SEARCH FOR LONG-LIVED NEUTRAL PARTICLES DECAYING INTO "LEPTON-JETS" WITH THE ATLAS DETECTOR IN PROTON-PROTON COLLISION DATA AT √S = 13 TEV (ATLAS-CONF-2016-042)

MOTIVATIONS

A wide range of Beyond the Standard Model (BSM) theories predict a hidden sector, weakly coupled to the visible sector. Discovery processes with peculiar signatures:

- Lightest unstable hidden states in MeV to GeV range typically produced with large boost → highly-collimated decay products
- Decay back to SM with high branching fraction → e^+e^-, $\mu^+\mu^-$, or light hadrons in final state
- Non-negligible lifetime → decay vertex displaced relative to primary vertex of event

Displaced Lepton-Jets (dLJs): Collimated jet-like structures, produced far from the primary vertex, containing pair(s) of muons, electrons, and/or light hadrons

dLJs IN DARK PHOTON MODELS

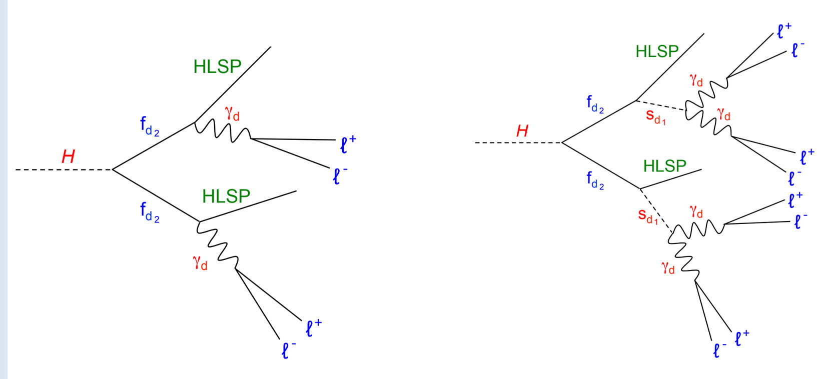
dLJs are signature of the dark photon (γ_d) decay, the heavy gauge boson of an additional U(1). In "vector portal" models, the γ_d kinetically mix with the SM photon:

$$\mathcal{L} \supset \frac{\epsilon}{2} F^{\mu\nu} b_{\mu\nu} + m^2_{\gamma_d} b^2$$

Smaller ε yields longer γ_d lifetime.
Branching ratios of the γ_d depend on its mass

BENCHMARK MODELS

Falkowsky-Ruderman-Volansky-Zupan (FRVZ) models:



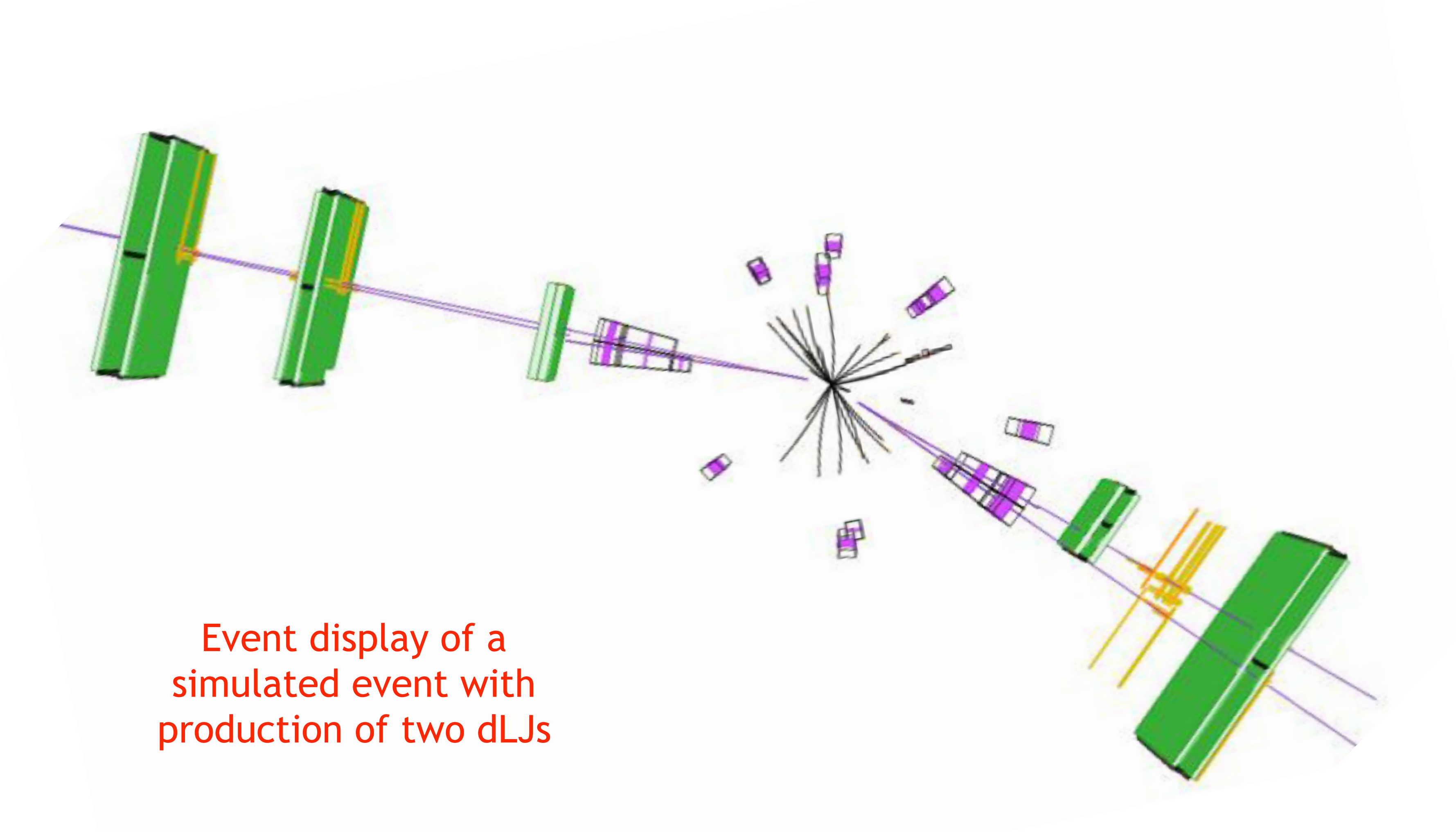
- SM Higgs or BSM additional heavy Higgs decays to hidden sector fermions f_{d2}
- Hidden shower ends with γ_d's and Hidden Lightest Stable Particles
- γ_d's produces LJs, which usually come off back-to-back

dLJ RECONSTRUCTION

Target γ_d decays beyond the Inner Detector (ID) up to the Muon Spectrometer (MS)

- Muon pairs appear in spectrometer as "MSonly" tracks (no associated ID tracks)
- Electron/pion pairs appear in calorimeters as narrow isolated jets, with much less energy deposition in EM calorimeter (EMCAL) than in Hadronic Calorimeter (HCAL)

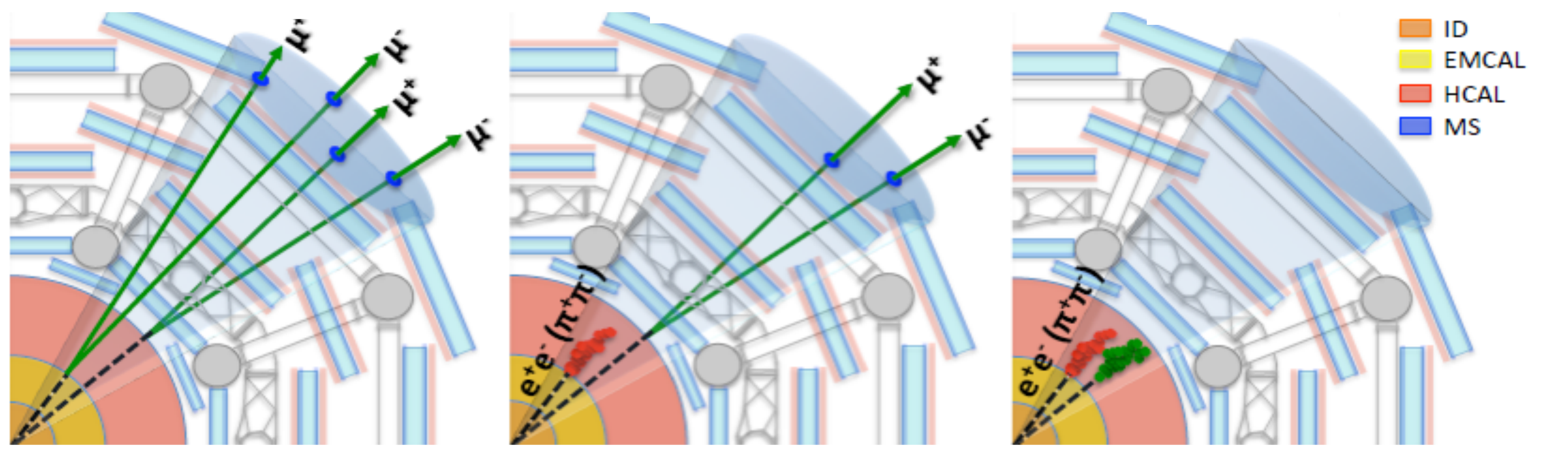
Use a LJ-finding clustering algorithm with ΔR = 0.5 cone (fully contains decay products)



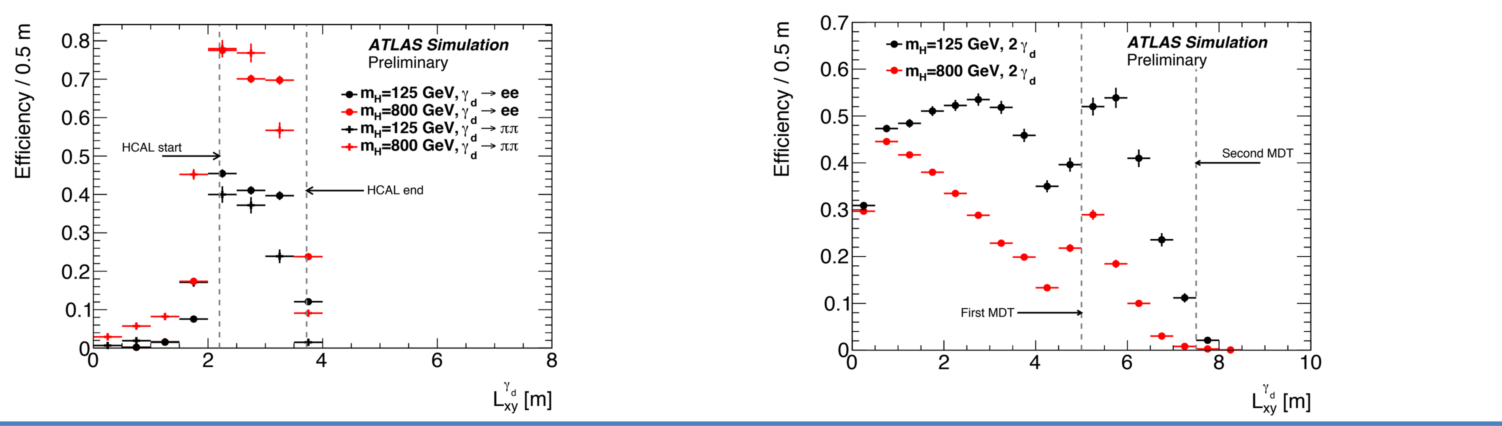
Event display of a simulated event with production of two dLJs

Categorisation of LJs into 3 types for ease of search & reconstruction:

TYPE0: ≥2 MS tracks, no jets **TYPE1**: ≥2 MS tracks, ≥ 1 jet **TYPE2**: 1 jet with low EM fraction, no muons



dLJ RECONSTRUCTION EFFICIENCY



TRIGGERS

Use OR of the following triggers:

- Tri-muon: 3 MSonly tracks, p_T > 6 MeV (for pair of TYPE0 dLJs)
- Narrow-scan: 2 MSonly tracks in ΔR = 0.5 cone, leading p_T > 20 MeV, sub-leading > 6 MeV (for TYPE0 and TYPE1 dLJs)
- CaloRatio: jet p_T > 30 MeV with low EM fraction of the energy (for TYPE 2 dLJs)

BACKGROUND SOURCES

- QCD multi-jet: γγ, γ+jets, tt, single-top, Drell-Yan e^+e^- / $\mu^+\mu^-$, Z/W+jets, diboson, heavy flavours
- Cosmic-ray muon energy deposits in calorimeters (for TYPE1 and TYPE2 dLJs): mis-reconstructed as jets
- Cosmic muon bundles (for Types 0, 1): mainly concentrated in barrel
- Beam-induced background (BIB) (for TYPE2): high-energy muon longitudinally crossing detector, with bremsstrahlung in HCAL barrel

SYSTEMATIC UNCERTAINTIES

- Overall normalization of integrated luminosity
- Muon trigger efficiency using a tag and probe method with J/ψ from data and Monte Carlo
- Close-by muon track reconstruction efficiency using a tag and probe method with J/ψ from data and Monte Carlo
- Effect of pile-up on $\sum p_T$
- ABCD background estimation

DISCRIMINANT VARIABLES AND ABCD-METHOD BACKGROUND ESTIMATION

Cuts defined to optimize signal significance, with variables ordered by separation power:

- Jet Width: Rejects QCD (TYPE2)
- Jet EM Fraction: Rejects QCD (TYPE2)
- Muon impact parameter: Rejects muon cosmics (TYPE0 and TYPE1)
- Jet timing: Rejects mis-reconstructed cosmics and BIB (TYPE1 and TYPE2)
- BIB tagging: Rejects BIB jets accompanied by φ–matched muons parallel to beam pipe (TYPE2)

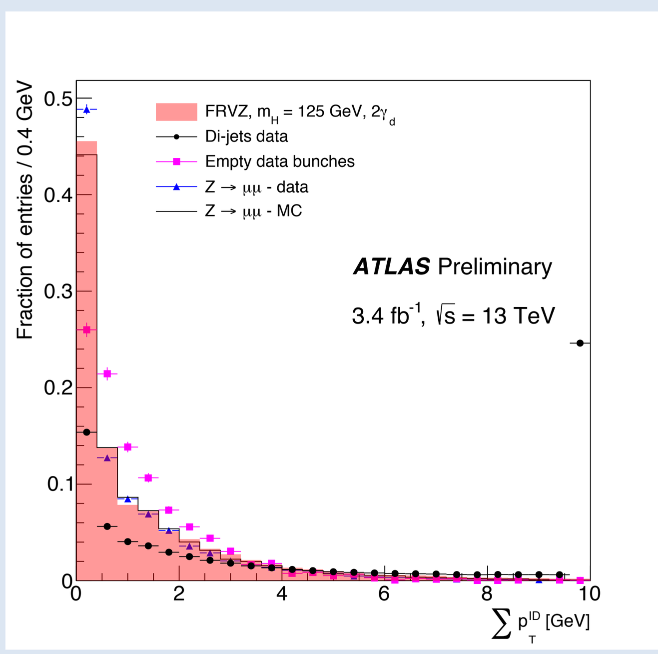
Cuts defined using data-driven method for residual (QCD multi-jet + cosmics) background estimation:

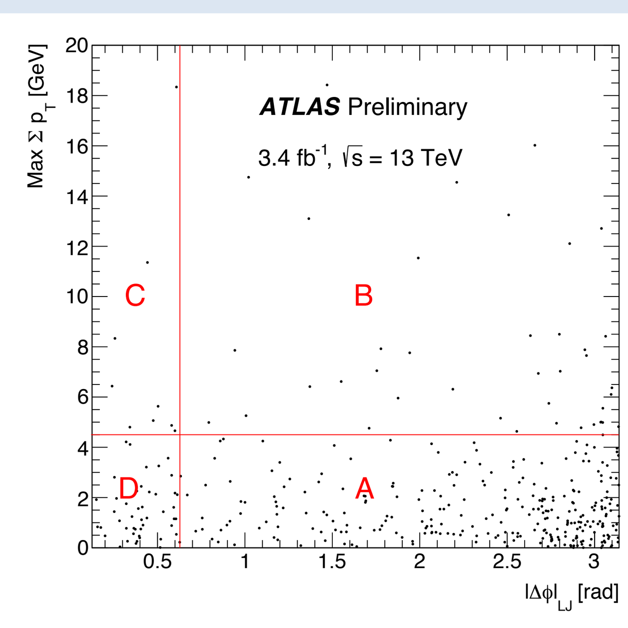
Matrix (ABCD) method assumes background factorizable in 2D plane

- $\sum p_T$: Scalar sum of transverse momentum of ID tracks belonging to the primary vertex of the event in ΔR = 0.5 cone around LJ centre (all dLJ types, dLJs are highly isolated in ID, variable validated using muons form Z boson decays)
- $|\Delta\varphi|$ between leading LJ in event and LJ that is farthest from it in φ

dLJs back-to-back from FRVZ processes have high $|\Delta\varphi|$ and low $\sum p_T$

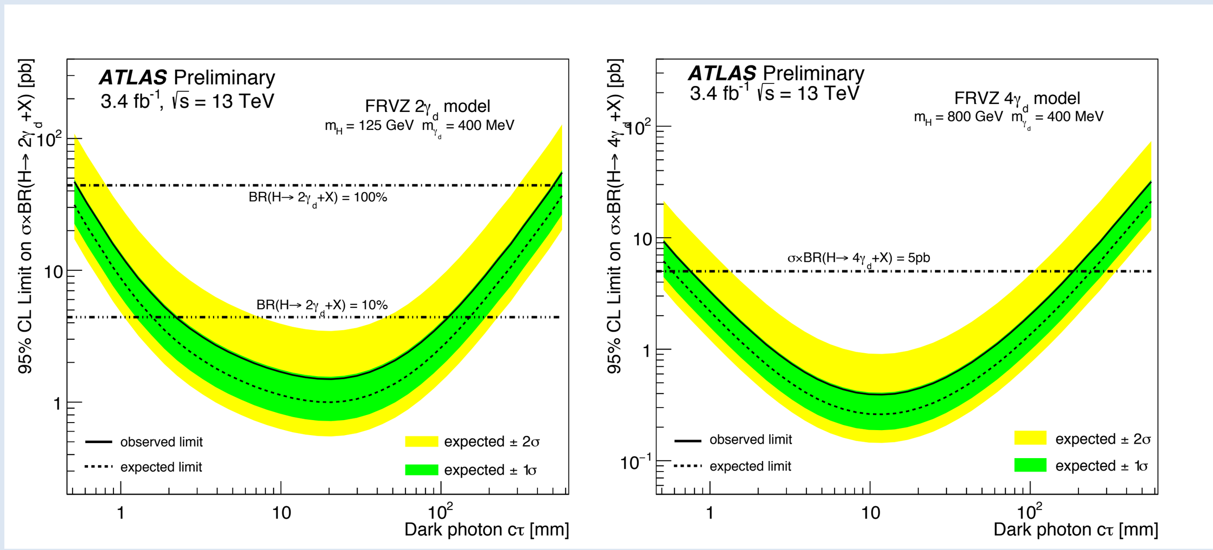
Simultaneous (signal + data) counting experiment in control and signal regions, with $N_A = N_D \times N_B / N_C$, provides estimate of background contamination in signal region A and optimisation of the cuts on the two ABCD variables.





RESULTS

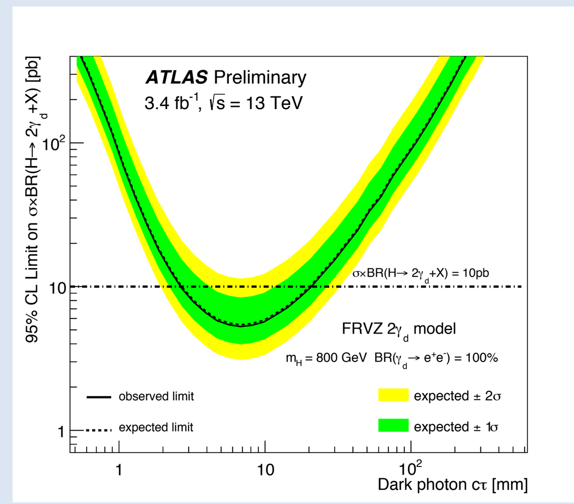
- Search for dLJ pairs performed using 3.57 fb^{-1} of 2015 pp data collected by ATLAS at $\sqrt{s}$ = 13 TeV
- Starting from a general definition of dLJs, a set of selection criteria able to isolate their signature from the SM, BIB and cosmic-rays backgrounds were defined
- Observed data consistent with the experimental background expectations
- Results of the search used to set upper limits on non-SM Higgs boson decays to LJs according to the FRVZ models with a γ_d mass of 0.4 GeV
- Limits set on the σ×BR for Higgs → 2(4)γ_d + X as a function of the long-lived particle mean lifetime
  - SM gluon fusion production cross section is assumed for the 125 GeV Higgs boson
  - conventional production cross section of 1.0 pb is assumed for the 800 GeV Higgs-like heavy scalar.



FRVZ model	Excluded cτ [mm] BR(10%)
125 GeV Higgs → $2\gamma_d + X$	$2.2 \le c\tau \le 111.3$
125 GeV Higgs → $4\gamma_d + X$	$3.8 \le c\tau \le 163.0$

FRVZ model	Excluded cτ [mm] $\sigma \times$ BR = 5 pb
800 GeV Higgs → $2\gamma_d + X$	$0.6 \le c\tau \le 63$
800 GeV Higgs → $4\gamma_d + X$	$0.8 \le c\tau \le 186$

- The recent observation of Anomalous Internal Pair Creation in Be8* is interpreted as a possible Signature of a Light, Neutral Boson of 16.7 MeV decaying in electron pairs from the dark sector
- TYPE2-TYPE2 signal can be related to the framework of this "protophobic" boson assuming a 100% 800 GeV heavy scalar decay to two γ_d of 16.7 MeV mass
- 95% CL upper limits are set on the σ×BR as a function of the γ_d lifetime



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Antonio Policicchio, Università della Calabria and INFN Cosenza
on behalf of the ATLAS Collaboration