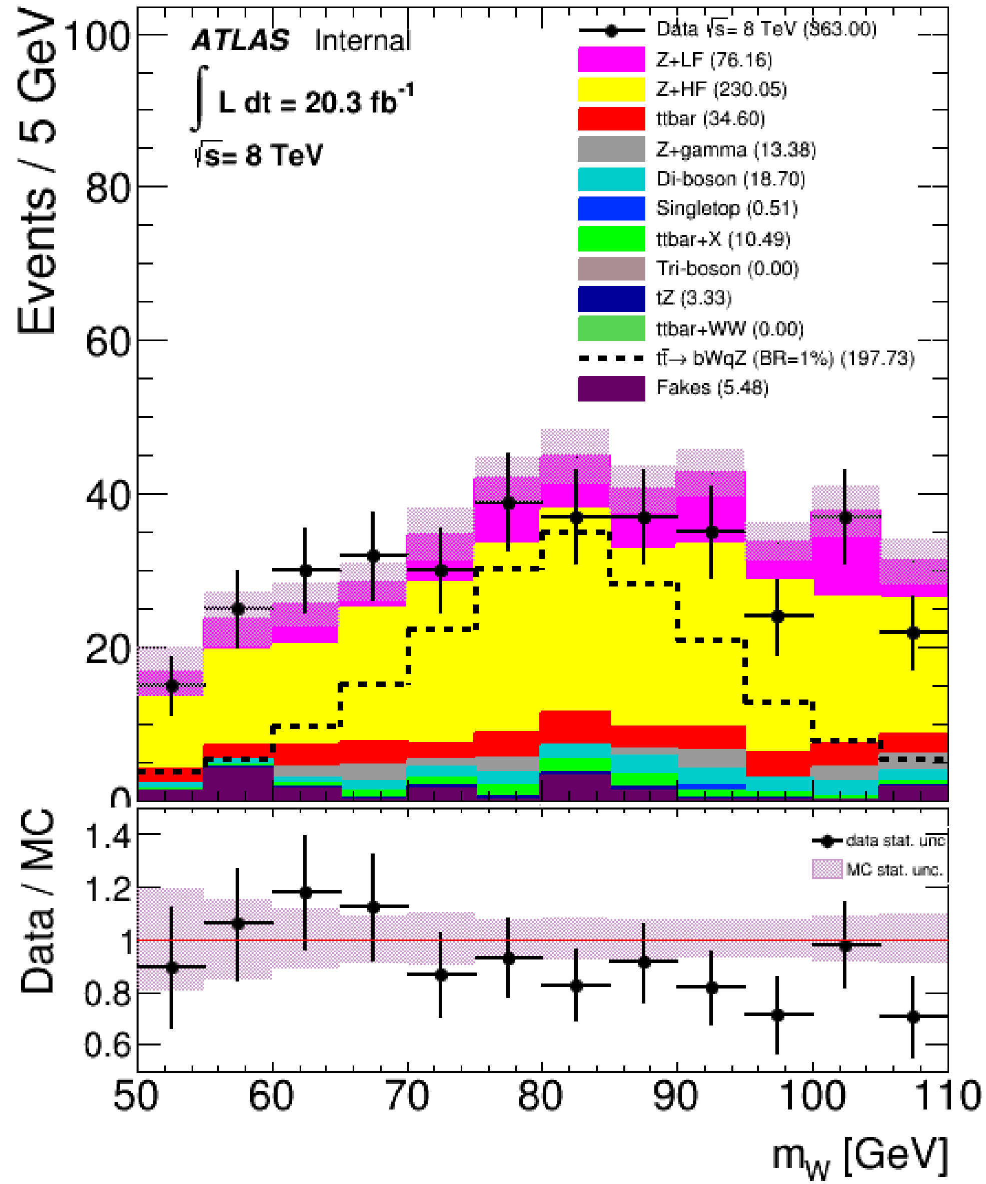
Systematic uncertainties

- Detector modelling systematic source is considered as significant with respect to MC statistics if its "up" and "down" variation are above the statistical uncertainty evaluated using the bootstrap method.

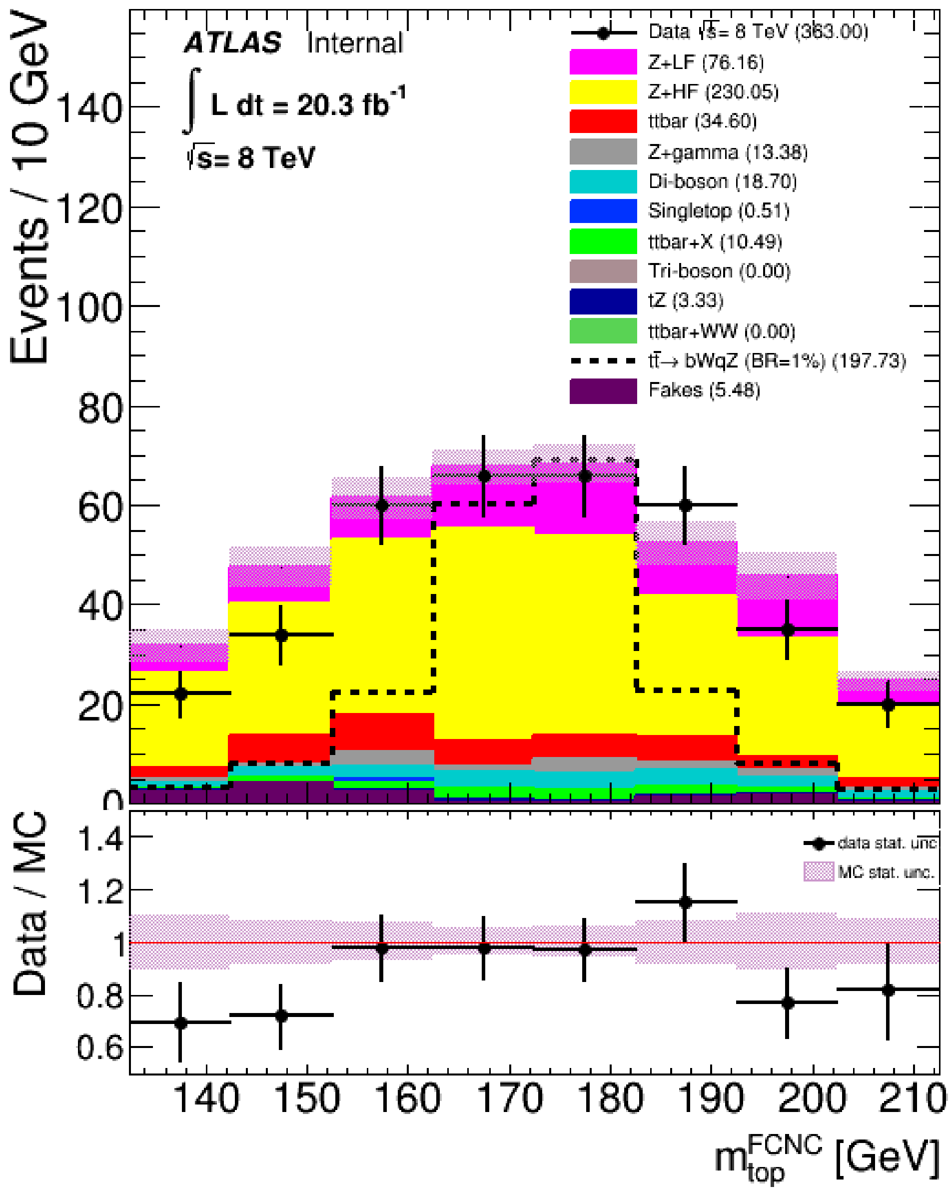


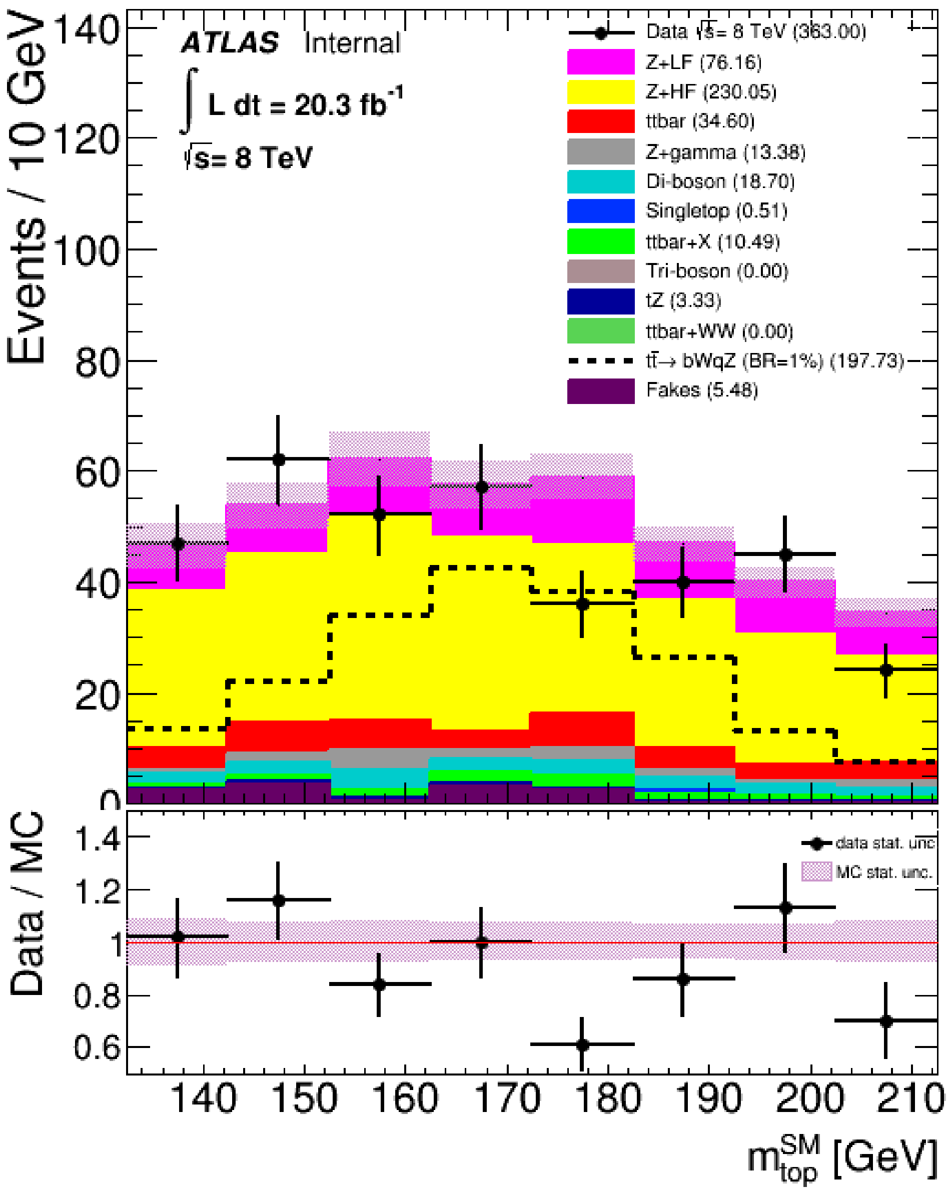
Distributions after the final selection





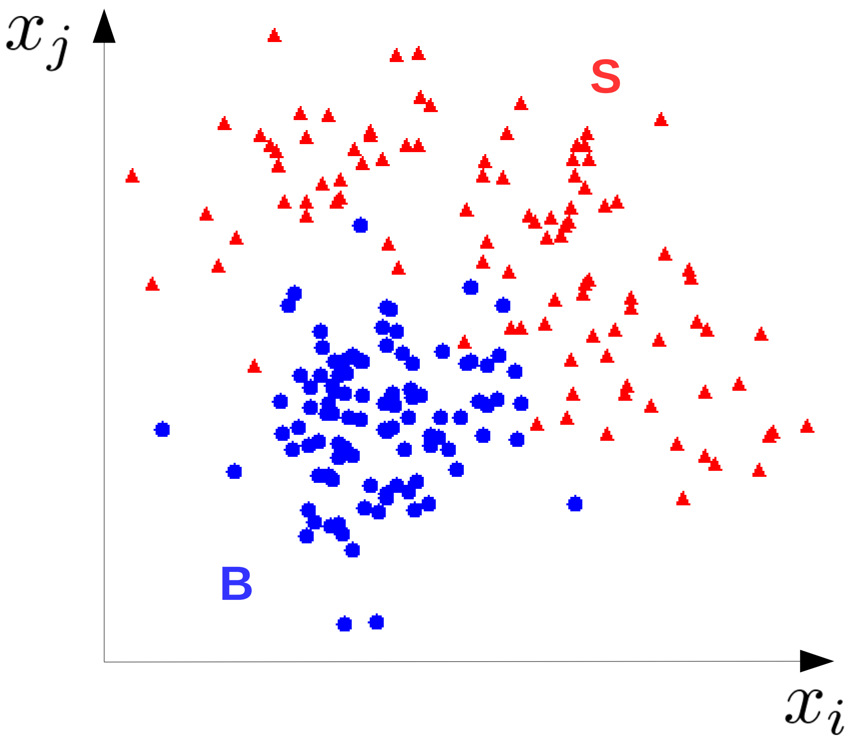
Distributions after the final selection





Multivariate discriminant analysis

- Goal of the multivariate discriminant analysis is to optimize the discrimination of the signal and background events (optimize the significance of signal s/√b)
- Strategy of the multivariate discriminant analysis:
  - Choose the uncorrelated physical variables which have a different distributions for the signal and background events
  - Construct the multivariate discriminant
  - Set the cut on the multivariate discriminant



Signal and background probabilities

- Suppose for each event we measure a set of uncorrelated variables
$$\vec{x} = (x_1, x_2, ..., x_n)$$
$$x_1 = m_{ll},$$
$$x_2 = \text{jet } p_{\mathrm{T}},$$
$$x_3 = H_{\mathrm{T}}, \ \ldots$$
- Each variable for signal and background events have a p.d.f.:
$$p_s^i(x_i) \quad \text{and} \quad p_b^i(x_i)$$
- Probability that we get the certain values for the set of variables from background event is
$$P_b(\vec{x}) = \prod_{i=1}^{n} p_b^i(x_i)$$
and from signal event
$$P_s(\vec{x}) = \prod_{i=1}^{n} p_s^i(x_i)$$

Multivariate discriminant

- Suppose we got the certain values for the set of uncorrelated variables in a certain event

$$\vec{X} = (X_1, X_2, ..., X_n)$$

- We need to decide if it is signal-like or background-like event
- If the signal probability

$$P_s(\vec{X})$$

is higher than the background probability

$$P_b(\vec{X})$$

then this event is signal-like event, or if

$$P_s(\vec{X}) < P_b(\vec{X})$$

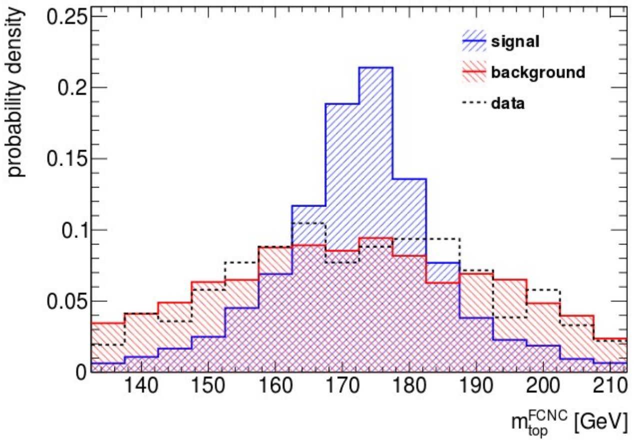
then it is background-like event

- So, the multivariate discriminant can be the following

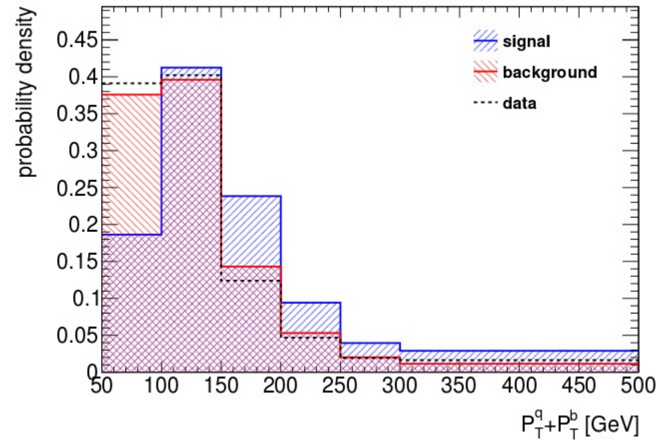
$$L_R = log\left(\frac{P_s}{P_b}\right)$$

Chosen physical variables

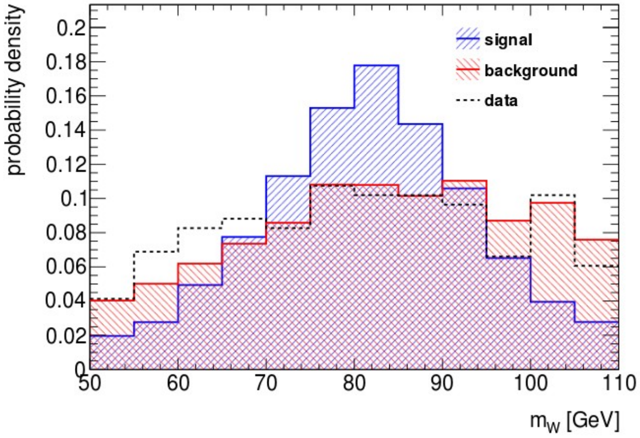
1. Mass of the reconstructed top FCNC



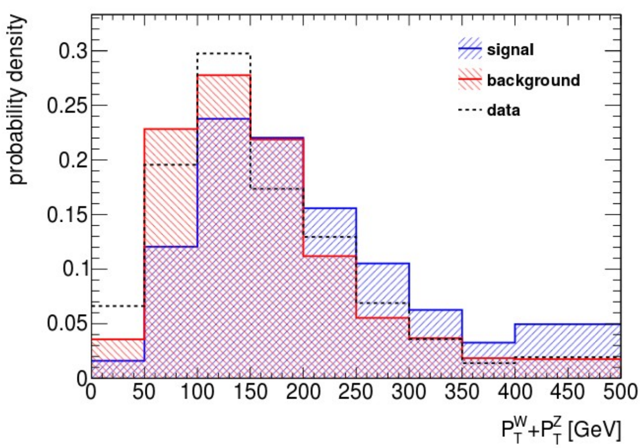
2. Sum of the transverse momentum of the reconstructed q and b quarks



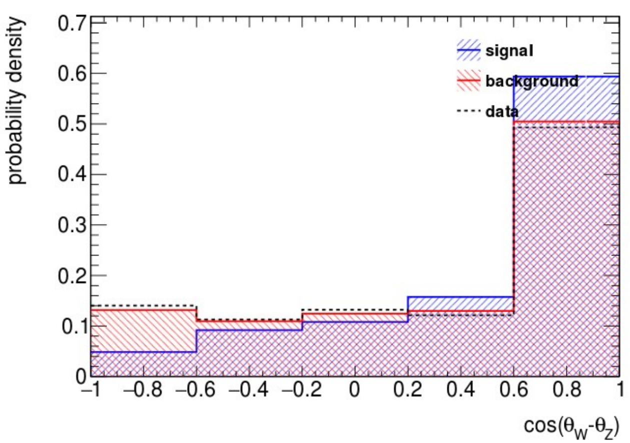
3. Mass of the reconstructed W boson

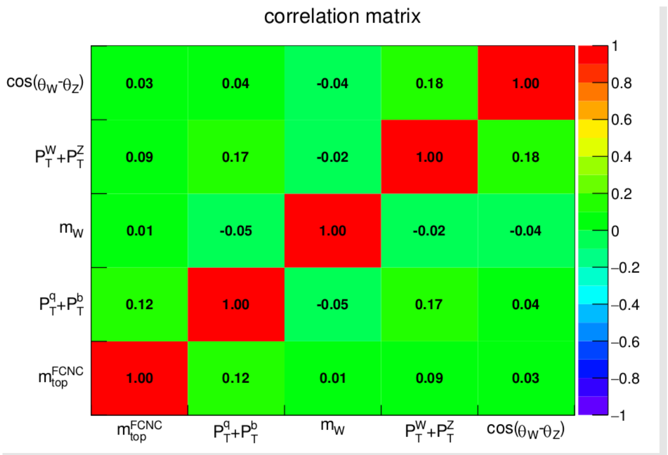


4. Sum of the transverse momentum of the reconstructed W and Z bosons



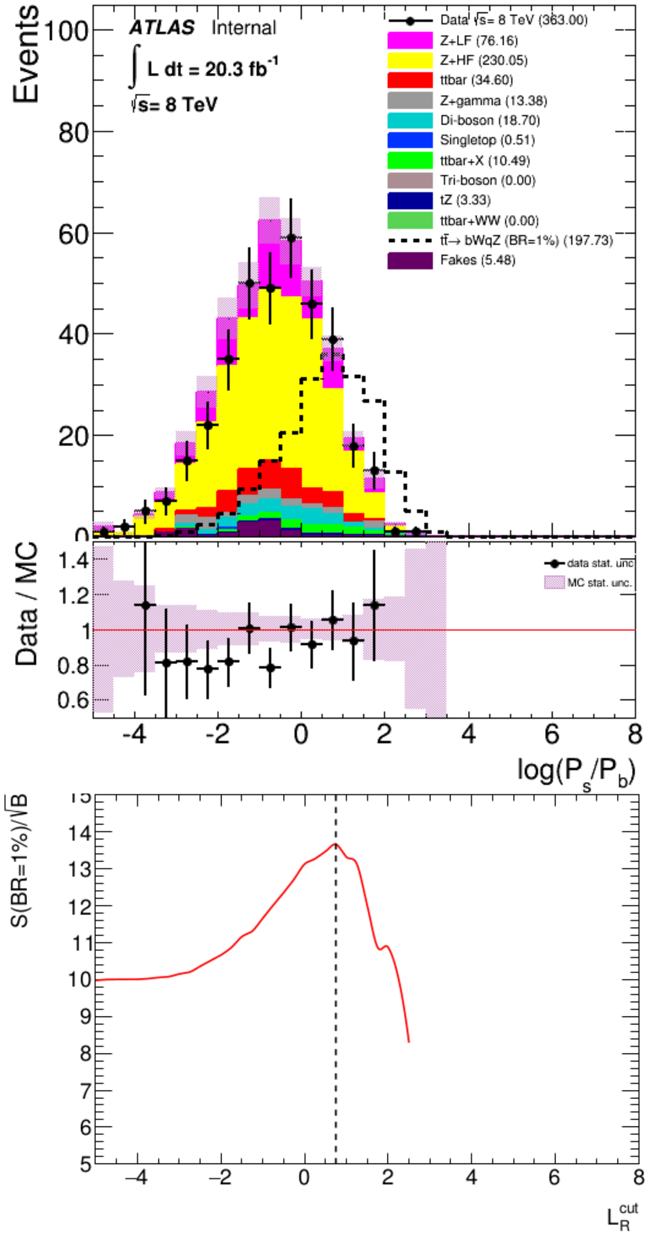
5. Cosine of the angle between the reconstructed W and Z bosons





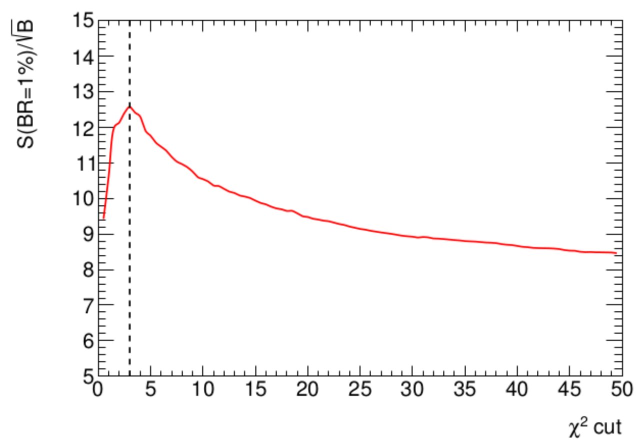
Optimization of S/√B

Multivariate discriminant



- The cut on the multivariate discriminant was placed such as the value of S/√B to be maximum.
- Cut: $L_R > 0.75$
- S(BR=0.01)/√B = **13.66**

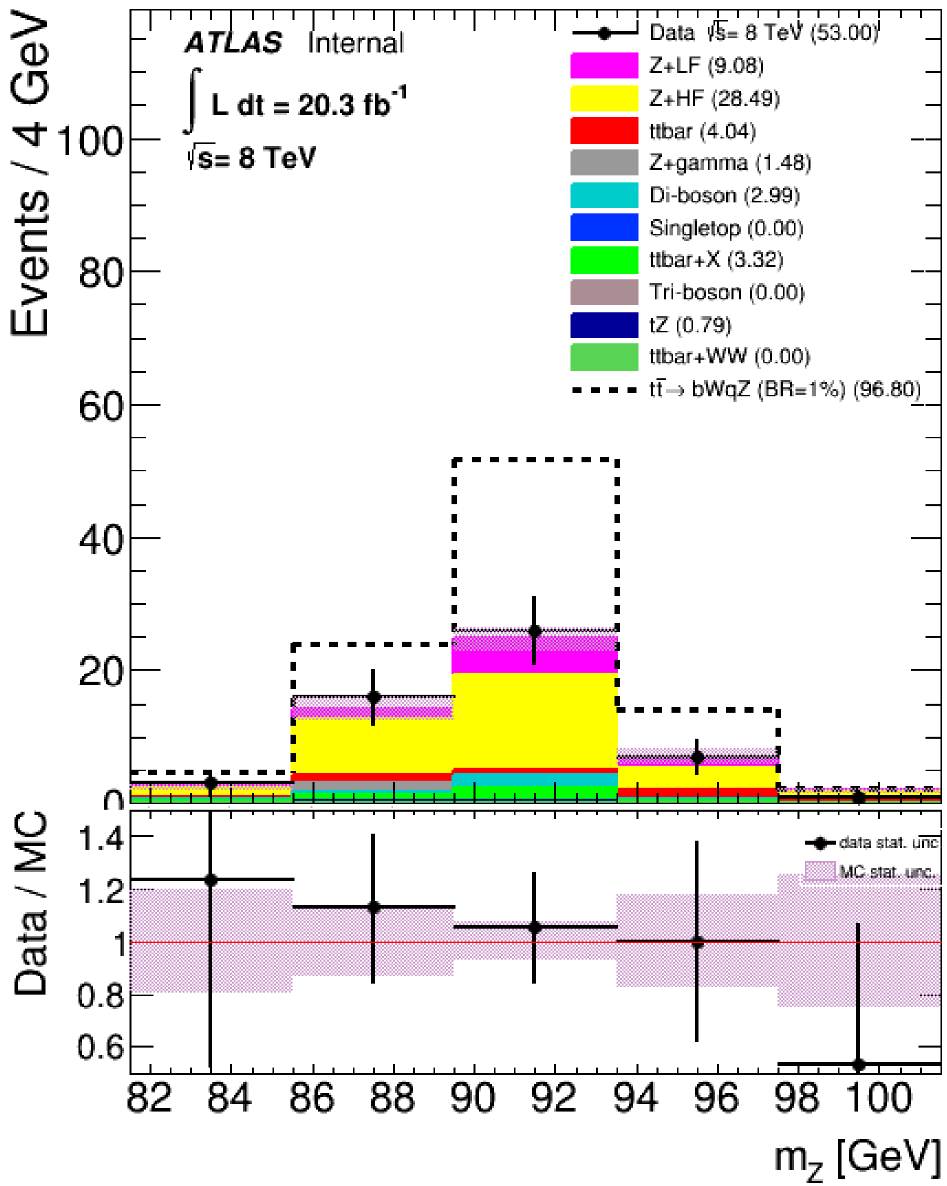
For comparison: cut on χ^2

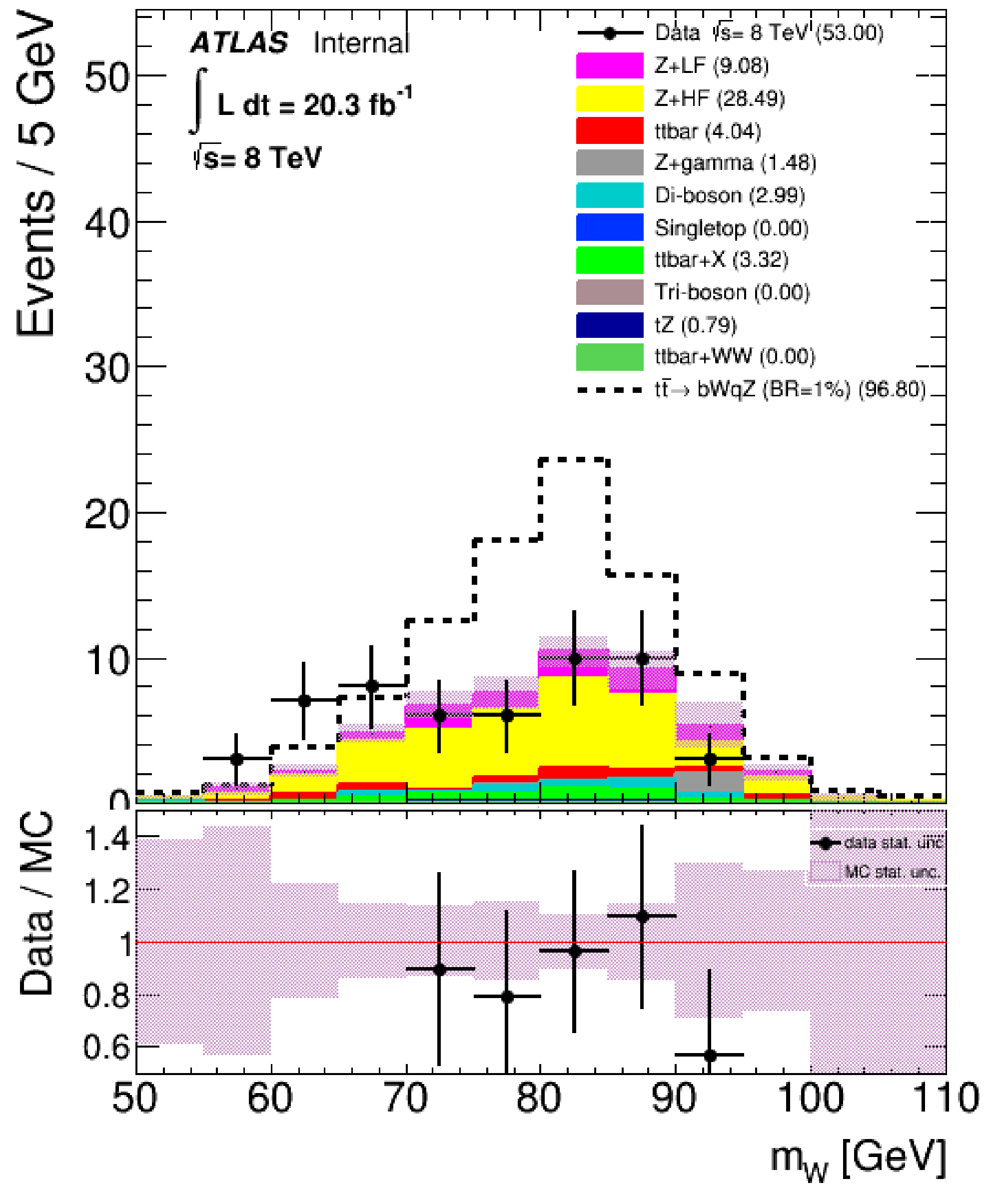


Cut: $\chi^2 < 3$

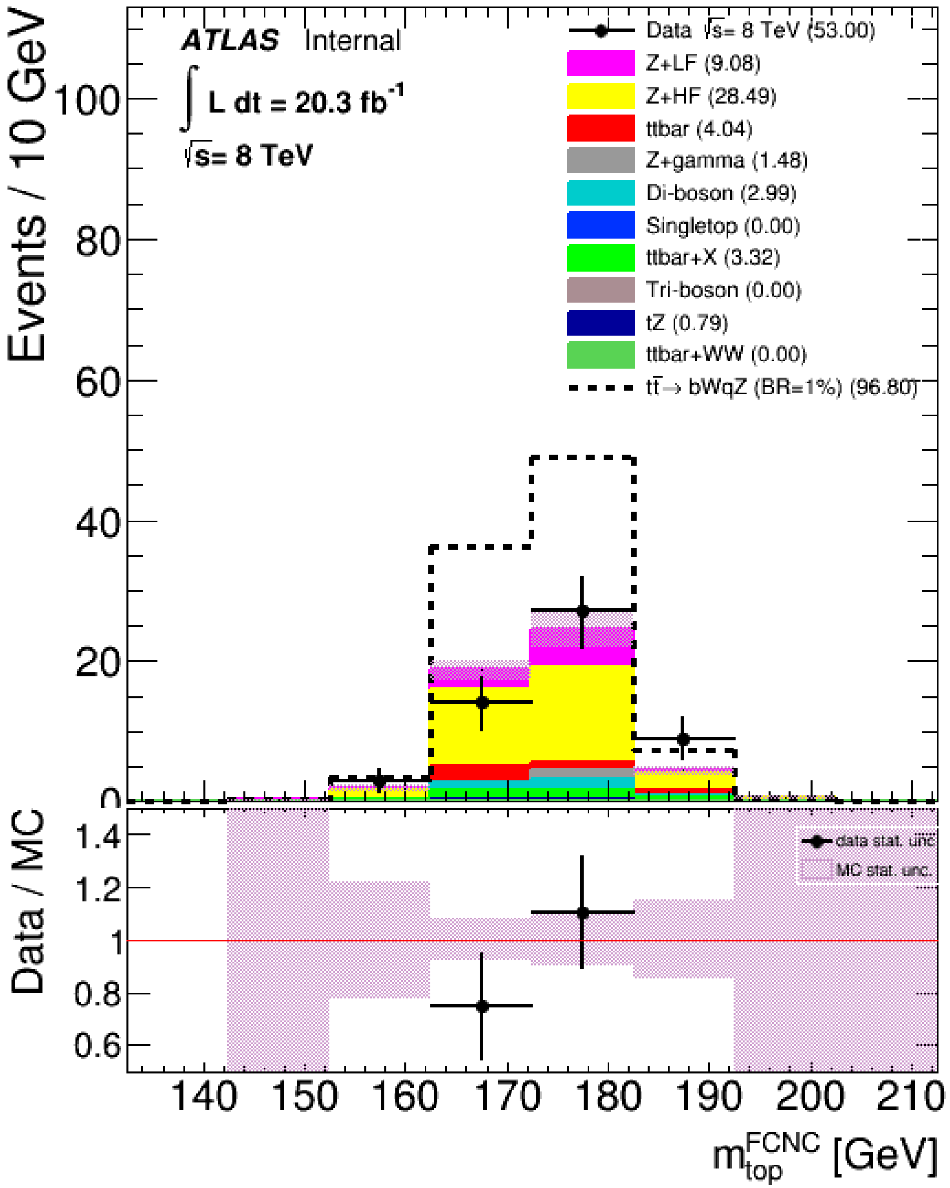
S(BR=0.01)/√B = **12.57**

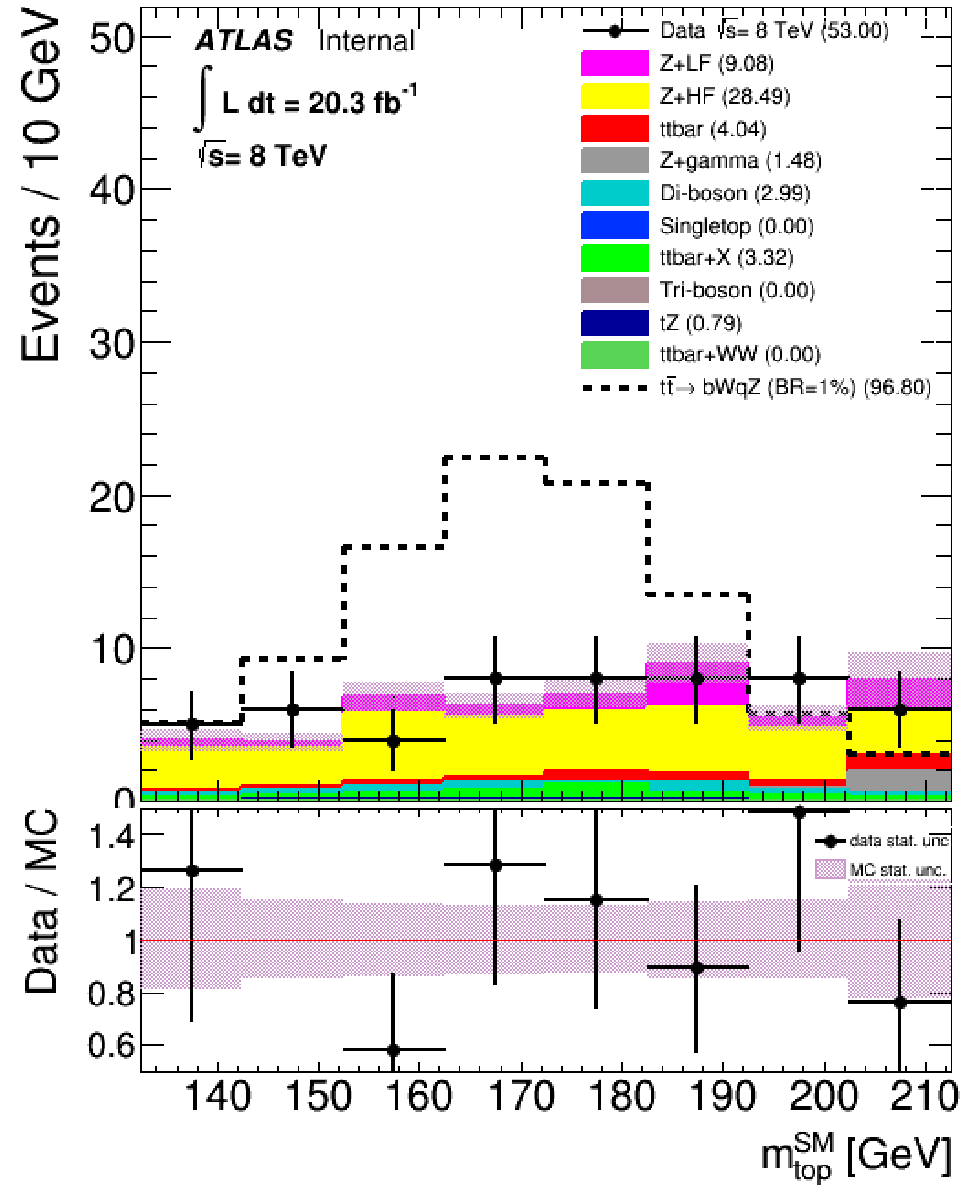
Distributions after the cut on L_R





Distributions after the cut on L_R





95% CL upper limits

- Upper limit on the signal events was obtained using the CL_s method as it is implemented in ***RooStats***.
- The statistical analysis is based on a likelihood function $L(\mu, \theta)$ which is constructed as a product of **Poisson** probability term for the number of observed events and several **Gaussian** constraint terms for θ .
- μ is the multiplicative factor for number of signal events n_s
- θ is a set of nuisance parameters that parametrize the effects of the systematic uncertainty sources
- The limits on the number of signal events were converted into upper limits on the corresponding branching ratios

	observed	(-1σ)	expected	(+1σ)
BR(t$\to qZ$)	3×10^{-3}	2×10^{-3}	3×10^{-3}	4×10^{-3}

ATL-PHYS-INT-2015-020

Summary and future plans

- Georgian ATLAS team is heavily involved in the ATLAS activities since a long time
- Continue all current activities in Tile Calorimeter of ATLAS
- Study of Flavor Changing Neutral Current (FCNC) top quark decays $t \rightarrow Zq$ (q=u,c quarks) in trilepton channel at $\sqrt{s}$=13 TeV
- Attract and involve young scientists, PhD, Masters and Bachelor students in ATLAS

Thanks for attention

Backup

BR(t→qZ) in trilepton channel

BR(t→qZ) in trilepton channel:

Eur. Phys. J. C (2016) 76:12

observed	7×10^{-4}
(-1σ)	6×10^{-4}
expected	8×10^{-4}
$(+1\sigma)$	12×10^{-4}

Z+jets background normalization

- Normalization of Z+LF and Z+HF samples is done using a likelihood fit within the *RooFit/RooStats* package
- Likelihood function **L(x, y, θ)** is constructed as a product of two **Poisson** probability terms for the number of observed events in Z+LF/Z+HF CRs and several **Gaussian** constraint terms for **θ** .
- **x** and **y** are the normalization factors of Z+LF and Z+HF samples, which are presented in likelihood as a multiplicative factors for the number of Z+LF and Z+HF background.
- **θ** is a set of nuisance parameters that parametrize the effects of the Detector Modelling systematic uncertainties and statistical uncertainty on the background expectation.

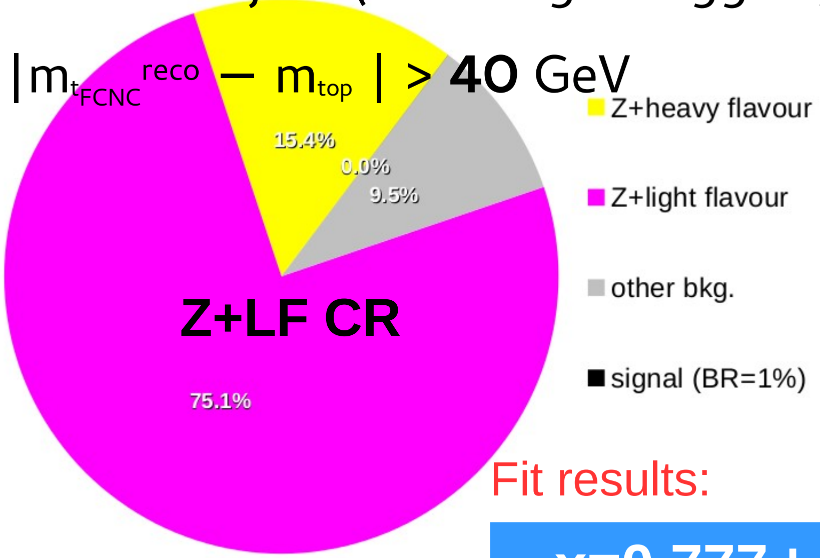
$$L(x,y,\alpha,\gamma) = \prod_{i\in CR} Pois(n_i^{obs}|n_{i,tot}^{exp}(x,y,\gamma_i,\alpha)) \times Gaus(1|\gamma_i,\sigma_i) \times \\ \times \prod_{j\in syst} Gaus(0|\alpha_j,1) \times Gaus(0|\alpha_{fakes\_syst},1)$$

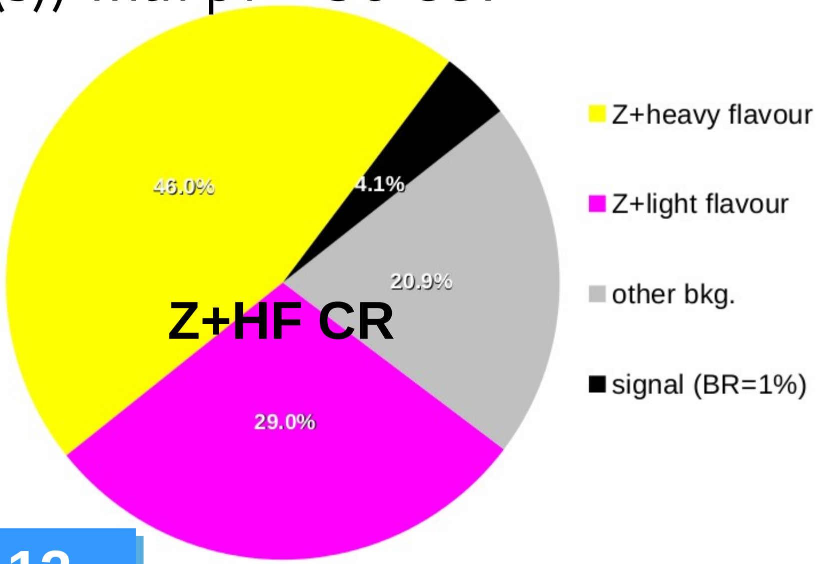
$$n_{i,tot}^{exp}(x,y,\gamma_i,\alpha) = x\cdot N_i^{Z+LF}\gamma_i\eta_i^{Z+LF}(\alpha_1) + y\cdot N_i^{Z+HF}\gamma_i\eta_i^{Z+HF}(\alpha_2) + \\ + \sum_{s\in otherMC} N_i^s \times \gamma_i\eta_i^{otherMC}(\alpha_3) + N_i^{Fakes}\eta_i^{Fakes}(\alpha_{fakes\_syst})$$

- Systematic uncertainties were evaluated using a Bootstrap method and only that ones are considered which are significant with respect to MC statistics

Z+jets background normalization

- **Z+LF CR**: $t\bar{t}\rightarrow bWqZ$ events are reconstructed with the requirements:
  - No b-tagged jet
  - At least 4 jets with pT > **30** GeV
  - $|m_W^{reco} - m_W| >$ **30** GeV and $|m_{t_{SM,FCNC}}^{reco} - m_{top}| >$ **40** GeV
- **Z+HF CR**: $t\bar{t}\rightarrow bWqZ$ events are reconstructed with the requirements:
  - At least one b-tagged jet
  - At least 4 jets (including b-tagged jet(s)) with pT > **30** GeV
  - $|m_{t_{FCNC}}^{reco} - m_{top}| >$ **40** GeV





Fit results:

x=0.777±0.112
y=1.319±0.211

Systematic uncertainties

- Detector modelling systematic uncertainties were estimated using a Bootstrap method
- Using a Bootstrap method the 1k pseudo-experiments are defined
- In each pseudo-experiment each event has attributed a random weight generated from a Poisson distribution, $P(\lambda=1)$, in a correlated manner in nominal and varied samples.
- In each pseudo-experiment the systematic variation ("up"/"down") is calculated and the mean of these variations in all pseudo-experiments is taken as a systematic uncertainty, while the spread is considered as a statistical uncertainty on the systematic.