Studies of the ATLAS hadronic Calorimeter response to muons at Test Beams

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Outline

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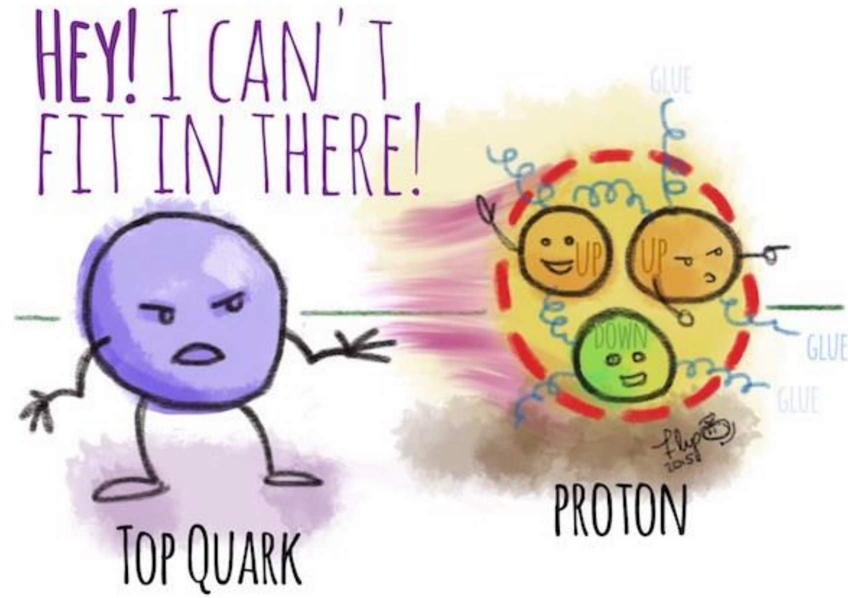
- ATLAS Tile Calorimeter
- Test Beam setup
- Signal reconstruction at Tile Calorimeter
- Electronics noise evaluation
- The results obtained using muons
- Summary

Large Hadron Collider

Physics beyond Standard Model

BSM:

- The extra dimensions of space
- Unification of fundamental forces
- Supersymmetry and string theory
- …



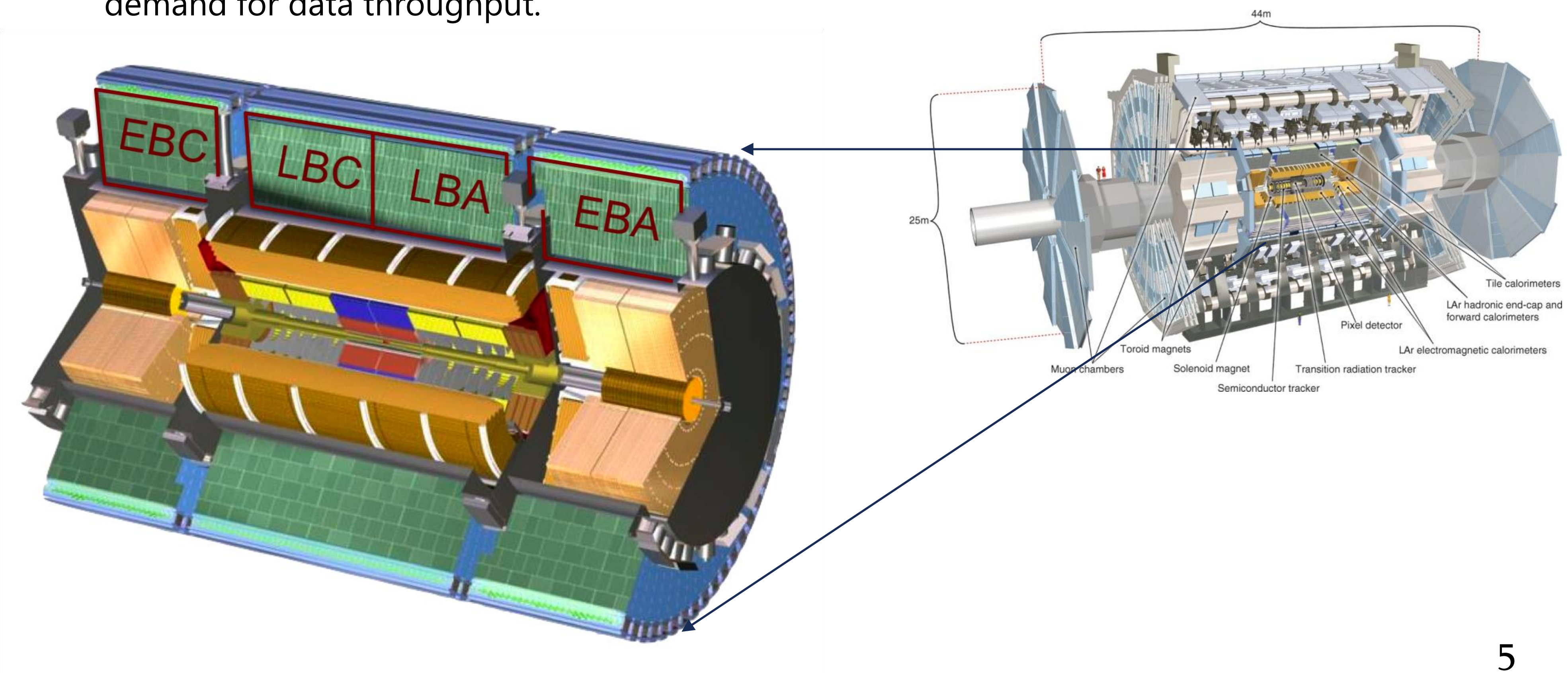
LHC is the machine where top quarks are produced in large numbers, so much so that it is sometimes called the "top factory".

Current studies in Physics field of ATLAS Georgian group of HEPI TSU:

- Search for Flavor Changing Neutral Current (FCNC) top quark decay (t->qZ);
- Study of the production mechanism of the top quark pair in association with a heavy vector quarkonium state.

ATLAS detector

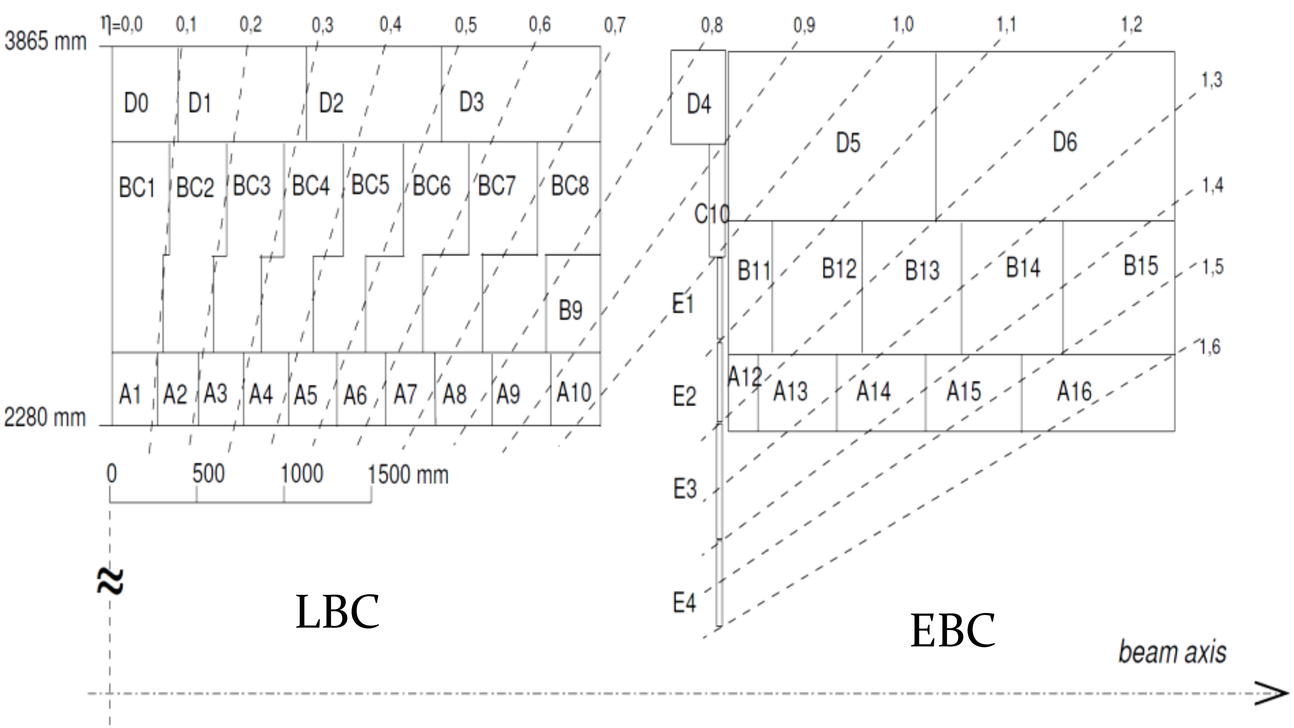
- The TileCal is the central hadronic calorimeter within the ATLAS at the LHC situated at CERN, Geneva.
- The TileCal is composed of four barrel sections (two central and two extended barrels), each containing 64 azimuthal slices.
- The Phase II Upgrade of the LHC plans to increase the present instantaneous luminosity by a factor of 5-10. will need to withstand a much higher radiation dose as well as a increased demand for data throughput.

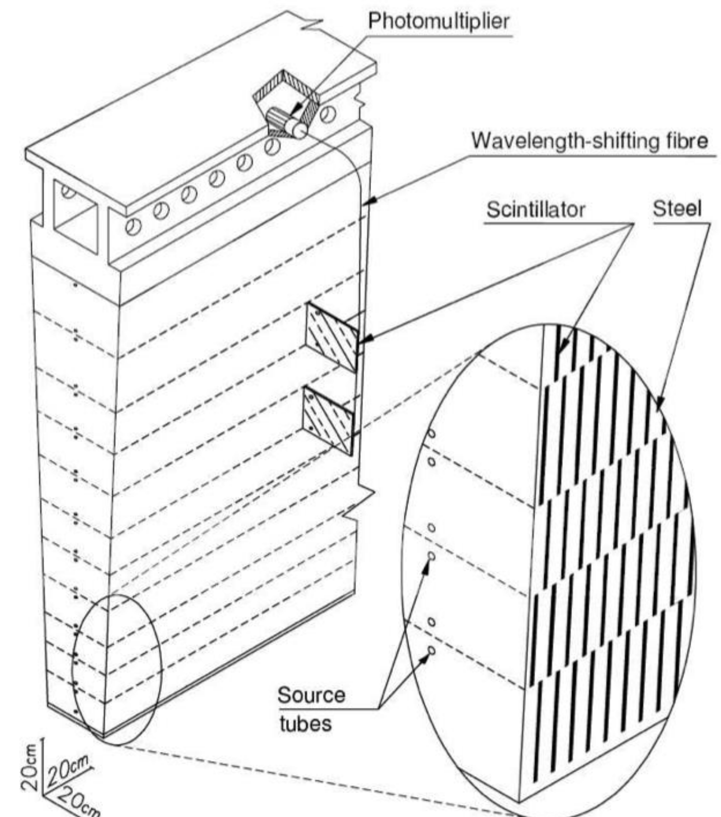


ATLAS Tile Calorimeter

Principle of TileCal:

- The defining role of hadron calorimetry is to measure the energies of jets.
- Measure light produced by charged particles in plastic scintillator.
- Scint. light from tiles collected by WLS fibers and delivered to PMTs.
- Tile readout is grouped into projective geometry cells. each cell readout by 2 PMTs except special cells (layer E).
- Each barrel consist of 11 tile rows which form 3 longitudinal layers (A, BC, D).

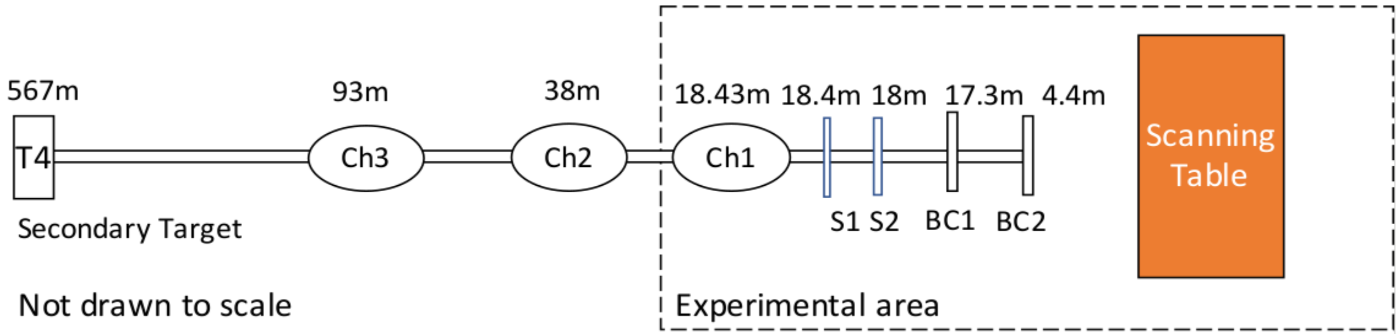


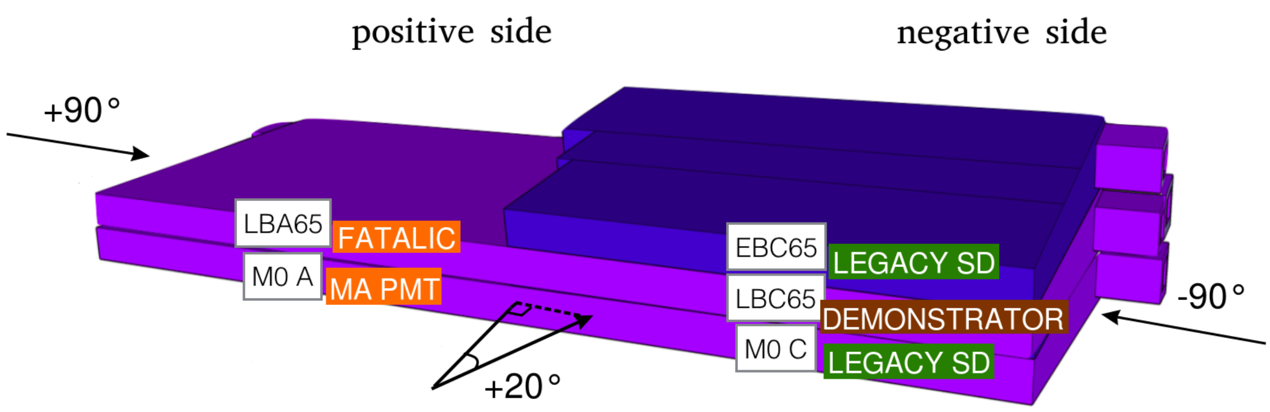


Test Beam setup

Motivation:
The Phase II Upgrade of the LHC – increase of instantaneous luminosity by a factor of 5-10.

- Test module has been equipped with so-called Hybrid **Demonstrator**. The 3-in-1 front-end option has been mounted in this Demonstrator which provides all the upgrade functionalities but maintaining the analog trigger signals for backward compatibility.





Following work is done using Demonstrator data.

Muons

- The high energy muons traverse the entire TileCal modules for any angle of incidence, thereby allowing a study of the module response in great detail through their entire volume.
- The interaction of muons with matter is well understood. The dominant energy loss process is ionization and the energy loss is essentially proportional to the muon track path length.
- Muon data allows us to:
  - **Verify the new electronics performance by checking the equalization of the cell response.**

SIGNAL RECONSTRUCTION

Methods to reconstruct amplitude (A), time (τ):

- ***Fit method:*** fit with $f(t) = Ag(t - \tau) + c$

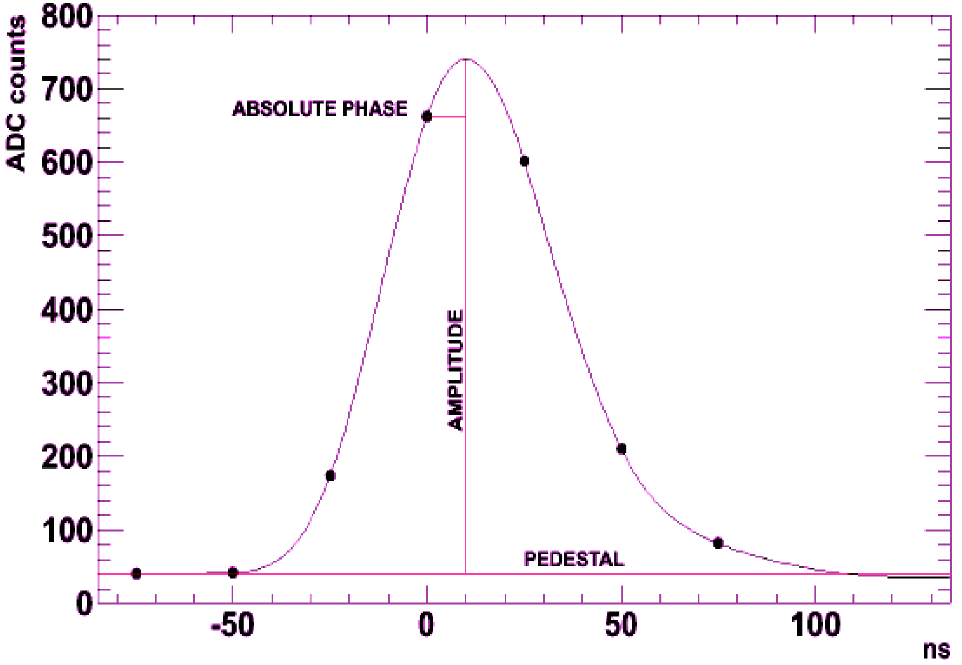
g - known normalized pulse shape,
A - amplitude,
τ - phase,
c - pedestal.

- ***Optimal Filter:*** weighted sum of measured samples, designed to minimize the noise:

$$A = \sum_{i=1}^{N} a_i S_i$$

$$A\tau = \sum_{i=1}^{N} b_i S_i$$

S_i - i^{th} sample
N - number of samples
A - amplitude of the signal
τ - the phase with respect to the expected sampling time



The analog signal from PMTs is shaped and sampled every 25 ns.

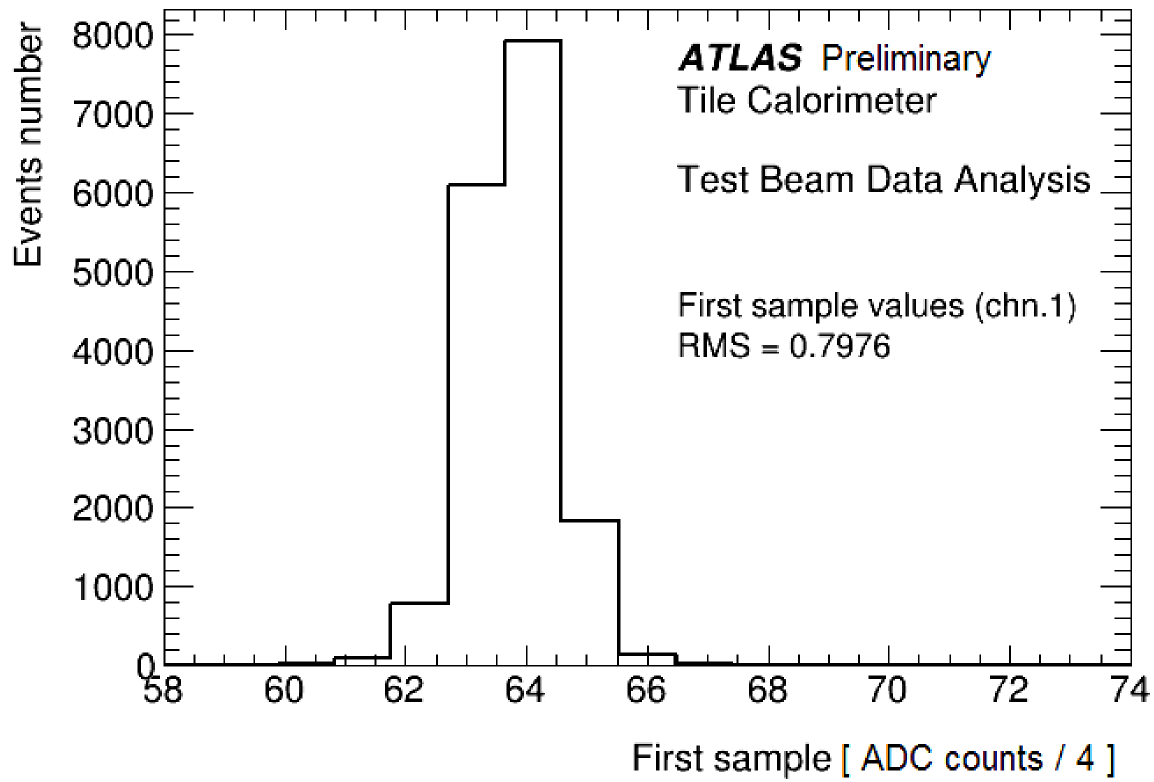
Iterative optimal filter: multiple iterations to find correct position of the peak.

if (max_sample - ped) <= threshold - no iterations in both methods, phase=0 is assumed.

Electronic noise evaluation

- Electronic noise RMS was evaluated using amplitude of the first sample (which never contains signal).
- For noise evaluation several thresholds were considered:

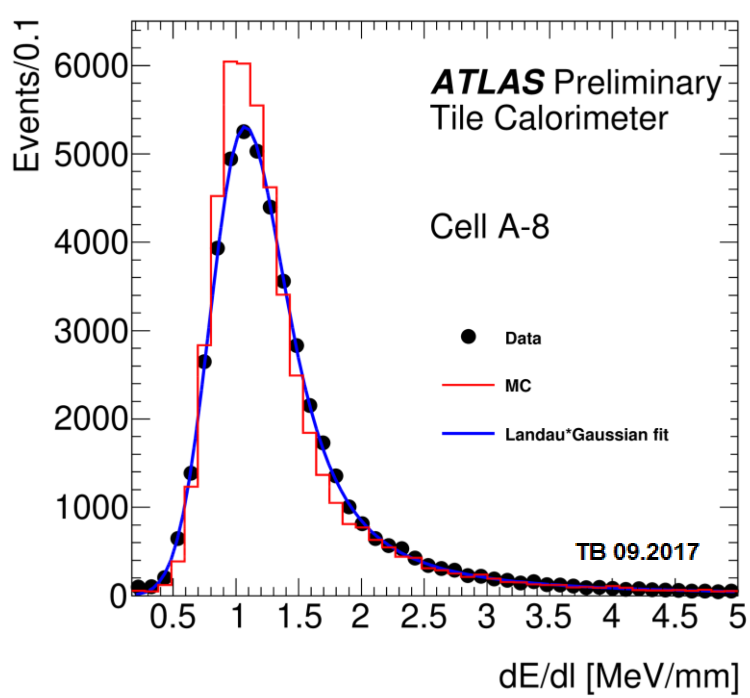
C * sampleRMS ,   where C=2, 3, 4



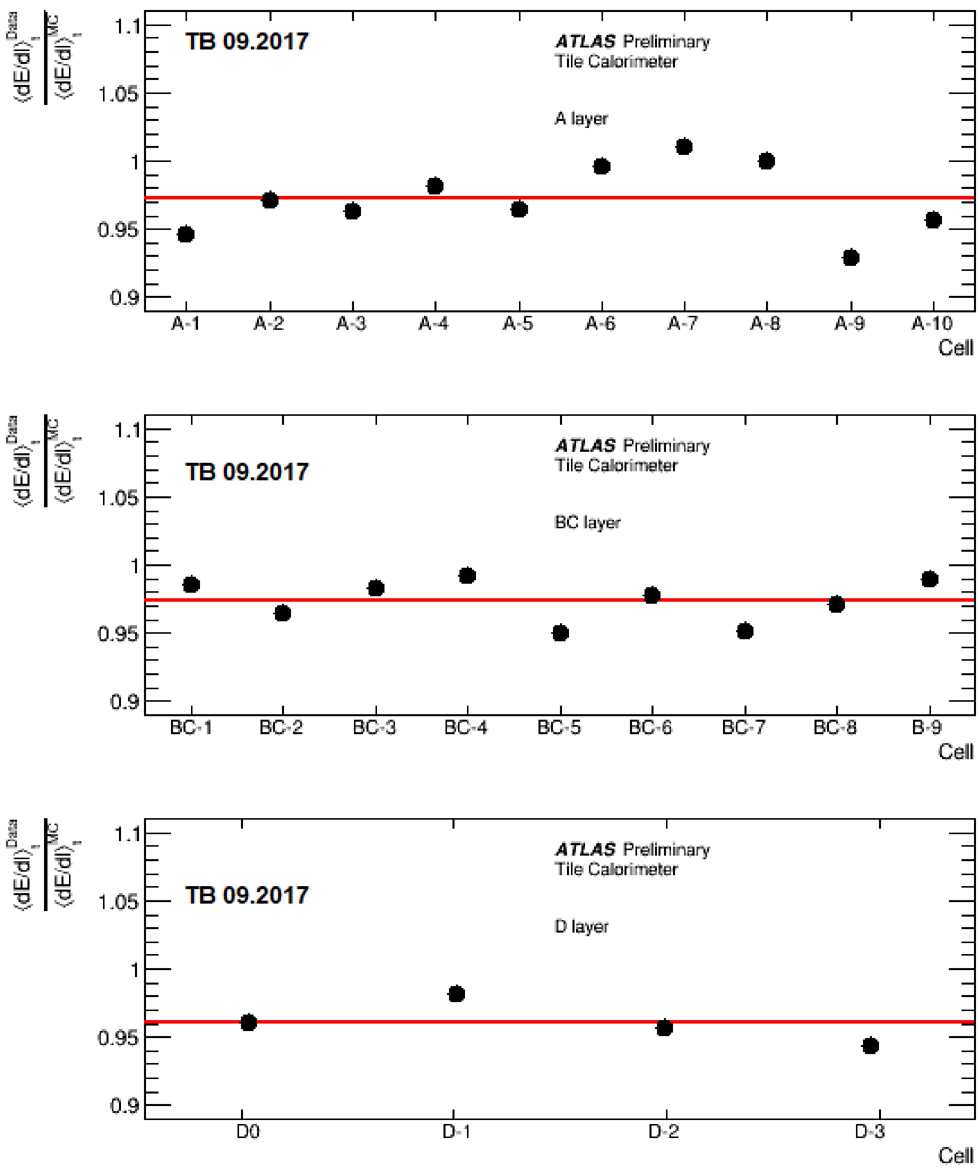
As a noise threshold 3*RMS is selected!

Results with muons: strategy

- The TileCal response to high energy muons follows a Landau type distribution with characteristically long tails at high energies.
- The most obvious definition, namely the most-probable (peak) value of the signal divided by the muon path length, displays a significant residual dependence on the path length.
- Instead, **the mean value of the measured muon energy loss spectrum truncated at 97.5% of the total number of entries was adopted.**
- The truncated mean was preferred to the full one because it is less affected by rare high energy loss processes.



Results with muons: dE/dl VS cell



- The response of the detector has been studied determining the ratio between the energy deposited in a calorimeter cell (dE) and the track path-length in the cell (dl) using 165GeV muons at an incident angle of -90°.
- The ratio of experimental and simulated dE/dl values was defined for each calorimeter cell:

$$R = \frac{\langle dE/dl \rangle_t}{\langle dE/dl \rangle_t^{MC}}$$

- The red horizontal lines - the mean values of dE/dl for each layer.
- The data show a layer uniformity at 1%. An offset of max 4% is observed for Data/MC.

Summary

- **Motivation:** The Phase II Upgrade of the LHC plans to increase instantaneous luminosity by a factor of 5-10. Electronics will need to withstand a much higher radiation dose as well as a increased demand for data throughput.
- A stack of three modules of the hadronic calorimeter of the ATLAS experiment (TileCal) equipped with the updated front-end electronics has been exposed to the beams of the SPS at CERN.
- The results obtained using muons are in agreement with the calibration settings obtained using the old electronics and with the expectations obtained using simulated data.
- The Results confirm good performance of the new electronics.

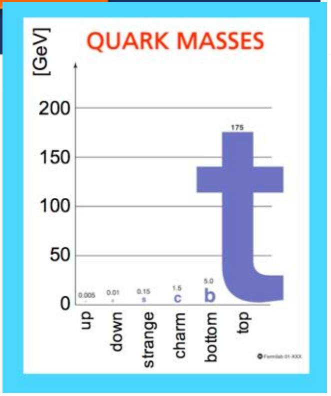
Thank you for your attention!

Backup

MOTIVATIONS FOR TOP QUARK PHYSICS STUDIES

quark was first observed in 1995 at the Fermilab $p\bar{p}$ Tevatron collider by CDF and DO experiments:

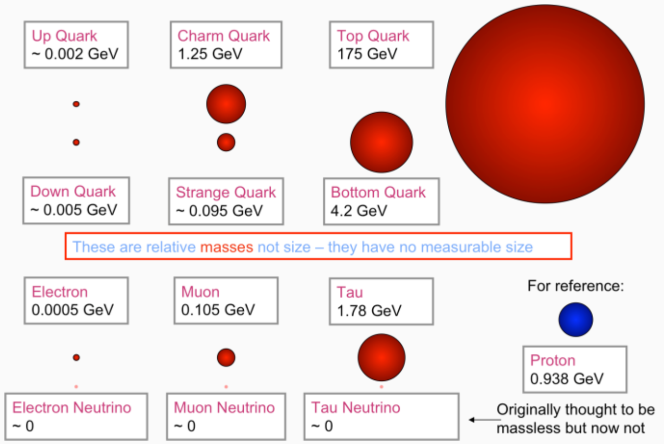
- $M_t = 174.3 \pm 3.2$ (stat) ± 4.0 (syst)
- $\sigma_{t\bar{t}} =$ (CDF $M_t = 175$ GeV) $= 6.5 \pm_{1.4}^{1.7}$ pb
- $\sigma_{t\bar{t}} =$ (Do $M_t = 172$ GeV) $= 5.9 \pm 1.7$ pb
- $Q^e_{em} = 2/3\ |e|$; Weak isospin partner of b quark:
- $T^t_3 = 1/2$; Color triplet, spin ½;



The top quark is the heaviest elementary particle yet discovered. Its mass, of the same orders the electroweak scale, is about twice that of the W and Z bosons and about 35 times larger than its isospin partner, the b quark and slightly less than the mass of the gold nucleus.

Large value of top mass and short lifetime ($\tau_t \sim 5\times10^{-25}$ sec) make top quark unique:

- Decays before hadronization
- Sensitive window for New Physics
  - Many new heavy particles produce top quarks
  - Detailed properties of top probe SM & beyond



- And in addition …

Experiment: Top quark useful to calibrate the detector

Beyond Top: Top quarks are major source of background for almost every search for physics beyond the SM – New Physics

Search for FCNC

Top-quark FCNC decay branching ratio:

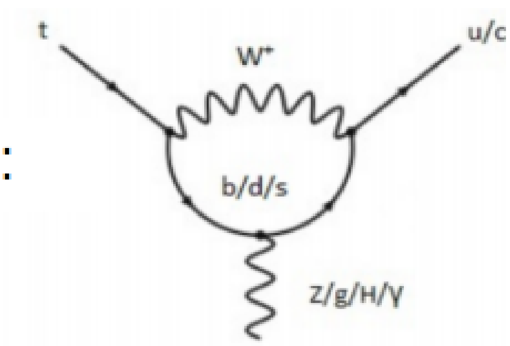
Model:	SM	QS	2HDM	FC 2HDM	MSSM	$\not{R}$ SUSY	RS	Mirror Model
BR($t \to qZ$):	10^{-14}	10^{-4}	10^{-6}	10^{-10}	10^{-7}	10^{-6}	10^{-5}	10^{-6}

A search for top quark **F**lavor **C**hanging **N**eutral **C**urrent decay in $t\bar{t}$ production:

One top decays through FCNC ($t \to qZ$) and other through SM dominant mode ($t \to bW$)

Leptonic decays of W and Z bosons

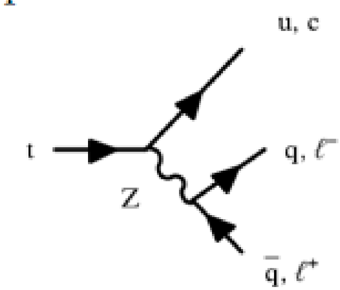
SM:



Strongly suppressed by GIM mechanism in SM

→ Powerful probe for new physics

BSM:

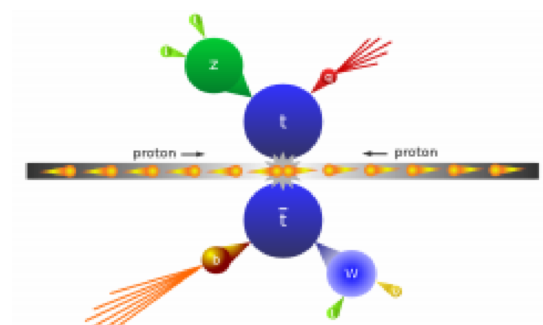


Signal sample

- Separate samples for $t \to uZ$ and $t \to cZ$
- $t\bar{t}$ production and decay processes are done by **MadGraph5_aMC@NLO** at NLO in QCD
- Top-quark FCNC decay is done by **TopFCNC** model: https://twiki.cern.ch/twiki/bin/viewauth/AtlasProtected/TopPropertiesFCNCMCRunII
- Parton shower with **Pythia8** and the A14 tune

Event topology

3 isolated leptons, at least two jets, with only one being b-tagged and missing transverse energy from the undetected neutrino



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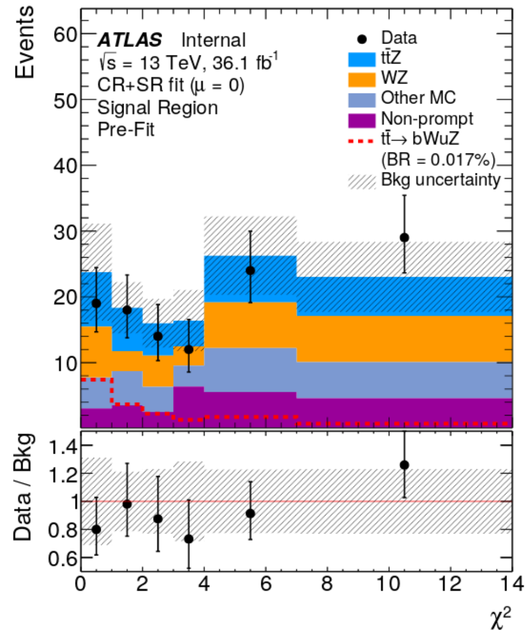
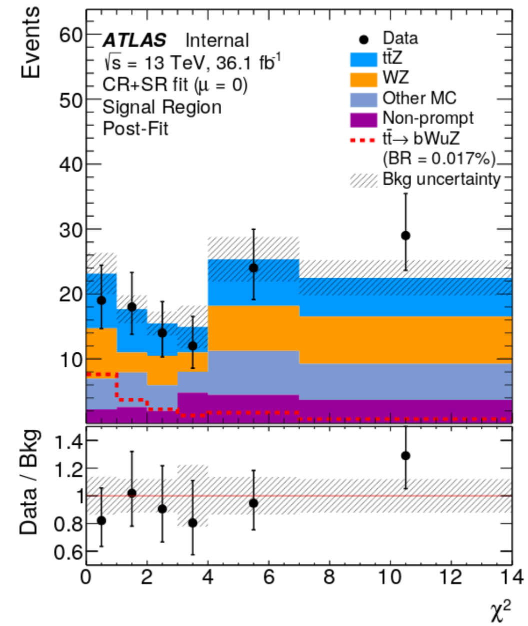
A.Durglishvili, T.Djobava, M.Mosidze (HEPI TSU, Georgia)
S.Hellman, S.Molander (Stockholm University, Sweden)

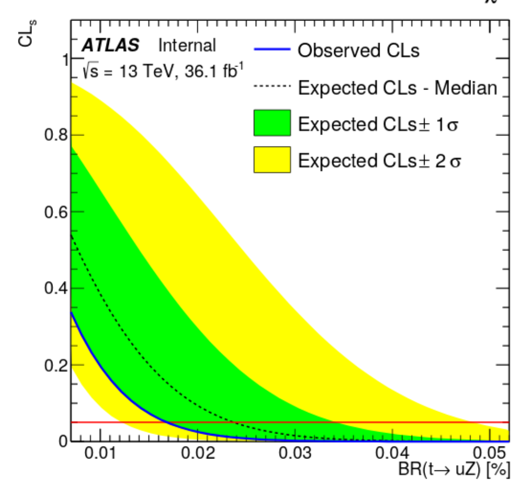
Results of $t \rightarrow qZ$ FCNC search

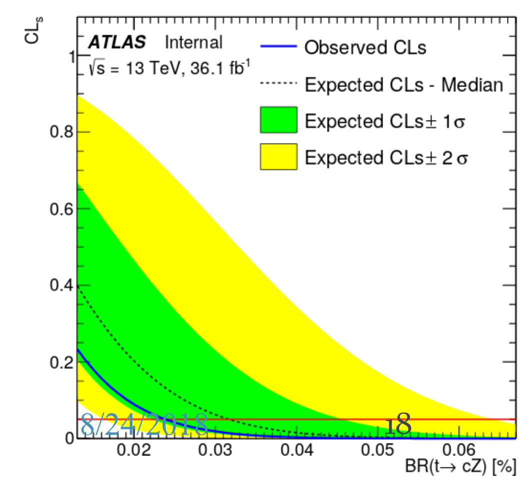
- 36 fb^{-1} of 13 TeV data analysed
- Observed data agree well with the SM background expectations
- No evidence of signal is found
- 95% CL upper limits are set on the branching ratios of $t \rightarrow uZ$ and $t \rightarrow cZ$

	Observed	-1σ	Expected	$+1\sigma$
$\mathcal{B}(t \rightarrow uZ)$ [%]	0.017	0.017	0.024	0.035
$\mathcal{B}(t \rightarrow cZ)$ [%]	0.023	0.022	0.032	0.046









J/ψ production with top pair

Analysis Team:
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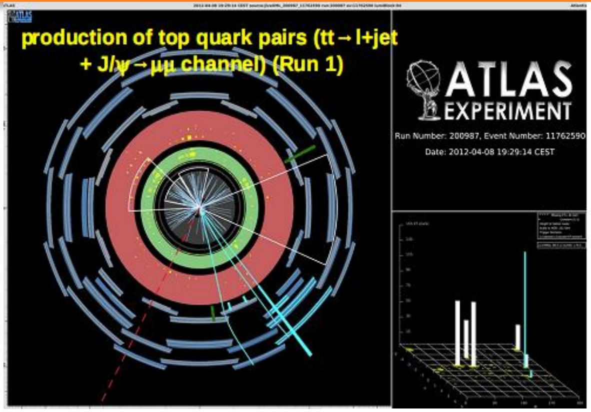
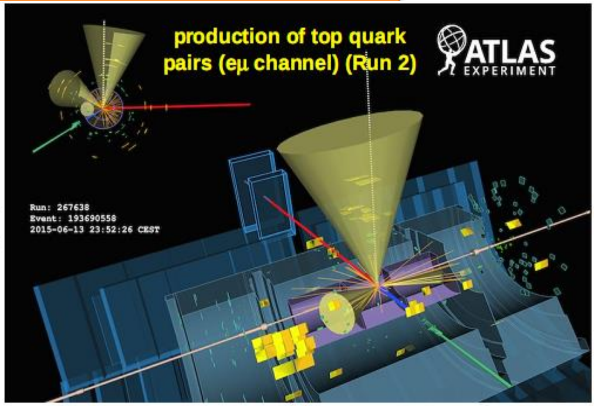
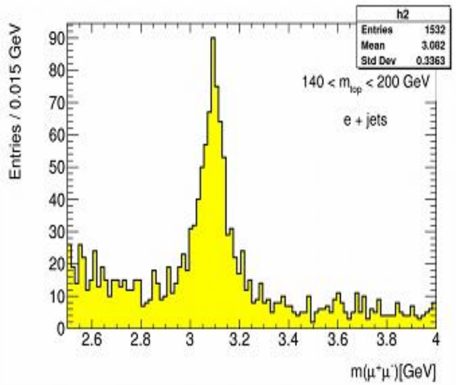
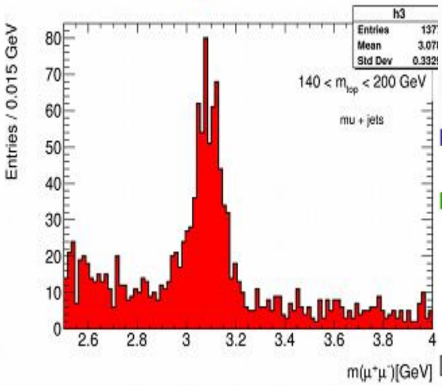
Prof.V.Kartvelishvili





Selection: lepton + 4jets + dimuon(s) (cut on top mass: $140 < m_t < 200$ GeV).





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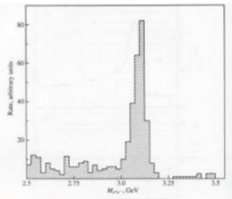
The Beginning: J/ψ



⇐ Discovery 1: Ting's group

$pN \to e^+e^- X$

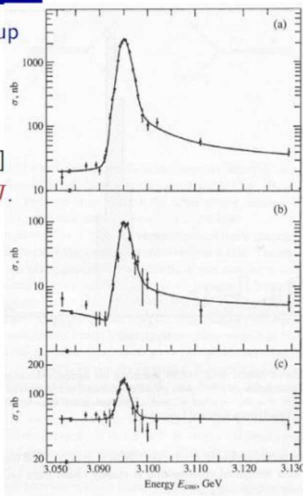
at $P_{lab} = 30$ GeV/c

[Aubert et al., PRL, 6/11/1974]

Found a peak in e^+e^- inv.mass at 3.1 GeV, called it J.

Discovery 2: Richter's group ⇒

(a) $e^+e^- \to$ hadrons
(b) $e^+e^- \to \mu^+\mu^-$
(c) $e^+e^- \to e^+e^-$

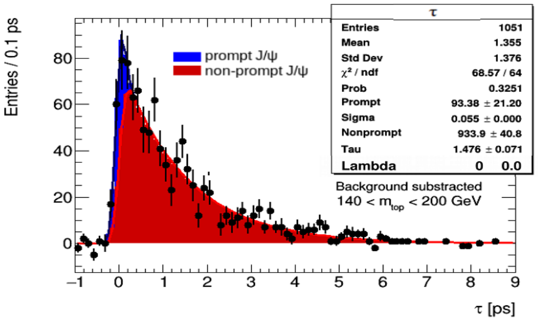


[Augustin et al., PRL, 7/11/1974]

Found a peak in all these three cross-sections, at the c.m.s. energy 3.1 GeV; called it ψ.

Lifetime of J/ψ candidates in top events

|Δη| and |sin(Δφ)| cuts applied.

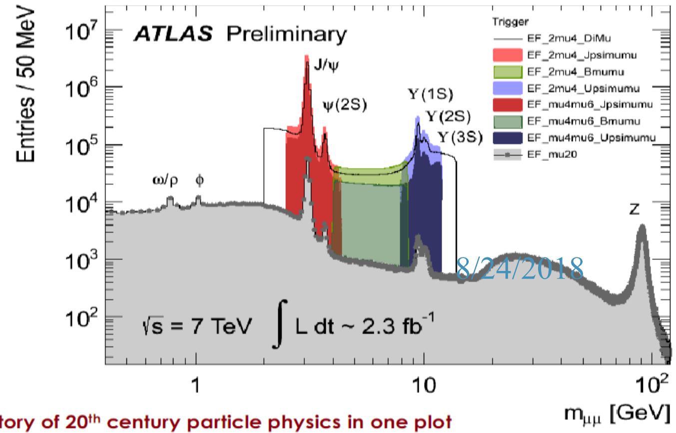


Fit function:
pdf={ε*δ(τ)+(1-ε)*exp(τ)} ⊗ Resolution

Resolution=λ*g(σ)+(1-λ)*g(2*σ)

Fit parameter Prompt – number of prompt J/ψ
Fit parameter Nonprompt – number of non-prompt J/ψ
σ is fixed, σ = 0.055 ps
λ is fixed to 0 - effectively sigma is 0.11, in-line with expectations.

Fit shows that we have 93 ± 21 prompt J/ψ - s!



History of 20th century particle physics in one plot