LHCP2015 Poster Session , 1 September 2015

Search for Quantum Black Holes in lepton and jet final state using pp collisions at √s = 8 TeV with the ATLAS

Introduction

Data were collected for 20.3 fb^{-1} @ 8 TeV.

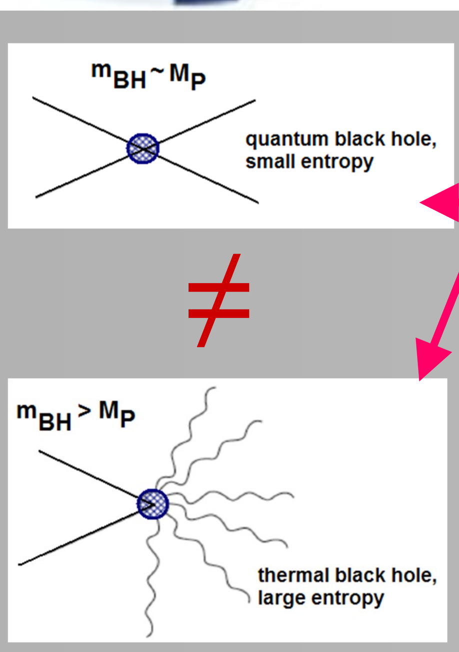
. *Why LHC?* Quantum Black Holes (QBHs) are predicted in low-scale quantum gravity theories that offer solutions to the mass hierarchy problem of the Standard Model (SM) by lowering the scale of quantum gravity (M_D) from the Planck scale (~10^{16} TeV) to ~1 TeV. That is why a search region for invariant masses of QBH was checked near 1-10 TeV. Here M_D is a multi-dimensional mass of QBH.

. *Signature.* The QBH's decay mode is assumed with 1 lepton (electron or muon) and a jet in final state. This mode has the best branching and Signal to Background ratio.

. *Features.* QBHs with masses near M_D have to conserve total angular momentum, color and electric charge. The most important: a behavior of QBHs differs from semi-classical black holes, which decay via Hawking radiation to a large number of objects (at the left).

. The Large Extra Spatial Dimension Model with n compact extra dimensions with a gravitational radius R was suggested by Arkani-Hamed, Dimopoulos and Dvali (ADD) [1-3].

[1] N. Arkani-Hamed, S. Dimopoulos, and G. R. Dvali, Phys. Lett. B 429, 263 (1998), arXiv:hep-ph/9803315.
[2] I. Antoniadis, N. Arkani-Hamed, S. Dimopoulos, and G. R. Dvali, Phys. Lett. B 436, 257 (1998), arXiv:hep-ph/9804398.
[3] N. Arkani-Hamed, S. Dimopoulos, and G. R. Dvali, Phys. Rev. D 59, 086004 (1999), arXiv:hep-ph/9807344.



Shortly about ADD-model

The Large Extra Spatial Dimension Model with n compact extra dimensions

. The multi-dimensional Planck scale is assumed to be equal to the electroweak scale $M_D = M_{EWK}$, for removing the hierarchy problem. Where the electroweak scale is M_{EWK} ~1 TeV and the true Planck scale is equal M_{Pl}~10^{16} TeV. Than the gravity becomes strong, and quantum effects are important. The true Planck Scale M_{Pl} is related to multi-dimensional one as:

$$M_{Pl}^2 \sim M_D^{2+n} R^n$$

. Extra spatial dimensions are large, i.e. the radius R could be from ~1 μm up to 1 mm.

. According to the ADD scenario it is expected, that the microscopic black holes should form, when collisions energy will exceed a certain threshold mass M_{th}. It can be above M_D, but far below M_{Pl}. This phenomenology of black holes production must be markedly distinguished.

Semi-classical case. If the black hole was produced far above threshold M_{th}, then it can decay into large quantity of objects via the Hawking radiation.

Case of Quantum Black Hole. QBH could form near threshold M_{th}. Later it can decay into the two-body final states. The production of QBH close to M_{th} dictates a possible quasi-resonant final state with an observable enhancement for a certain invariant mass.

About branching fractions

. The largest cross section of QBH production for final state with lepton and jet depends on initial state.

. *For initial two u-quarks* and objects with electric charge of +4/3 the branching fraction BF=11%.

. *For initial ud-quarks* and objects with charge of +1/3 the branching fraction BF=5.7%.

. *For initial dd-quarks* and objects with charge of −2/3 the branching fraction BF=6.7%.

. Processes with initial states of anti-quarks and heavier sea-quarks are suppressed by a factor of ~100.

Event selection

1) In the electron (muon) channel events are required to have exactly 1 electron (muon).

2) Electron candidates are identified as localized depositions of energy in the EM calorimeter with p_{Te}>130 GeV and |η|<2.47, excluding the barrel-endcap transition region, 1.37<|η|<1.52, and matched to a track reconstructed in the tracking detectors.

3) Isolated electrons are selected by requiring the transverse energy deposited in a cone of radius $\Delta R=\sqrt{(\Delta\eta)^2+(\Delta\varphi)^2} = 0.3$ centered on the electron cluster, excluding the energy of the electron cluster itself, to be less than ($0.0055p_{Te}$+3.5) GeV after corrections for energy due to pileup and energy leakage from the electron cluster into the cone.

4) Muon candidates are required to be detected in at least three layers of the muon spectrometer and to have p_T>130 GeV and |η|<2.4.

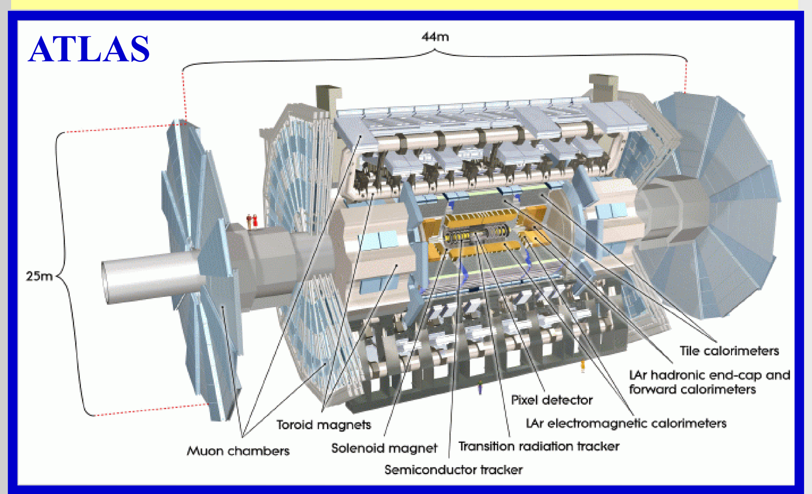
5) Signal muons are required to be isolated such, that Σp_T<$0.05 \times p_{T\mu}$, where Σp_T is the sum of the p_T of the other tracks in a cone of radius ΔR=0.3 around the direction of the muon.

6) Jets are constructed from three-dimensional noise-suppressed clusters of calorimeter cells using the anti-kt algorithm with a radius parameter of 0.4. All jets are required to have p_T>50 GeV and |η|<2.5. In addition, the most energetic jet is required to have p_T>130 GeV.

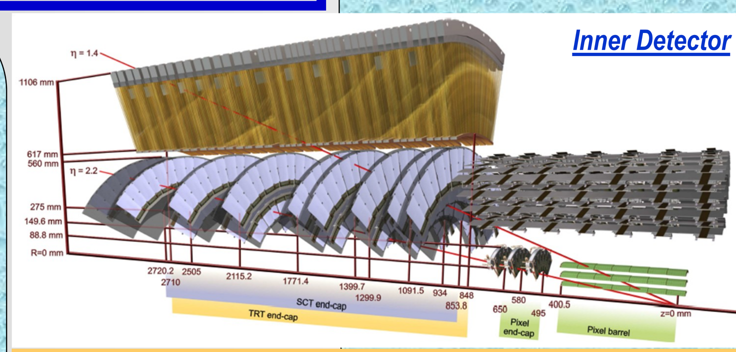
The experimental efficiency falls from 89(59)% to 81(50)% for masses QBH from 1 TeV to 6 TeV in the electron (muon) channel.

[4] Search for Quantum Black Hole Production in High-Invariant-Mass Lepton+Jet Final States Using pp Collisions at √s = 8TeV and the ATLAS Detector, The ATLAS Collaboration, Phys.Rev.Lett. 112 (2014) 091804 (2014-03-05), DOI: 10.1103/PhysRevLett.112.091804 CERN-PH-EP-2013-193, e-Print: arXiv:1311.2006v2 [hep-ex].

Detector



. Cut-away view of the ATLAS detector. The dimensions of the detector are 25 m in height and 44 m in length. The overall weight of the detector is approximately 7000 tonnes.
. ATLAS is a multipurpose detector with a forward-backward symmetric cylindrical geometry and it covers about 4π of solid angle. Identification of vertex, electrons, muons and jets and measurement of energy and momentum are achieved by a combination of different detectors and systems.
. They are Magnetic system, Inner Detector, Liquid-argon electromagnetic calorimeter, Hadronic calorimeters and Muon system.



The ATLAS Inner Detector (ID) is designed to provide hermetic and robust pattern recognition, excellent momentum resolution and both primary and secondary vertex measurements for charged tracks.

The ID is contained within a cylindrical envelope of length 3512 mm and of radius 1150 mm. Point z=0 mm is a point of the protons colliding.

Backgrounds for Quantum Black Holes

Dominant backgrounds obtained from Monte Carlo simulation:

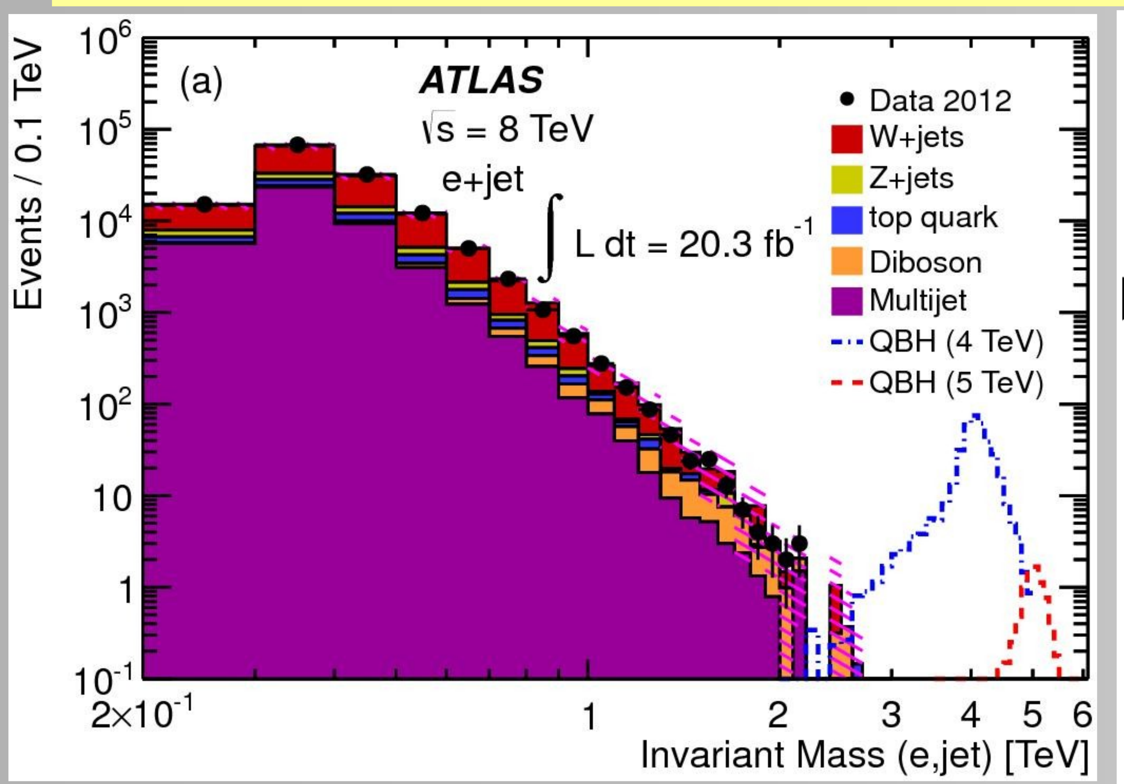
1) W+jets,
2) Z+Jets;
3) Dibosons: WW, WZ, ZZ;
4) ttbar pairs;
5) Single top-quarks;
6) Multijets (QCD).

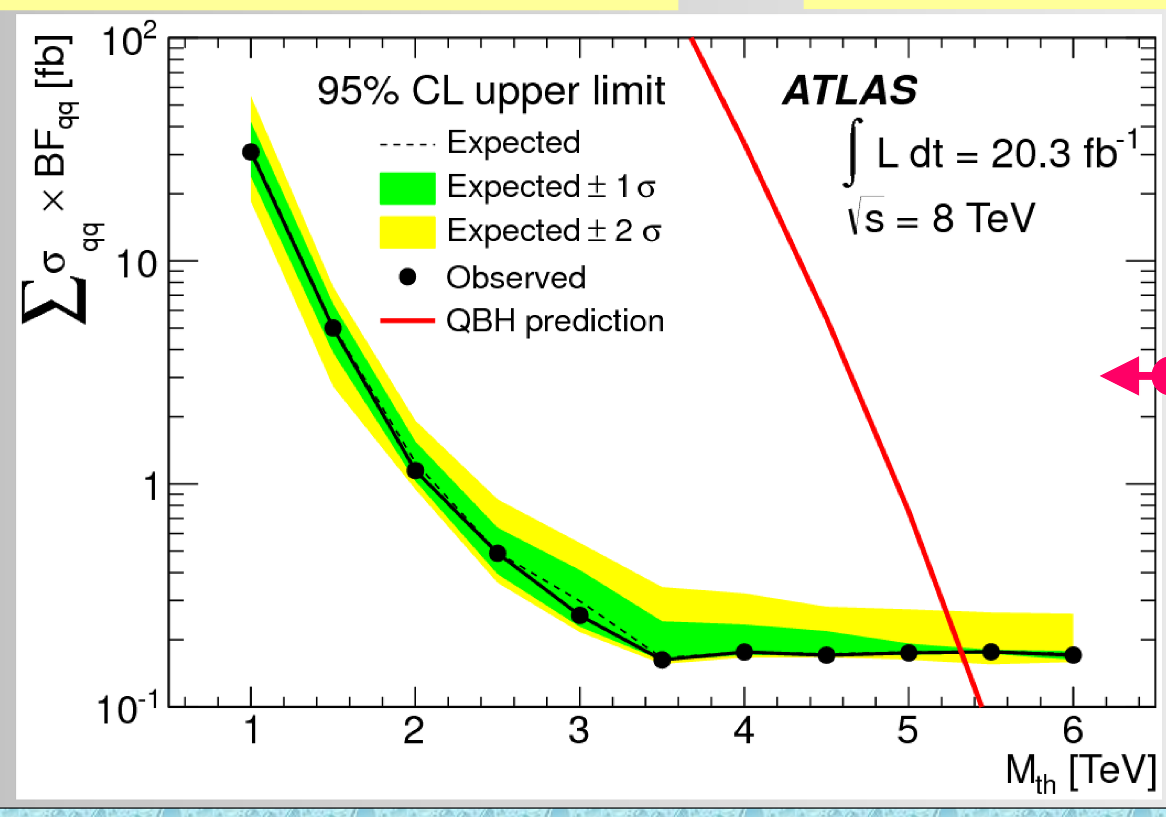
. Events with a high p_T of lepton and 1 or more jets can arise from electroweak processes. They include a vector-boson production with additional jets and dibosons (WW, WZ, ZZ). Strong processes include top-quark pairs (ttbar), a single top-quark (t or tbar) and multijets (QCD) production. Last can be include non-prompt leptons of semileptonic hadron decays and jets, which were misidentified as leptons.

. The electroweak background in Signal Region was estimated using Monte Carlo samples, normalized to data in Control Regions. Simulation was based on GEANT4 and with the corresponding model of the ATLAS detector geometry.

. Additional inelastic proton-proton's interactions, termed pileup, were included into the event simulation thus, in order to accord with the data distribution over number of interactions per bunch crossing. Average number of interactions per bunch crossing was about 21.

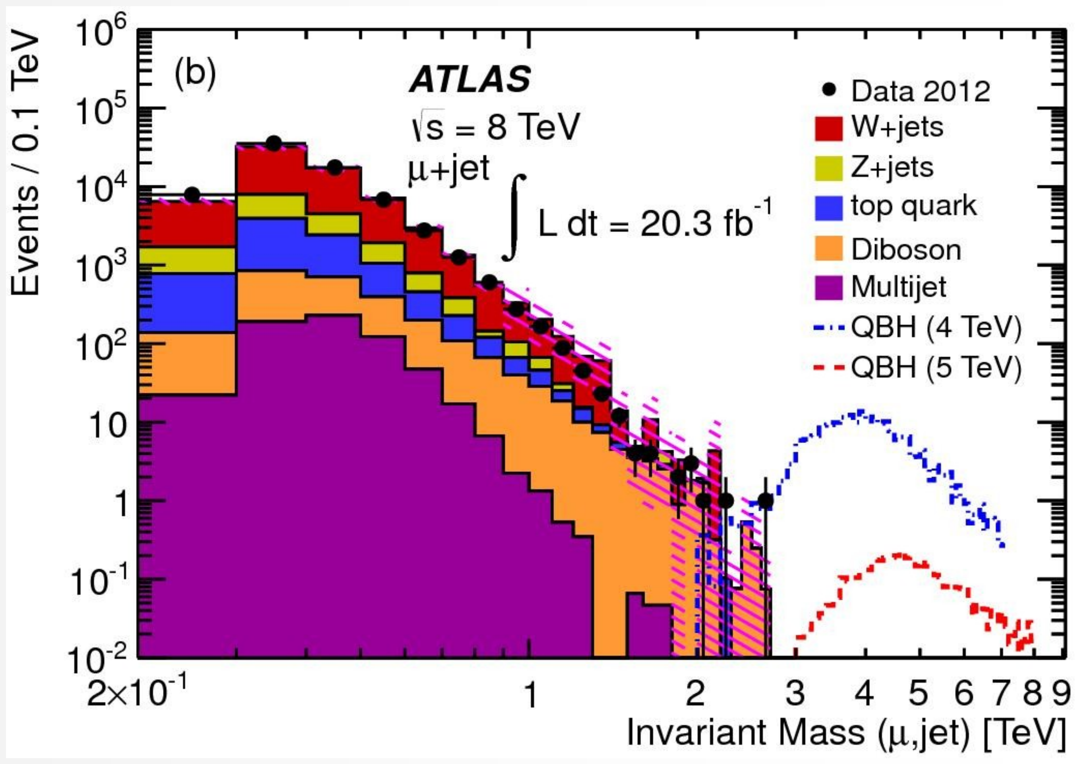
Results of the searching for QBH in RUN-I (8 TeV) at the ATLAS (1)





Results of the searching for QBH in RUN-I (8 TeV) at the ATLAS (2)

. The combined 95% CL upper limits on $\Sigma\sigma_{qq}\times BF_{qq}$ for QBHs decaying to a lepton+jet, as a function of M_{th}, assuming M_D=M_{th} and n=6 of ADD extra dimensions. Region above line with points is excluded. The limits take into account statistical and systematic uncertainties. The upper limit is M_{th} = 5.3 TeV. Masses M_{th}≤5.3 TeV were excluded in result.



e + jet channel

Distribution of the *Invariant Mass* of the lepton and highest-p_T jet in the electron+jet channel for data (this are points with error bars) and for SM backgrounds (they are solid histograms).

Some total comments for left and right panels.

. Two examples for the QBH signals are pointed with help of curves of the blue and red colors. Blue line – it is a simulation of QBH with the invariant mass, which is equal 4 TeV. Red line – it is the simulation of QBH with the invariant mass, which is equal 5 TeV.
. Hatched area shows the sum of uncertainties related to the finite Monte Carlo (MC) sample size and various sources of systematic uncertainties.
. To get the upper limit for the lepton+jet cross section, a fit of the invariant mass distribution was done, by method replacing the MC sample size uncertainties by the statistical uncertainties with the fit parameters.

μ + jet channel

Distribution of the *Invariant Mass* of the lepton and highest-p_T jet in the muon + jet channel for data (this are points with error bars) and for SM backgrounds (they are solid histograms).

Results of the searching for QBH in RUN-I (8 TeV) at the ATLAS (3)

Source	Electron+jet %	Muon+jet %
Lepton reconstruction, scale and resolution	$^{+2}_{-1}$	$^{+30}_{-7}$
Jet reconstruction, scale and resolution	$^{+31}_{-15}$	$^{+5}_{-5}$
Multijet modeling	$^{+27}_{-27}$	-
PDF	$^{+52}_{-33}$	$^{+100}_{-69}$
Fit	$^{+77}_{-77}$	$^{+130}_{-71}$
Total	$^{+100}_{-89}$	$^{+170}_{-100}$

TABLE I. Breakdown of relative systematic uncertainties on the Standard Model background for the threshold mass M_{th}=5 TeV. The uncertainties are added in quadrature to obtain the total uncertainty.

Struggle against the systematic uncertainties

. *The systematic uncertainties* on the background are evaluated as a function of m_{inv}.
. *The systematic uncertainties* caused by uncertainties of PDFs in the Monte Carlo generators: SHERPA and ALPGEN.
. *The systematic uncertainties* from the simulation of the detector response are associated with the jet and electron energy scales and resolutions, and also the muon momentum scale and resolution, and also with the trigger requirement efficiency.
. *For the electron channel* the combined uncertainty on the background prediction ranges from 16% at 1 TeV up to 100% at 6 TeV.
. *For the muon channel* the combined uncertainty on the background prediction ranges from 50% at 1 TeV up to 170% at 6 TeV.
. *Background systematic uncertainties* for M_{th} = 5 TeV are given in Table I (at the left).

Results of the searching for QBH in RUN-I (8 TeV) at the ATLAS (4)

M_{th}	Electron+jet Obs.	Electron+jet Exp.	Electron+jet Eff.	Muon+jet Obs.	Muon+jet Exp.	Muon+jet Eff.
TeV			%			%
1.0	1200	1210^{+230}_{-220}	57 ± 4	620	550 ± 280	38 ± 4
1.5	100	110 ± 40	57 ± 4	49	65^{+45}_{-40}	36 ± 4
2.0	12	19^{+13}_{-12}	56 ± 4	8	14^{+16}_{-14}	36 ± 4
2.5	0	$5.3^{+4.5}_{-3.9}$	55 ± 4	3	5^{+6}_{-5}	34 ± 4
3.0	0	$1.8^{+1.8}_{-1.6}$	54 ± 4	1	$2.1^{+2.9}_{-2.1}$	34 ± 4
3.5	0	$0.76^{+0.79}_{-0.67}$	54 ± 4	0	$1.0^{+1.6}_{-1.0}$	33 ± 4
4.0	0	$0.35^{+0.38}_{-0.34}$	53 ± 4	0	$0.57^{+0.94}_{-0.57}$	33 ± 5
5.0	0	$0.09^{+0.10}_{-0.09}$	52 ± 4	0	$0.24^{+0.39}_{-0.24}$	32 ± 5
6.0	0	$0.03^{+0.04}_{-0.03}$	52 ± 4	0	$0.13^{+0.22}_{-0.13}$	32 ± 6

TABLE II. Numbers of expected background (Exp.) and observed (Obs.) events along with the cumulative signal efficiencies (Eff.), with uncertainties including the statistical and systematic components for various M_{th}. Number of events are integrated above m_{inv} corresponds to the preset M_{th}.

Struggle against the systematic uncertainties

. *The uncertainties on the signal efficiency* are associated with the requirements on Δη, Δφ, <η>, m_{inv}, isolation. Also we take into account the *uncertainties on the detector simulation, background and luminosity.* The combined uncertainty on the signal efficiency from these sources occupied ranges: from 3.5% at 1 TeV up to 3.9% at 6 TeV for the electron channel and from 3.6% at 1TeV to 5.6% at 6 TeV for the muon channel.
. The cumulative efficiency in Table II is taken from the signal MC simulation for QBHs with charge of +4/3. The differences in efficiency between the +4/3 charge state and other charged states are substantially smaller, than the above uncertainties.
. The observed numbers of events and expected backgrounds in Table II are in agreement within the total uncertainty. There is no evidence for any excess. Upper limits on $\Sigma\sigma_{qq}\times BF_{qq}$ for the production of QBHs >M_{th} are determined in the interval 1−6 TeV. Used CLs method is designed to give conservative limits in cases, where the observed background fluctuates below the expected values.
. *The statistical combination of the channels* uses a likelihood function constructed as the product of terms of the Poisson probability, which are describing the total number of events observed in each channel.
. *The systematic uncertainties* are included as noise parameters into the likelihood through their effect on the average of the Poisson function. And also they are included by convolution with the Gaussian distributions.

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ATLAS EXPERIMENT