Experiment ATLAS/LHC and participation of Slovakia

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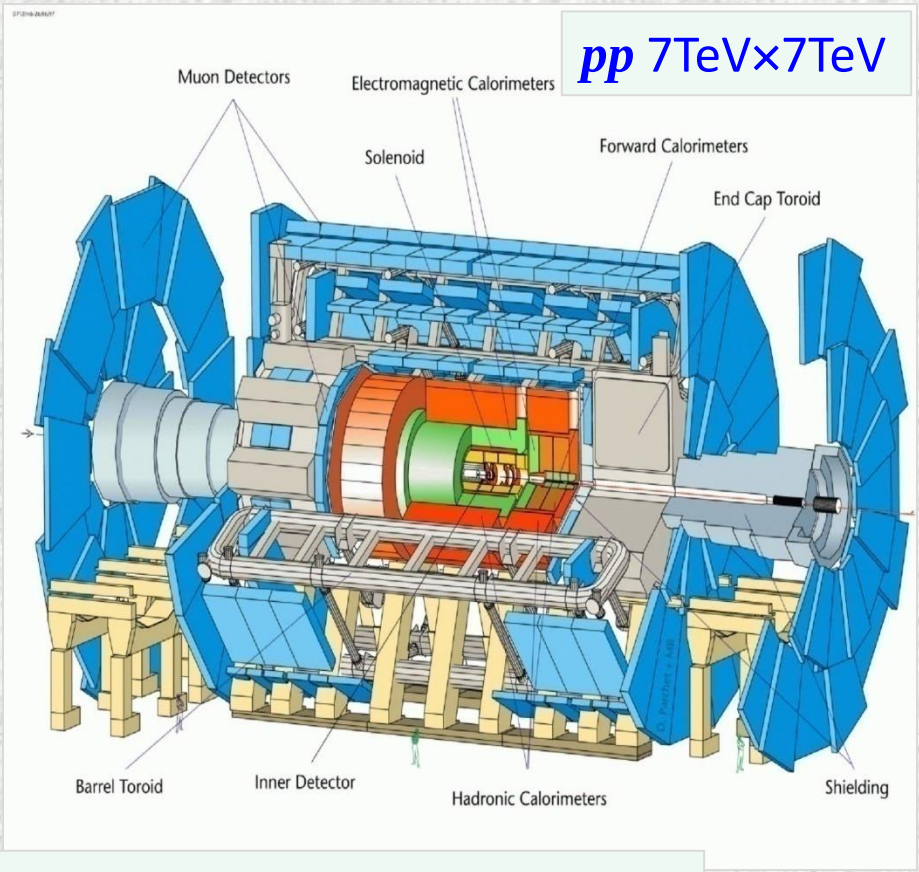
Outline

- Experiment ATLAS – basic facts
- Participation of Slovak teams in building of ATLAS
- On Kosice team ATLAS activities
- On Bratislava team ATLAS activities
- Conferences, outreach,...
- Conclusions

ATLAS detektor

Multi-purpose particle collider detector (it covers $|\eta|=5$, $L=10^{34}\,cm^{-2}s^{-1}$)



- **Inner Detector**
  $\sigma/p_T \approx 0.05\% \cdot p_T(GeV) \oplus 0.1\%$
  Tracking range $|\eta|< 2.5$
- **EM Calorimetry**
  $\sigma/E \approx 10\%/\sqrt{E(GeV)} \oplus 1\%$
  Fine granularity up to $|\eta| < 2.5$
- **Hadronic Calorimetry**
  $\sigma/E \approx 50\%/\sqrt{E(GeV)} \oplus 3\%$
  Range: $|\eta| < 4.9$
- **Muon System**
  $\sigma/p_T \approx 2-7\%$, **range:** $|\eta| < 2.7$

2T Solenoid + 3 air core toroids
R. 2010: 3.5TeV × 3.5TeV
R. 2012: 4TeV × 4TeV
R. 2015: 6.5TeV × 6.5TeV

Precision physics in $|\eta|<2.5$
Lepton energy scale: 0.02% ($Z\rightarrow\ell\ell$)
Jet energy scale: 1.0 % ($W\rightarrow jj$)

ATLAS in numbers

Mass: 7 000 tons dimensions: 25m × 46m (diameter × length)
Electronic channels: ~100 millions ~ 3000 km cables

Luminosity 2×10^{34} cm^{-2} s^{-1} : ~1 billion collisions /sec
1st level Trigger : ~ 75 000 events /sec
2nd level Trigger: ~ 2 000 events /sec
Event filter: ~ 300 events /sec (permanent recording)

Beam: 3808 bunches, 1.15×10^{11} protons/bunch
Bunch : transverse size= 16 μm, length ~10 cm

Detector ATLAS: gigantic microscope with resolution $\leq 10^{-20}$ m
Optical microscope: resolution ~ 2×10^{-7} m
Electron microscope: resolution ~ 10^{-10} m

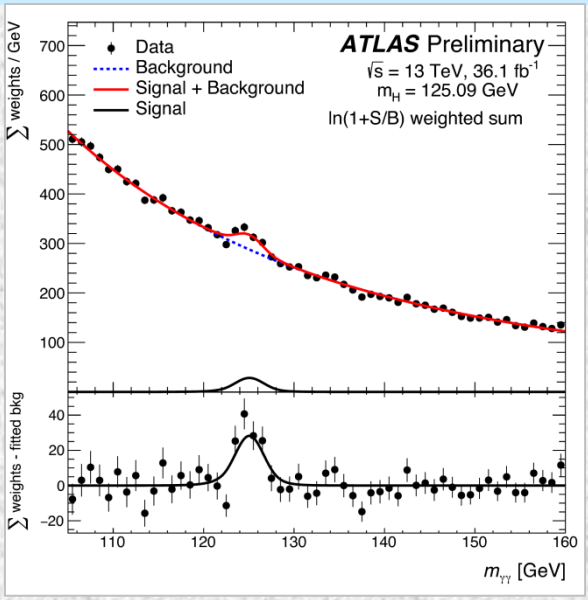
The ATLAS experiment: goals, status

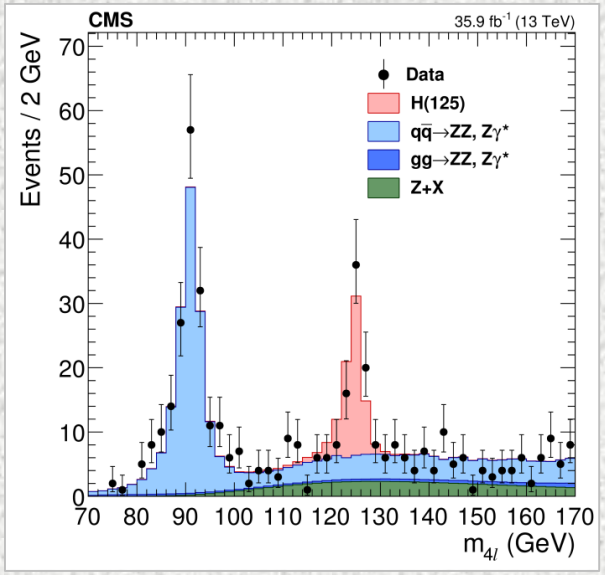
Basic goals of the experiment ATLAS:

- Study of the symmetry breaking in Higgs sector → in SM the Higgs sector: 1 neutral Higgs boson H.
- Precision tests of SM / looking for physics beyond SM.

Present status of the research by ATLAS:

- Discovery of Higgs boson together with CMS (2012).
- ATLAS+CMS: $M_H = 125.09 \pm 0.21$GeV.
- The observed boson is fully compatible with the SM Higgs boson.
- Precision tests within top quark physics, EW physics, jet physics.





No significant sign of physics beyond the SM!

⇒ Extended borders of validity of the SM!

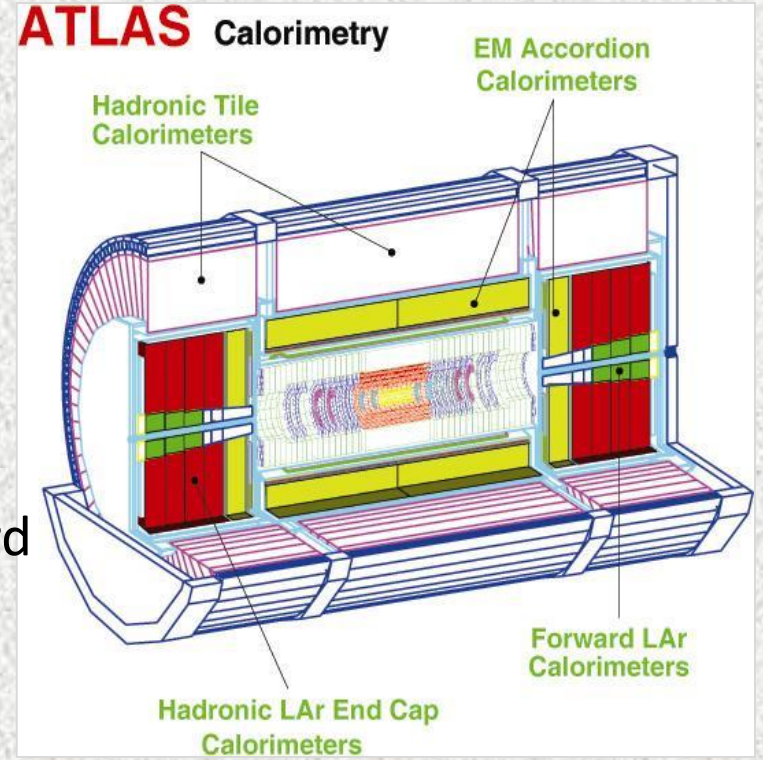
Total number of ATLAS publications: > 700

In the past...

Development, assembling and commisioning of the ATLAS detector

Construction and testing of ATLAS detector

- **Kosice team**: Hadronic LAr End Cap calorimeter (HEC) based on liquid argon technology
- **Bratislava team**: Hadronic Tile calorimeter (Tile) – scintill. tiles +fibers



- **Hardware activities**

✓Development, production and tests of Forward readout board (with Columbia Univ.) (HEC)

✓Production of so-called cold electronics (HEC)

✓Iron plates for Tile calorimeter

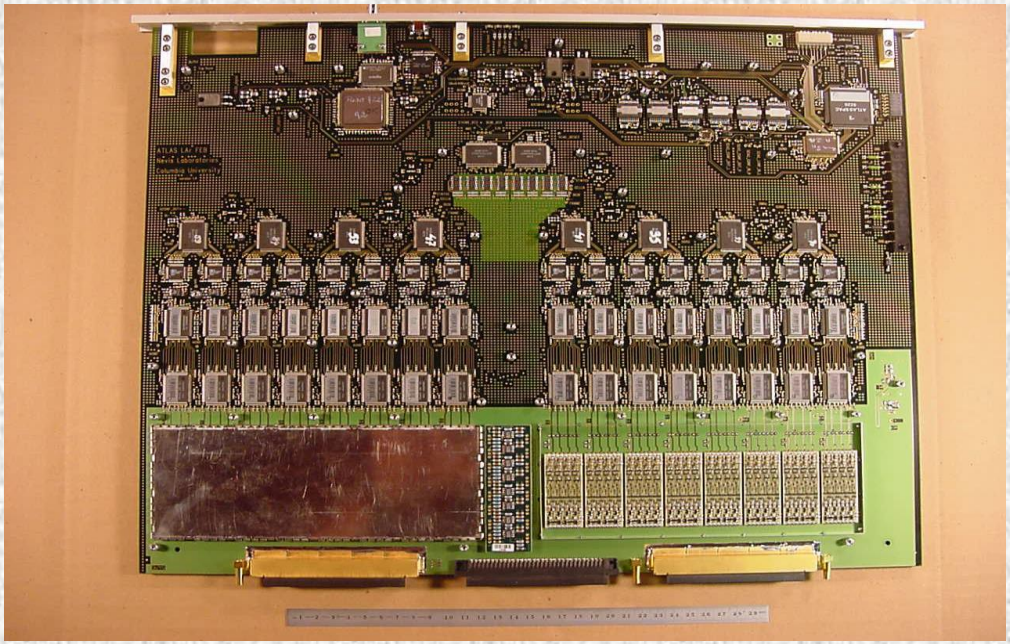
✓Angle bracket for tile modules manipulations

Both teams: in assembling and commissioning of Calo's

✓Tests of photomultipliers using single photoelectron approach

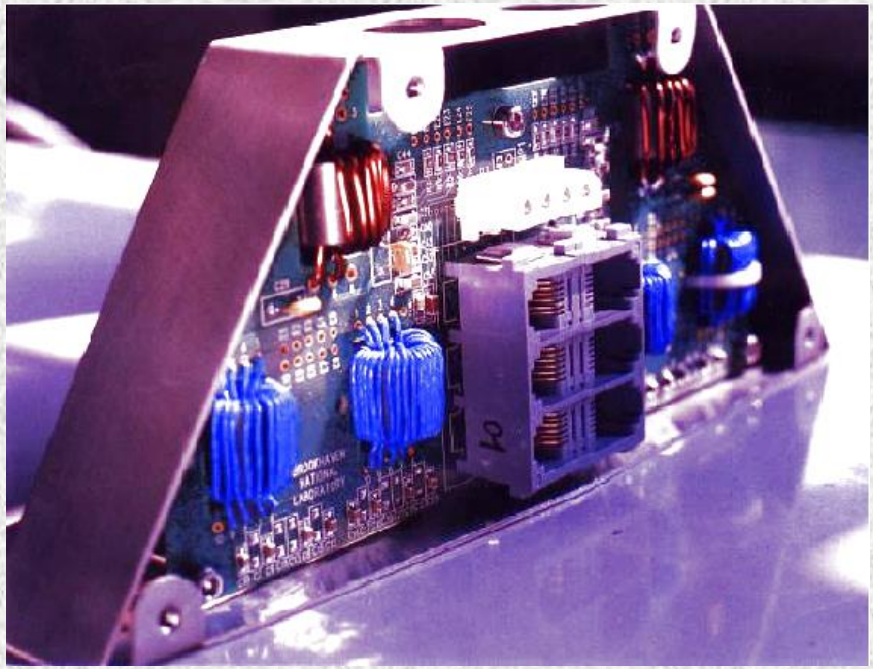
✓Reconstruction of calorimeter response to pions, electrons, muons (linearity, homogenity, energy resolution, EM scale).

Moments from history



Front-end board for HEC produced by Košice team along with Nevis Lab.

Filter box, produced in Košice, for full ATLAS calorimetry production according to BNAL design



Present activities

Slovak cluster

≡

Bratislava + Košice teams

History and present status quo of Košice staff

Present status: 4 physicists + 4 engineers + 1PhD student

Members from 1992 and present status:	Dušan Bruncko	- chief, founder
	Pavol Stríženec	- founder
	Jozef Urbán	- from 2015
	Jaroslav Bán	- ended: 31. 12. 2017, founder
	Pavol Binko	ǂ 27 October 2013
	Eduard Kladiva	† 3 November 2017, founder
	Jaroslav Antoš	- finished 1 September 2014
	Jozef Ferencei	- finished 30 June 2012
	Pavel Murín	- from 2016
	Filip Tomasz	- finished 1 September 2013
PhD student:	Filoména Sopková	- from 2016
PHD student (successful)	Martin Pécsy	- from 2007 – to 2011
Engineers:	Ingrid Kuľková	
	Miloslav Straka	
	Richard Bílek	
	Jozef Špalek	

Detector maintenance and operation

Present activities:

- ✓ Responsibility for electronics calibration for the ATLAS LAr calorimetry.
- ✓ Performance studies of various aspects of the LAr calorimetry, data preparation tasks.

Other responsibilities in the period 2012 – 2016:

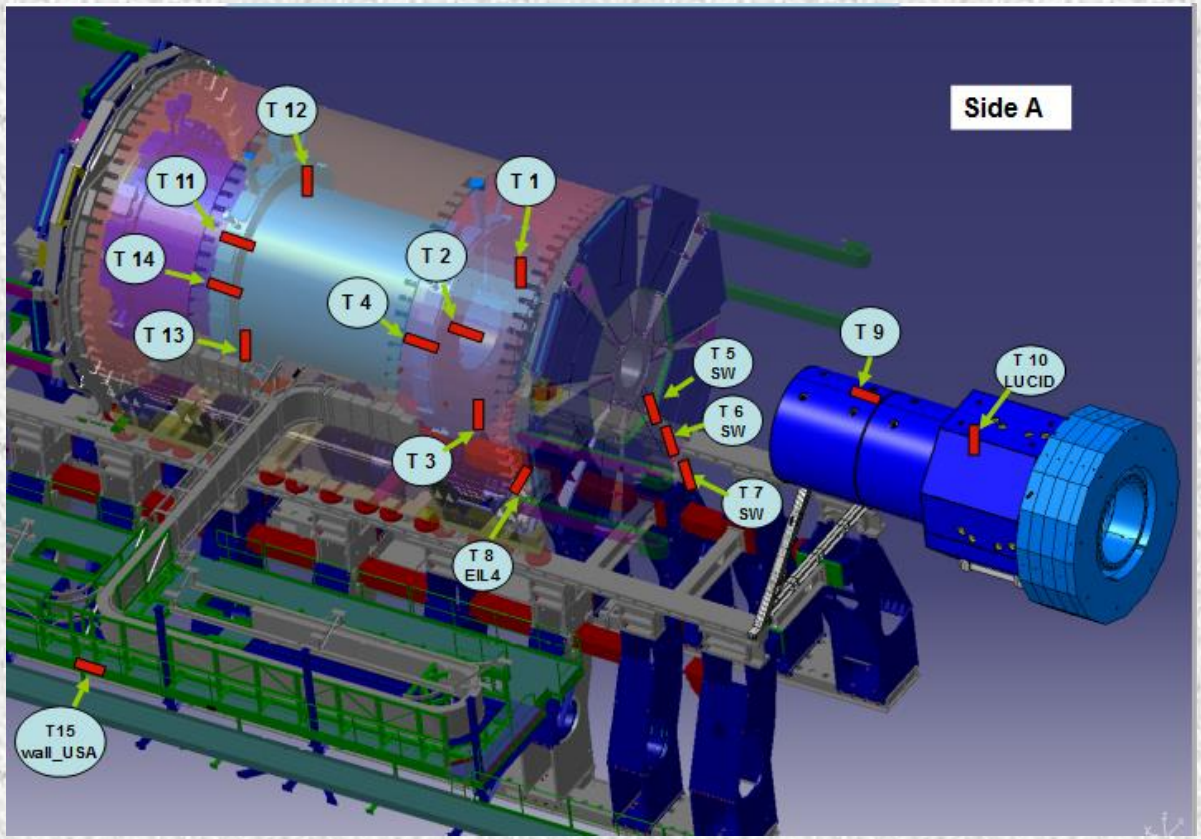
- ✓ Software and data preparation Coordination
- ✓ LAr Steering Group and LAr Management Group
- ✓ LAr Speaker Committee

- ✓ Data analysis of the High luminosity runs in Protvino.

- ✓ Electronic upgrade (ADC,...) for ATLAS upgrade - in a close collaboration with Columbia Univ., USA.

Lumi measurement in ATLAS using Timepix sensors

Sensor's Timepix map in ATLAS detector

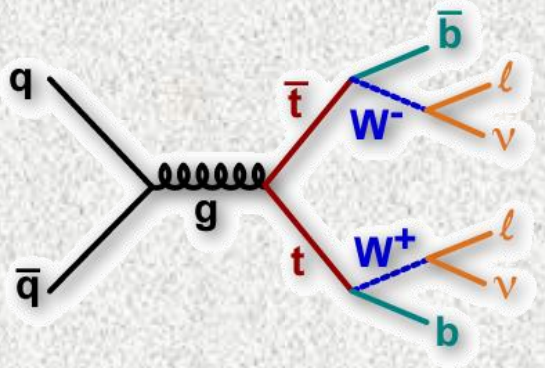


Our contribution: the analysis time's shifts frames from sensors, Monte-Carlo simulations.

Physics analyses

Participating in Top working group:

- ✓ determination of top quark mass using KIN method in dilepton channel at 8 TeV – preliminary results are in ATLAS internal note.
- ✓ study top quark spin characteristics in dilepton channel at 13 TeV.



$t\bar{t}$ dilepton channel (leptons: e,μ):
low BR (4.9%), high S/B

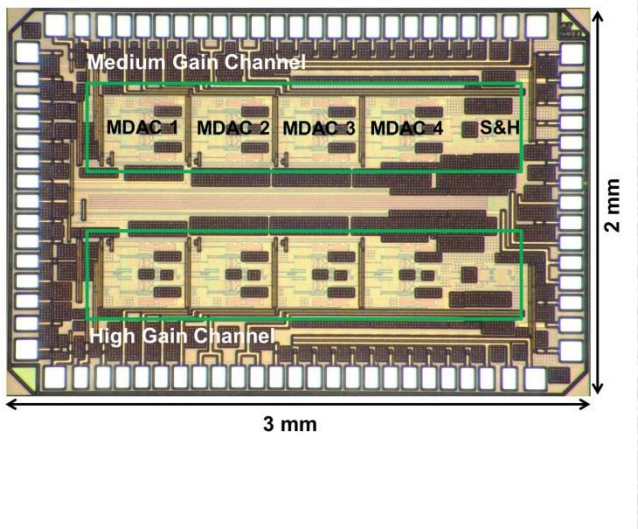
- ✓ Reviewing Bratislava team's top quark studies
- ✓ High activity as a reading institute

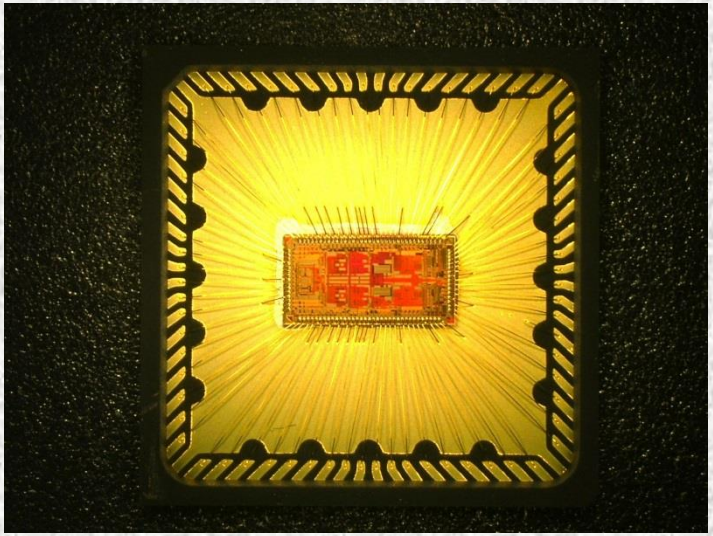
Collaboration with Czech Academy of Science (Prague) and MPI Munich.

Nevis ADC chip features

ADC developed by Nevis and Košice (J. Bán) for upgrade of LAr detector.

4 channels of 12bit ADC (4MDACs and 8bit SAR)
– Differential signal input of 2.4V FS with 1.25V common mode voltage
– Conversion result available 87.5ns after sampling
– Data sent out serially using 320MHz DDR SLVS clock signaling
– Power dissipation of ~43mW/channel (preliminary measurement on few chips)





ATLAS team in Bratislava

Team: 6 physicists, 7 PhD students, 1-2 technicians, 3 Students

Physicists: Stanislav Tokár (team leader)
Róbert Astaloš
Pavol Bartoš
Tomáš Blažek
Ivan Sýkora
Tibor Ženiš
Pavel Šťavina †2010

Phd students:
Tomáš Dado
Matej Melo
Juraj Smieško
Sofiia Hyrych
Michal Dubovský
Oliver Majerský
Michal Račko

Students: Dominik Babál Barbora Eckerová Jakub Senderák

Technicians: Tomáš Stuk, Miroslav Šulc

Successfully defended PhD students since 1995: 11 (8 after 2005)

Bratislava ATLAS team: present activities

Present activities:

✓Atlas shifts – data accumulations

✓DQ coordinator for TileCal, development of software for TileCal DQ

Physics analyses:

✓Top quark physics studies: Top quark charge, Top quark width, Charge asymmetry in ttbar, associated production of ttbar Z ($Z \rightarrow \ell\ell$, ttbar – all hadronic), Boosted objects

✓Intrinsic charm in proton via ℓ+jet events

✓Soft QCD: Bose-Einstein correlation studies

ATLAS upgrade:

✓ new PMTs for TileCal

✓ their tests and commissioning together with INFN Pisa,

✓ our commitment: 300 kCHF

BA-team: Top Quark charge

- To decide between 2 scenarios: SM (Q_{top} = 2/3) vs exotics (Q = -4/3):

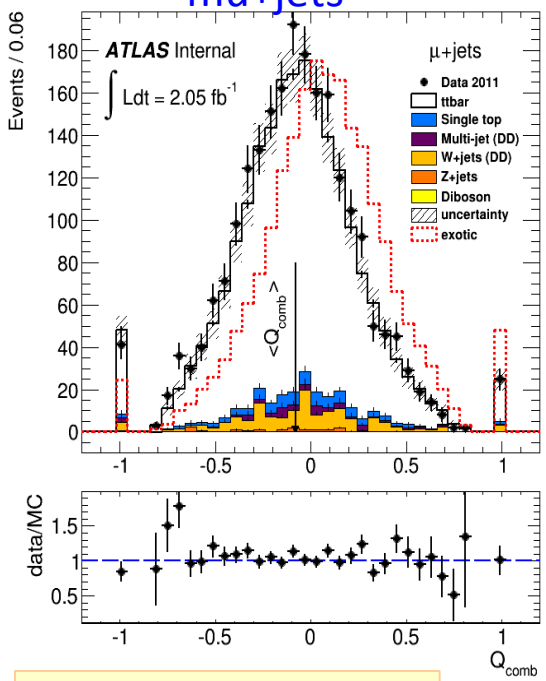
$$t \to b + W^+ \to b + \ell^+ \nu_\ell \quad \text{vs} \quad \hat{t} \to b + W^- \to b + \ell^- \bar{\nu}_\ell$$

JHEP 11 (2013) 031

- Sensitive variable: $\bar{Q} = \langle Q_l \times Q_{bjet} \rangle$ <0: SM, >0: Exo

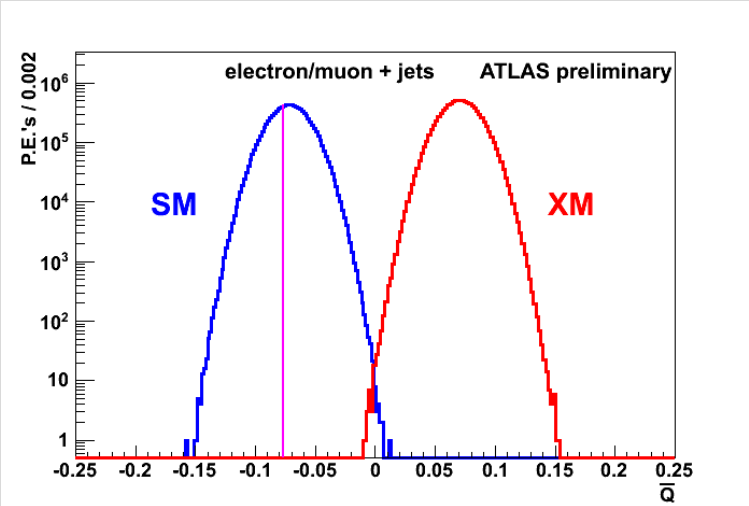
$$Q_{b\text{-jet}} = \frac{\sum_i^N q_i \left| \vec{j} \cdot \vec{p}_i \right|^\kappa}{\sum_i^N \left| \vec{j} \cdot \vec{p}_i \right|^\kappa}$$

mu+jets



Muon: χ^2 =31.6/32

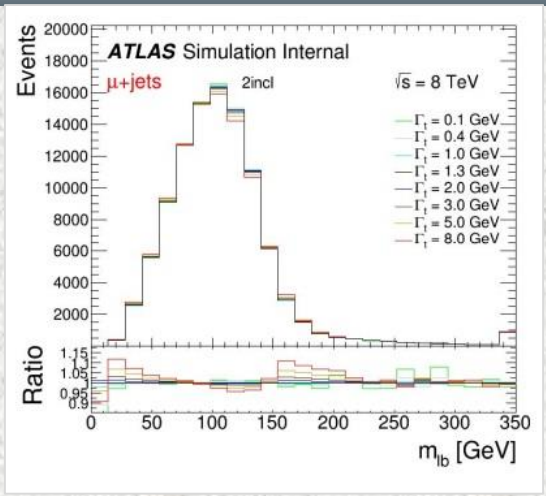
Experiment outcomes for SM and XM vs data



channel	pV_{SM}	pV_{XM}	σ_{XM}(S.D.)
el	0,832	<1.E-7	7,9
mu	0,964	<1.E-7	7,5
el+mu	0,892	<1.E-7	8,9

Top quark decay width

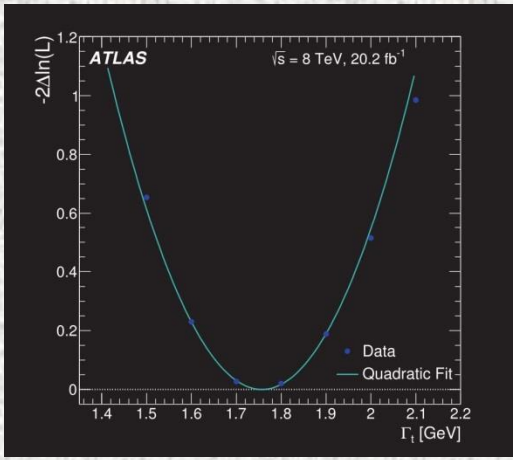
- ✓ Top quark decay width (Γ_t) ≡ an important parameter- some BSM models predict very different Γ_t w.r.t. SM
- ✓ SM prediction: Γ_t = 1.32 GeV (NNLO, m_t = 172.5 GeV)
- ✓ Using template fit to extract Γ_t from data
- ✓ Top-quark pair production - ℓ+jets channel (8 TeV and 13 TeV) and dilepton (13 TeV)

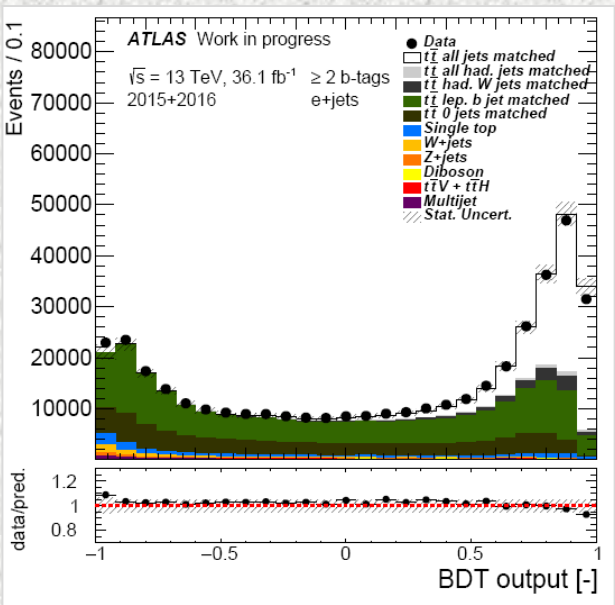


Analysis AT 8TeV ($\int Ldt$ =20.2 fb-1) finished:

$$\Gamma_t = 1.76 \pm 0.33(\text{stat.})\,^{+0.79}_{-0.68}\ \text{GeV}$$

(Eur. Phys. J. C 78 (2018) 129)





- 13 TeV analysis (2015, 2016, 2017) - in progress
- ∫Ldt ≈ 80 fb^{-1}
- Using reconstruction BDT+ profile likelihood

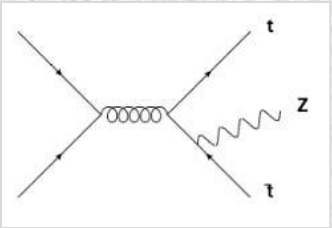
Partners: Univ. Goettingen, thesis: T. Dado

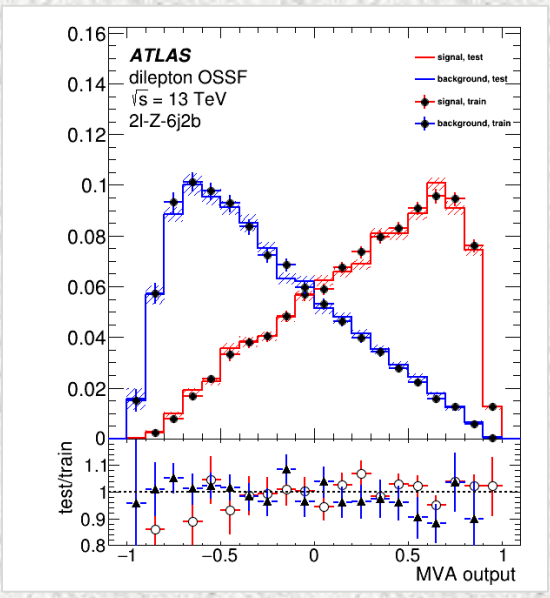
Associated production of ttbar and Z

Goal: cross section measurement of $t\bar{t}\,Z$ $\left(Z \to \ell^+\ell^-,\ t\bar{t} \to \text{jets}\right)$

✓ at $\sqrt{s}$ = 13 TeV using $\int L dt = 36.1\ \text{fb}^{-1}$.

thesis: M. Dubovský



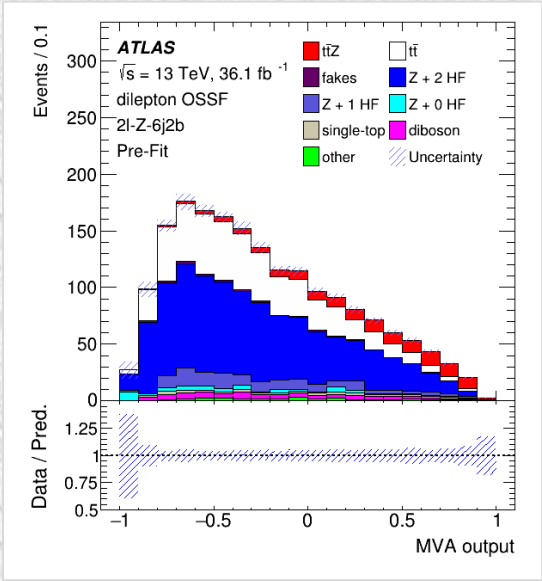


2ℓ OS channel:

- Branching ratio: 3.4 %
- Main background: $t\bar{t}$ and Z+jets
- Signal fraction is 2-8 % after selection (depends on the region)
- BDT is used in order to separate signal from background

3ℓ and 4ℓ channels are studied intensively by groups in Bonn, Mainz and Goettingen.

Results available soon!



Dominant systematics:

2ℓ OS: Z+jets parton matching scale, Z+jets radiation systematics, $t\bar{t}\,Z$ modelling

Combined: WZ and $t\bar{t}\,Z$ modelling, b-tagging, luminosity

Charge asymmetry in tt-bar production

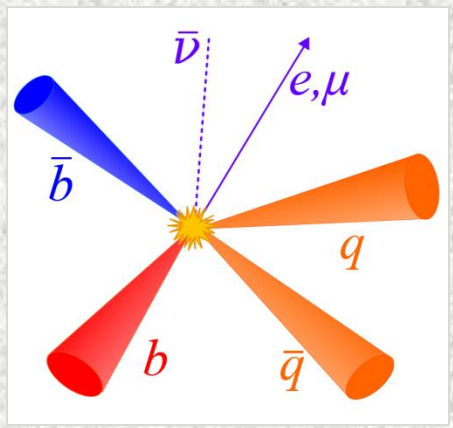
Charge asymetria in pair top quark production at √s = 13 TeV

- Partners: Univ. Mainz , thesis: **M. Melo**

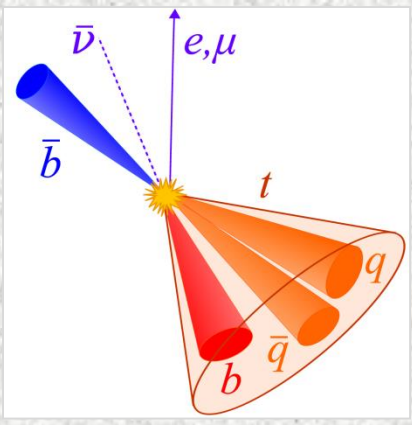
Goal:

To study charge asymmetry A_C using

- ℓ+jets channel - in „resolved“ and „boosted“ topologies
- To obtained a common result with dilepton channel (Kobe Univ., Birmingham Univ.)

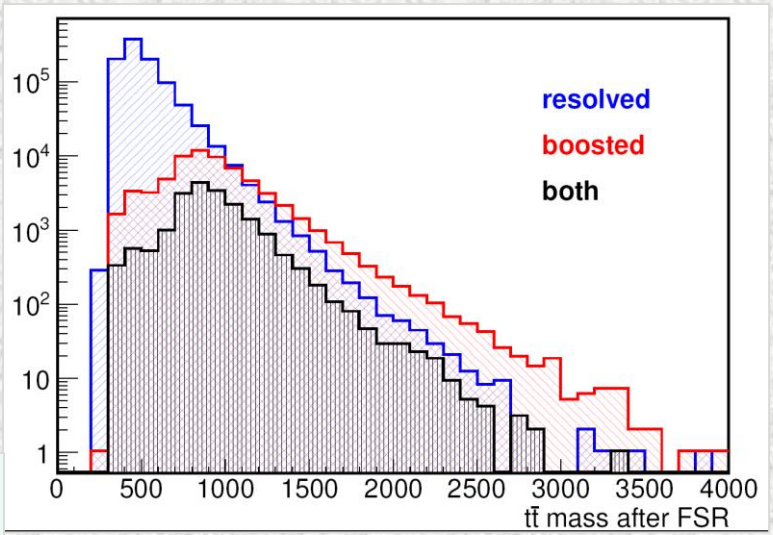


resolved topology



boosted topology

- ✓ Development of common code for resolved + boosted topology.
- ✓ Preliminary results obtained at 36 fb^{-1}
- ✓ Basic studies are carried out using sample of 36 fb^{-1} → publ. at 80 fb^{-1}

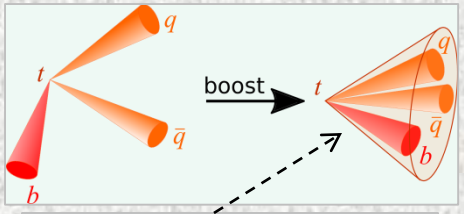


Resolved a boosted topologies - complementarity

Boosted objects

Boosted top quark and W boson's objects

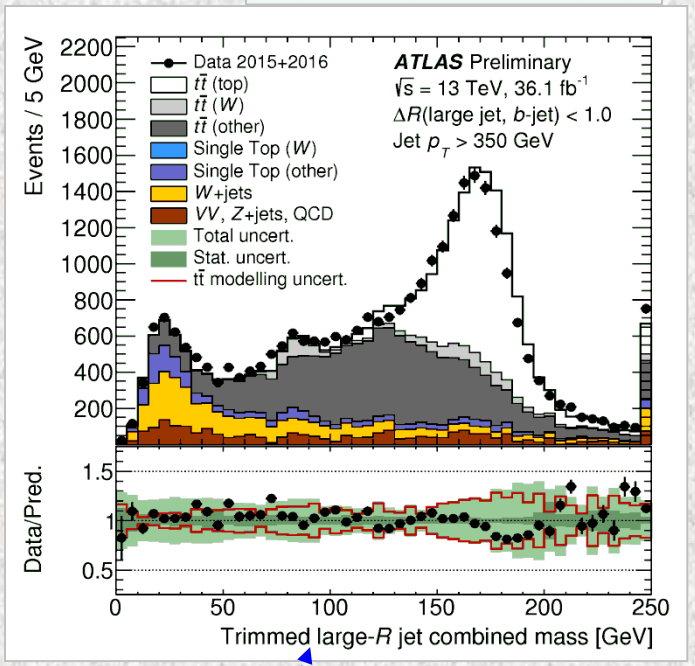
- Thesis: **O. Majerský**
- Partners: Geneva University



Boosted top object

Goal: measurement of various taggers of so-called boosted top quarks and *W* bosons at √s of 13 TeV.

- ✓ Development of reconstruction procedure for boosted objects
- ✓ Tunning of MC modeling on data
- ✓ Measurement of signal efficiency
- ✓ Systematic uncertainties

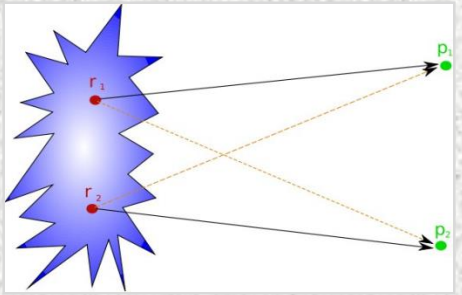


Invariant mass of big jet initiated by top quark (ATLAS-CONF-2017-064)

Bose-Einstein correllation studies

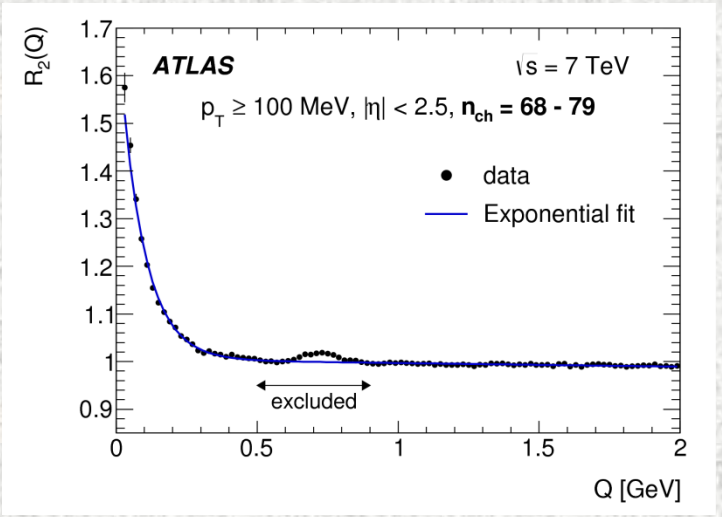
Bose-Einstein correlations in pp collisions at √s= 7 - 13 TeV

- Partners: JINR Dubna, thesis: S. Hyrych



Two particle correlation investigated: $C_2(Q) = \frac{P(p_1, p_2)}{P(p_1)P(p_2)}$

- ✓ analysis at 7 TeV published: EPJC 75 (2015) 466
- ✓ Analysis at 13 TeV finished - note and paper draft at EdBoard.
  - $C_2(Q)$ corrected by MC → $R_2(Q)$
  - „Bayesian unfolding“ used to take into account detector effects
  - basic BEC parameters (R, λ) extracted
- ✓ analysis at √s= 8 TeV – influence of jets on BEC effect.
- ✓ R.2018: 3D-analysis started.



$$R_2(Q) \sim 1 + \lambda \exp(-RQ),$$

$$Q = \sqrt{\left|(p_1 - p_2)^2\right|}$$

Hadronization radius

Study of intrinsic charm of proton

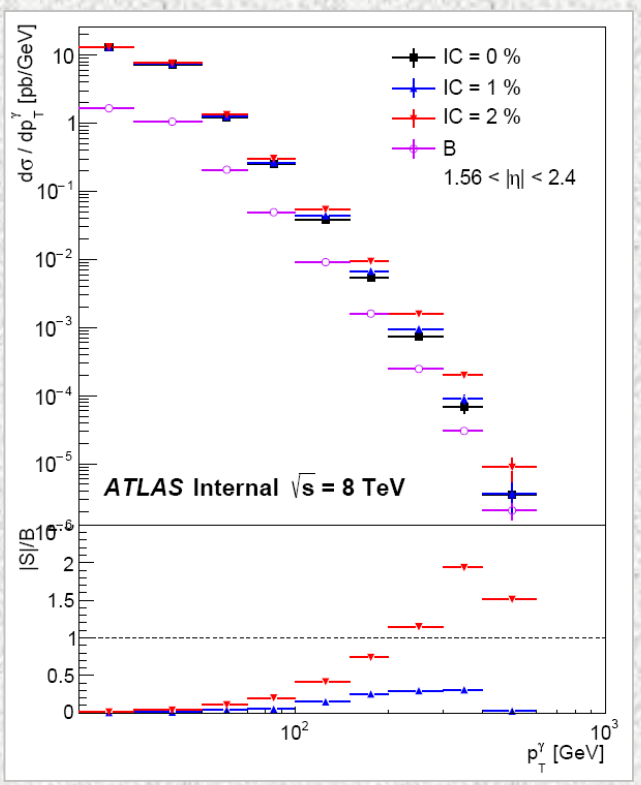
Study of intrinsic charm in proton – using published ATLAS **γ – jet** events

- ✓ Thesis: **J. Smieško**
- ✓ Partners: JINR Dubna

Goal: to explore presence of intrinsic charm in proton: $p \equiv w_1 \left|uud\right\rangle + w_2 \left|uud\bar{c}\bar{c}\right\rangle$

Status:

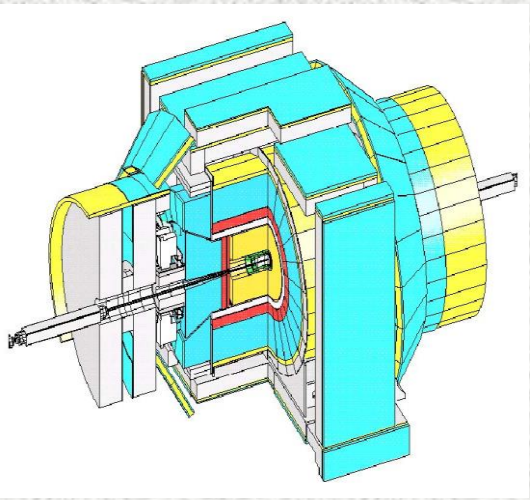
- Simulated data with intrinsic charm (IC) in proton: experiment ATLAS has a potential to determine of IC presence in proton, using sample of 20 fb^{-1} at 8 TeV provided the weight of effect is at level $\geq$ 2%.
- Obtained an upper limit on presence of the IC in proton the paper sent to Phys. Rev. Lett.



A review article on the intrinsic charm written and published:
Prog. Part. Nucl. Phys. 93 (2017) 108 (together with JINR Dubna + S. Brodsky)

Joint Slovak team in the CDF experiment

Tevatron was stopped in 2011 - physics analysis continued Bratislava (P. Bartos, O. Majersky and S. Tokar) and Košice (J. Antos, R. Lysak) joint Slovak team worked in heavy flavour and top quark:



- Top quark determination – exotic quark with charge -4/3 excluded at 95% C.L. (Phys. Rev. D88 (2013) 032003)
- Forward-Backward asymmetry in bb production – the asymmetry found to be compatible with the SM prediction (Phys. Rev. D 93 (2016) 112003)
- A lot of work as Reading institute and „Godparents“ (expert scrutiny of other analyses)

Present activity:

- ✓ Bratislava team work on determination of the top quark mass in lepton+jets mode using the full CDF statistics.)
- ✓ Two students (D. Babál, J Senderák) joined to the analysis.
- ✓ Result is expected during 2018.

Organized conferences and meetings

Conferences, workshops, meetings organized by Slovak cluster:

- Physics in Collisions in Štrbské Pleso, High Tatras, September 2012
- ATLAS Hadron Calibration Workshop in Bratislava, September, 2015
- OVERVIEW ATLAS Week Meeting in Bratislava, October 2017

Organization of (regular) workshops:

- Special Tile IB on Upgrade at Bratislava, September 2015
- CZ-SK workshop on collider physics (the nearest on organized in Košice, June,7-8, 2018)
- GRID workshop on LHC computing (the last one in High Tatras 2017)
- Master classes organized not only in Bratislava and Košice, but also in other Slovakian cities.

Outreach activities

- Popular presentations for high schools and general public
  - ✓ Day of CERN was organized in Bratislava and Košice in March 2015 with Special presentations devoted to LHC experiments.
  - ✓ Popular presentations on the present elementary particles physics for high schools in many cities of Slovakia - organized yearly.
  - ✓ Night of researcher organized regularly – usually in September.
- Performances in Slovak TV and Radio, newspapers and journals
  - ✓ Particle physics, from collider experiments attracts attention of the Slovak media.
  - ✓ The particle physics issues are regularly discussed on TV, Radio or in newspapers-Journals - a few performances per year.
  - ✓ E.g. in 2017 (Overview ATLAS Week) we or our guests have 8 performances on TV

Conclusions

- Experiment ATLAS it is an outstanding opportunity for scientists of Slovakia, especially young people, to be in contact with frontier high energy physics.
- Our teams contributed quite a lot to the ATLAS calorimetric system in each step of its construction, testing, commissioning...
- We actively participate in physics studies (top physics, QCD) and we are ready to do our best for a success of ATLAS.
- We still believe that ATLAS (along with other LHC experiments) will provide us with exciting discoveries that will promote particle physics to deeper understanding of Nature.
- In CERN experiments we have reached a global unification of people of different nations - hopefully this example will have a positive impact on all other mankind activities.

Thank you !