SK contributions to the ATLAS experiment

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(Comenius University)

30th anniversary of the accession of the SR to CERN

with contributions from:
P. Stríženec (IEP), I. Sýkora (CU), S. Tokár (CU)

27 June 2023, Bratislava

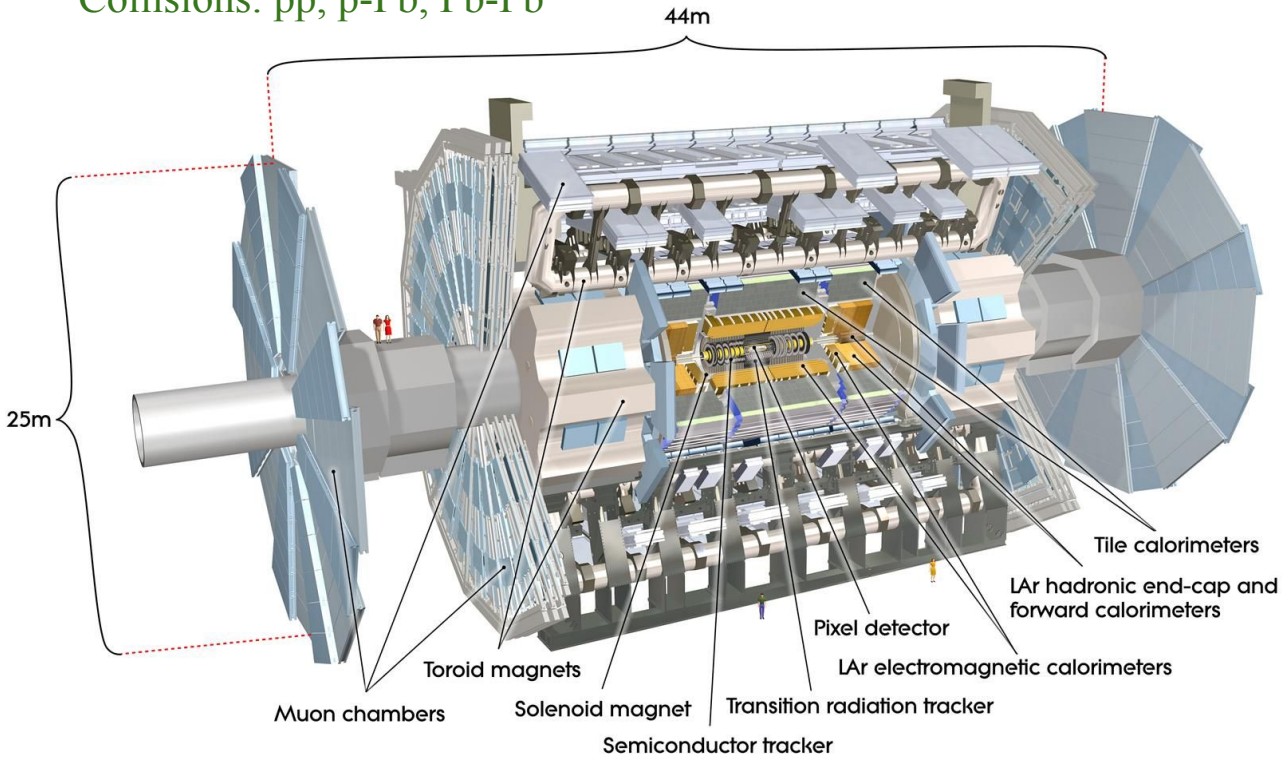
Outlook

- Experiment ATLAS – basic facts
- Participation of Slovak teams in building of ATLAS
- Present activities in maintenance and operations
- Detector upgrade
- Physics analysis
- Outreach
- Conclusions

ATLAS detector

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

Collisions: pp, p-Pb, Pb-Pb



- Inner Detector
  $\sigma/p_T \approx 0.05\,\% \cdot p_T(\mathrm{GeV}) \oplus 0.1\%$
  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 $|\eta| < 2.7$

ATLAS experiment: goals, status

Basic goals of the ATLAS experiment

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

Present status of the research by ATLAS:

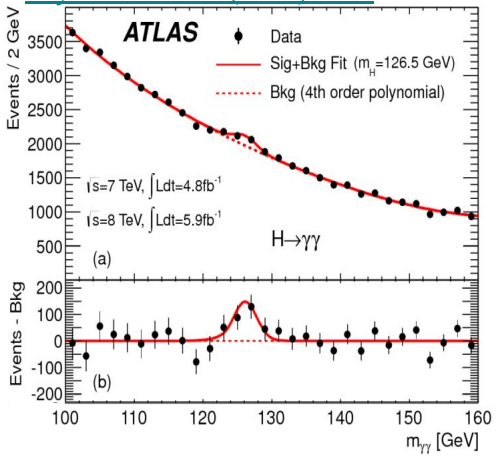
- Discovery of the Higgs boson together with the CMS (2012)
  - ATLAS+CMS: $\boldsymbol{M}_{\mathrm{H}} = 125.09 \pm 0.24$ GeV
- The observed boson is fully compatible with the SM Higss boson
- Precision tests within top quark physics, EW physics, *B*-physics, jet physics, searches for exotic physics

No significant sign of physics beyond the SM!

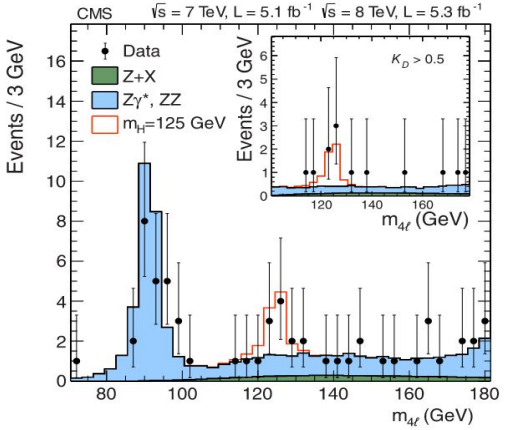
=> Extended borders of validity of the SM!

Total number of ATLAS publications: > 1000

Phys. Lett B 716 (2012) 1–29



Phys. Lett. B 716 (2012) 30–61



ATLAS experiment: goals, status

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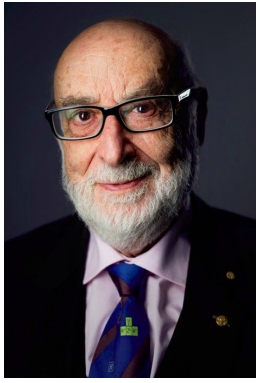
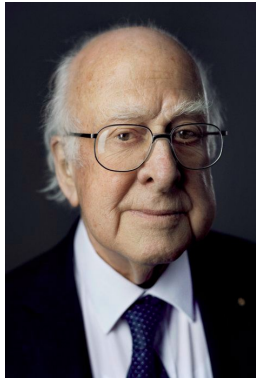
Nobel prize for Physics 2013

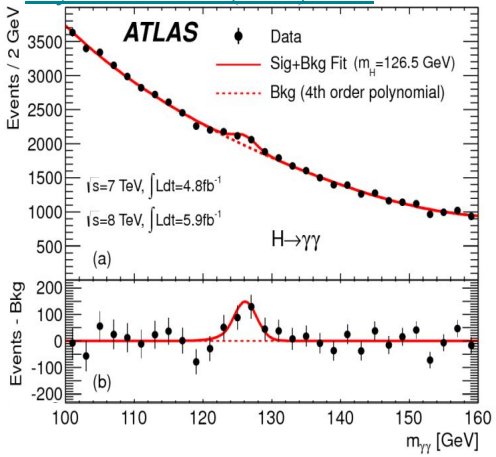


François Englert



Peter W. Higgs

Phys. Lett B 716 (2012) 1–29



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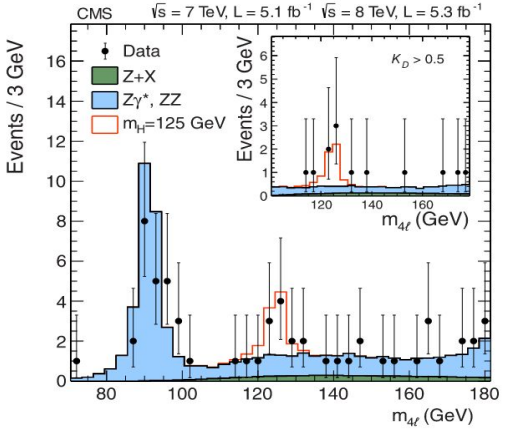
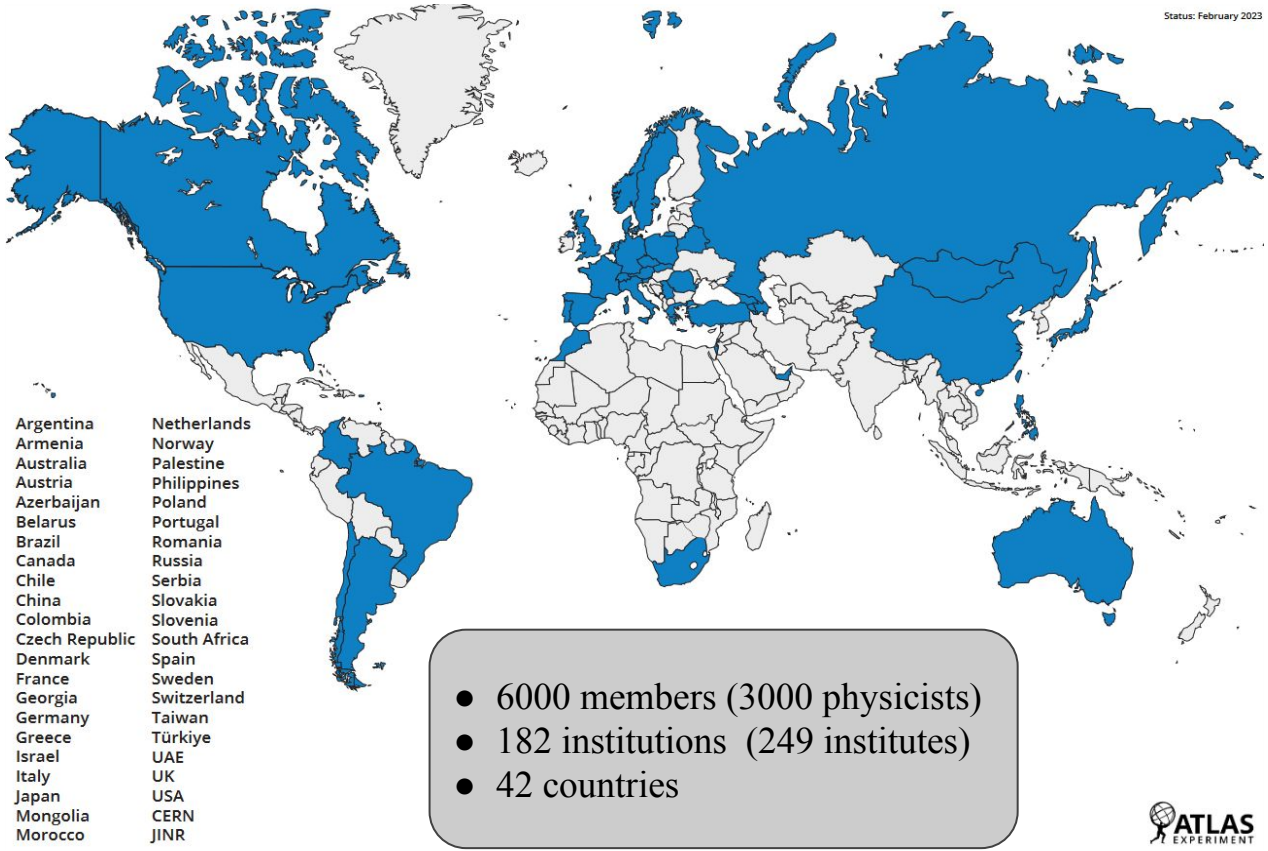


ATLAS collaboration



- 6000 members (3000 physicists)
- 182 institutions (249 institutes)
- 42 countries

Slovak cluster

Institute of Experimental Physics of Slovak Academy of Science, Košice

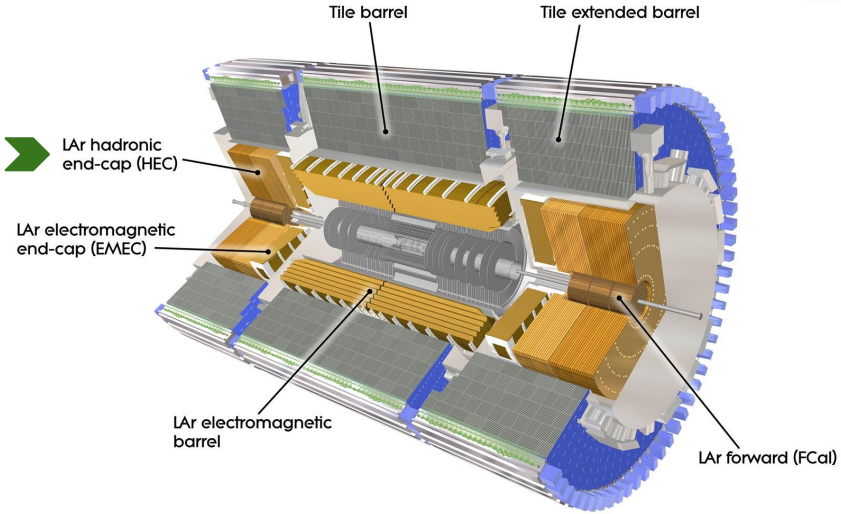
- 4 physicists
  (2 former PhD students)
- 4 engineers

Comenius University, Bratislava Faculty of Mathematics, Physics and Informatics

- 7 physicists
- 3 PhD students
- 1 technician
- 2 und. students

Contribution to ATLAS construction

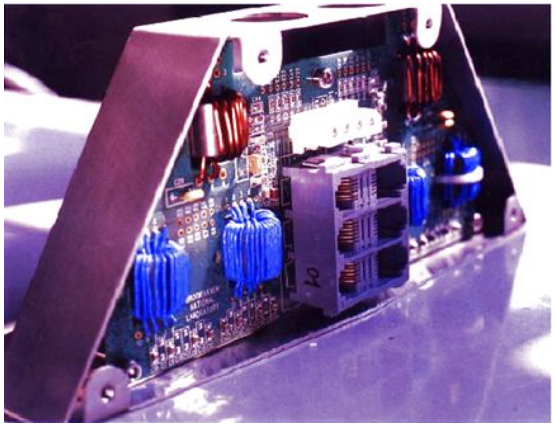
ATLAS calorimetry



- Košice team: Hadronic LAr End Cap calorimeter (HEC) – sampling calorimeter using liquid argon as active medium

Hardware activities (Košice)

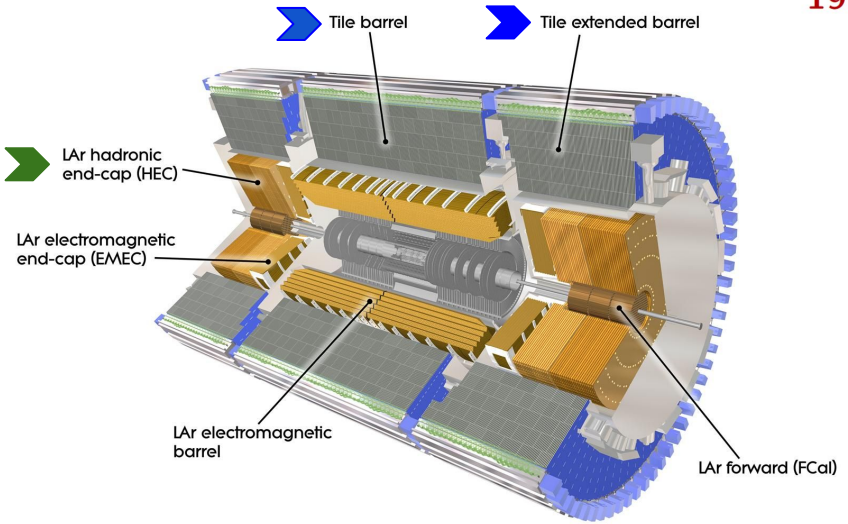
- Development, production and tests of Forward readout board (HEC) (with Columbia Univ.)
- Production of so-called cold electronics (HEC)



Filter box **produced in Košice** for full ATLAS calor. designed by Brookhaven National Laboratory

Contribution to ATLAS construction

ATLAS calorimetrv



- Košice team: Hadronic LAr End Cap calorimeter (HEC)
- Bratislava team: Hadronic Tile calorimeter – scintillator tile + fibers

Hardware activities (Bratislava)

- Iron plates for Tile calorimeter
- Angle bracket for Tile modules manipulations
- Tests of photomultipliers (Tile) using single photoelectron approach
- Reconstruction of calorimeter response to pions (linearity, homogenity, energy resolution)
- Method of energy reconstruction using topology of hadronic shower
- Method of fast simulation of hadronic calorimeter

Both teams: in assembling and commissioning of Calo's

Detector maintenance and operation

Present activities

Košice team:

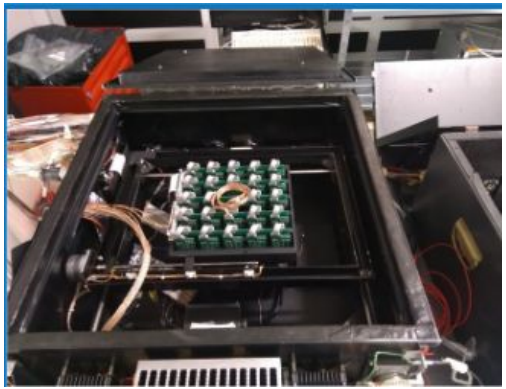
- Responsibility for electronics calibration for the ATLAS LAr calorimetry
- Performance studies of various aspects of the LAr calorimetry, data preparation tasks
- Software and data preparation Coordination
- LAr Steering Group and LAr Management Group
- LAr Speaker Committee

Bratislava team:

- ATLAS shifts in control room – data accumulations
- Software development for Tile Data Quality (DQ)
- DQ coordinator for TileCal
- TileCal Speaker Committee

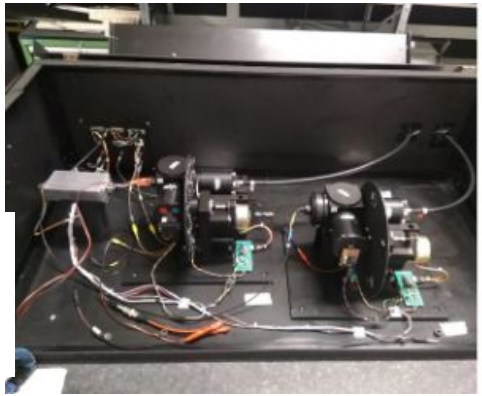
Detector (Tile) upgrade

- **PMT response degrades** over time with large sample-to-sample spread in response loss as a function of the integrated anode charge.
- **TileCal will replace** PMTs whose response loss could exceed 25% if operated until the end of the HL-LHC data taking (from 2029) – **1,000** of 10,000 **PMTs** have to be replaced
- Three almost identical **test bench**es operating **in Bratislava**, Pisa and CERN
  - Test-bench transported from Clermont-Ferrand to Bratislava (20 Sep 2019)
  - Commissioning phase completed by February 2022
  - Test of the result uniformity of the different labs (completed in July 2022)



A box containing a movable grid with PMTs under test and Peltier cells for thermal stabilization

An optics box with 2 light sources (DC LED, Pulsed LED), filter wheels and photodiode monitors



Physics analysis

Top quark physics studies:

- top quark charge: JHEP11 (2013) 031
- top quark decay width: Eur. Phys. J. C 78 (2018) 129
- charge asymmetry in top quark pair production arXiv, hep-ex 2208.12095, accepted by JHEP
- associated production of $t\bar{t}Z$:
  - Phys. Rev. D 99 (2019) 072009, Eur. Phys. J. C 81 (2021) 737, + NEW ongoing
- top quarks entanglements (ongoing)

Intrinsic charm in proton via ℓ+jets events: Eur. Phys. J. C (2019) 79:92

Soft QCD:

- Bose-Einstein correlations:
  - Eur. Phys. J. C 75 (2015) 466, Eur. Phys. J. C 82 (2022) 608, + NEW ongoing
- Minimum bias (ongoing)

Charge asymmetry

sensitive variable: $\Delta|y| = |y_t| - |y_{\bar{t}}|$

$$A_C^{t\bar{t}} = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

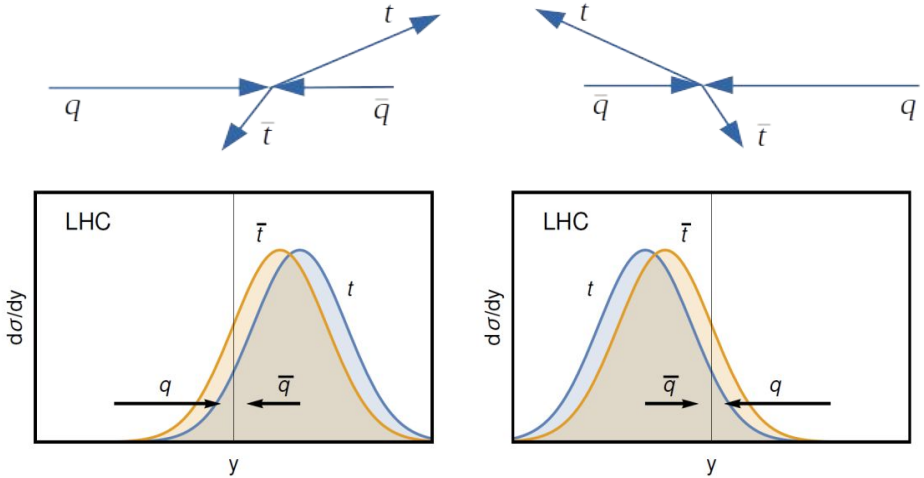
Goal: to measure inclusive and differential charge asymmetry in $t\bar{t}$ production
→ effect of higher order corrections in perturbative QCD

Cooperation: Mainz, Kobe, Birmingham

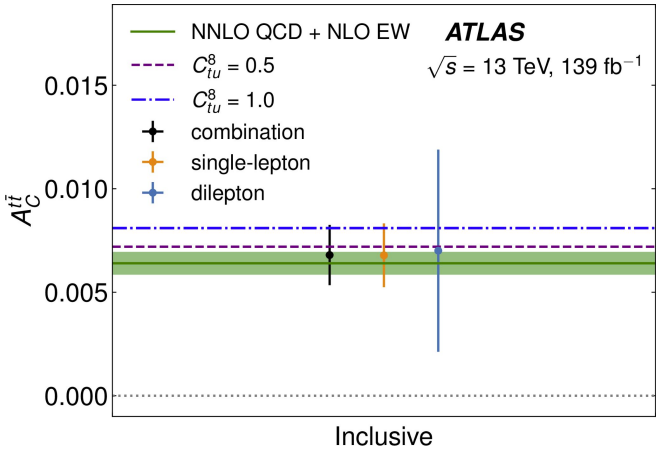
arXiv, hep-ex 2208.12095, accepted by JHEP

Our contribution:
– single-lepton decay channel
– **analysis contact**, **main analyzers** from Slovak cl.

Δ|y| > 0 : top in q direction



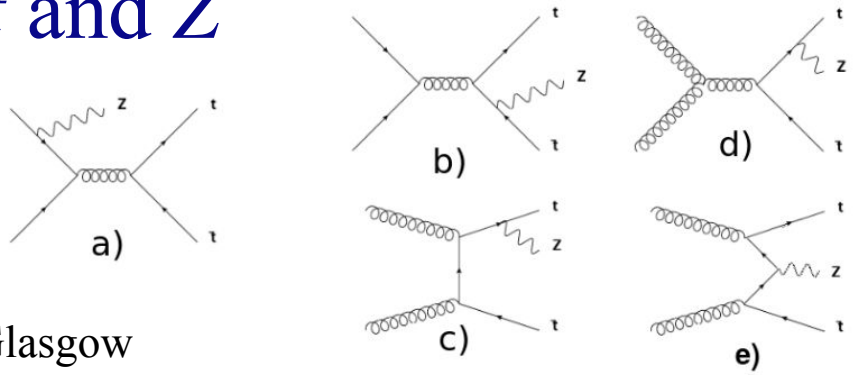
Δ|y| < 0 : top in q̄ direction



Non-zero excess of $A_C^{t\bar{t}} = 4.7\sigma$ in inclusive case for combination

Associated production of $t\bar{t}$ and Z

Goal: to measure inclusive and differential production cross section of $t\bar{t}Z$
→ test of SM (coupling top quark and Z boson)



Cooperation: Bonn, Mainz, Goettingen, Sussex, Glasgow

Phys. Rev. D 99 (2019) 072009

Our contribution:

– inclusive fit in 2ℓ decay channel

– **main analyzer** from Slovak cluster

Fit configuration	$\mu_{t\bar{t}Z}$	$\mu_{t\bar{t}W}$
Combined	1.08 ± 0.14	1.44 ± 0.32
2ℓ-OS	0.73 ± 0.28	–
3ℓ $t\bar{t}Z$	1.08 ± 0.18	–
2ℓ-SS and 3ℓ $t\bar{t}W$	–	1.41 ± 0.33
4ℓ	1.21 ± 0.29	–

Eur. Phys. J. C 81 (2021) 737

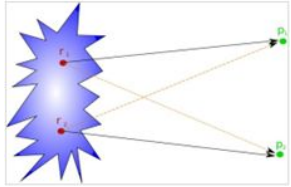
Our contribution:

– inclusive fit in 4ℓ decay channel and all differential measurements

– **main analyzers** from Slovak cl.

Channel	$\mu_{t\bar{t}Z}$
Trilepton	$1.17 \pm 0.07\,(\text{stat.})\,^{+0.12}_{-0.11}\,(\text{syst.})$
Tetralepton	$1.21 \pm 0.15\,(\text{stat.})\,^{+0.11}_{-0.10}\,(\text{syst.})$
Combination ($3\ell + 4\ell$)	$1.19 \pm 0.06\,(\text{stat.}) \pm 0.10\,(\text{syst.})$

Bose-Einstein correlation studies



Goal: to measure Bose-Einstein correlations in *pp* collisions at $\sqrt{s}$ = 7 – 13 TeV

→ characteristics of hadronization region

→ Two particles correlation investigated: $C_2(Q) = \frac{P(p_1 . p_2)}{P(p_1)P(p_2)}$

Cooperation: Pisa, JINR Dubna

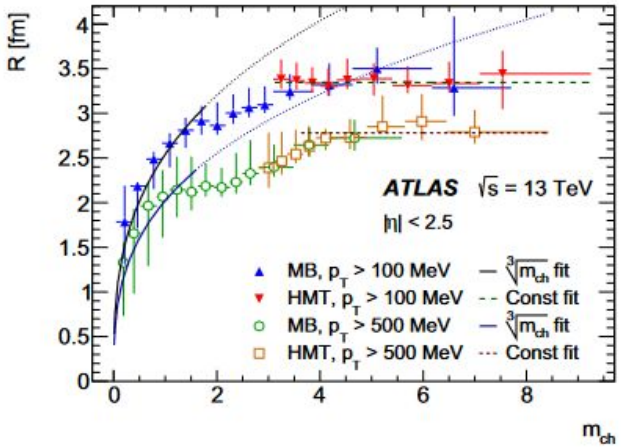
- 7 TeV analysis published: Eur. Phys. J. C 75 (2015) 466
- 13 TeV analysis published: Eur. Phys. J. C 82 (2022) 608
  - C_2=(Q) corrected by MC → R_2=(Q)

$$R_2(Q) = 1 + \lambda \exp(RQ)$$

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

  - basic BEC parameters (R, λ)

R – hadronization radius



- Ongoing: 3D – analysis

Our contribution:

– **main analyzers** from Slovak cl.

Organized conferences and meetings

- Physics in Collisions, Štrbské pleso, High Tatras, September 2012
- ATLAS Hadron Calibration Workshop, Bratislava, September, 2015
- Overview ATLAS collaboration week, Bratislava, October 2017
- Several ATLAS CZ+SK workshops, Bratislava / Košice / Žilina

Outreach activities

- Exposition about CERN – project LHC / ATLAS and ALICE
  - at 8 places during 2009-2010, 167 days
  - 30 popular presentations on high energy physics matter
  - visited by 295 groups; 15,000 visitors
- Popular presentations for high school and general public
  - day of CERN was organized in Bratislava and Košice when first collisions occured
  - special presentations devoted to LHC experiments (also on CDs)
- 10th anniversary of Higgs boson observation (whole particle physics comm.)
  - Presentations and panel discussions, Bratislava, Košice, Banská Bystrica
- Pohoda (2019), each year Masterclasses, Night of science
- Performance in Slovak TV and Radio, newspapers and journals

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, soft QCD) and we are ready to do our best for a success of ATLAS
- We are optimistic and 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!

Back up

ATLAS in numbers

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

Luminosity $2\times10^{34}\ cm^{-2}\ s^{-1}$: ~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