Research Overview of Ian Shipsey 2017

Shipsey's scientific career has been based on the conviction that world-class science can best be performed by the development of innovative state-of-the-art instrumentation. Shipsey is distinguished for his elucidation of the physics of heavy quarks, particularly charm, as leader of the CLEO/CLEO-c collaborations at Cornell where he made the most precise measurement of four of the nine quark couplings in nature, and for his outstanding development of charged-particle tracking technology. He was a pioneer of new gaseous tracking detectors and a leader in constructing silicon detectors for CLEO and CMS at LHC. A leading member of CMS, he made the first measurement of b quark production at LHC, observed upsilon suppression in heavy-ion collisions, and observed a long-sought rare b-quark bound state process. Since moving to Oxford to head the Particle Physics Sub-Department, he has joined ATLAS. He is taking a leading role in developing new silicon detectors for both ATLAS and for astronomical applications, specifically for the Large Synoptic Survey Telescope (LSST) project, and in ATLAS data analysis.

Shipsey's research can be divided into the following major activities:

I. Heavy quark physics with the CLEO-c & CLEO at Cornell (1986-2012). Quarks are fundamental particles that exist in bound states (mesons and baryons) held together by the strong force. The heavier varieties of quark, such as the beauty (b) quark, disintegrate via the weak force to produce lighter particles at rates constrained, but not determined, by the Standard Model (SM) of particle physics. The pattern is obscured by the confining effects of the strong force. The strong-force effects can be calculated with Lattice QCD. Shipsey was one of four intellectual leaders who proposed and designed a new experiment, CLEO-c, at a modified accelerator CESR-c at Cornell University to explore these effects and the validity of the lattice calculations [1]. Shipsey played the leading role in persuading the U.S. particle physics community and funding agencies to support the CLEO-c proposal. He recruited new university groups to the effort and established the twenty-university CLEO-c collaboration. He served as the elected co-Spokesperson (co-Leader) of CLEO and CLEO-c for three consecutive terms between 2001 and 2004. CLEO-c took data until 2008, opening a new frontier in our understanding of the weak and strong interactions. These precision measurements have provided critical tests of Lattice QCD and validated the approach at the few percent level. Shipsey led many CLEO-c flagship measurements. Between 2004-2010, in a sequence of four papers, he made the first observation of five new charm semileptonic decays, and in 2008/9 the most precise and robust measurements of the semileptonic form factors in the $D \to K/\pi e\nu$ decay, providing a stringent test of LQCD [2]. He extracted the CKM matrix elements V_{cs} and V_{cd} with an experimental precision of 1% and 3% respectively, the most precise and most robust determinations of these quantities to date [2]. Shipsey made the long-awaited measurement of the form factors in $D \to \rho e\nu$ [3], contributed to the measurement of important hadronic modes of the D meson and in spectroscopy led three papers including discovery of 13 new decay modes of the psi(2S) [4]. In total the CLEO-c experiment that Shipsey played a major role in creating has produced over 100 papers.

Shipsey made the first observation of the production of the strange B meson at the Y(5S) [5]. He developed a new analysis technique to do so that avoided reconstruction of the photon from the excited B_s thereby greatly increasing the sensitivity of the analysis, which is important input to the B physics program of super B factories, notably Belle II/SuperKEKB in Japan. In a sequence of five papers (1995-2005), Shipsey and his students conducted a unique and comprehensive study of charm baryon semileptonic decays culminating in [6]; these are an important test of Heavy Quark Effective theory. He observed two new charm baryon semileptonic decays ($\Omega_c \to \Omega e\nu$ & $\Xi_c^+ \to \Xi^0 e^+ \nu$) as part of this programme. Shipsey also made the most sensitive searches for several rare B decays [7], and what were then the most precise determinations of the fundamental quark couplings V_{cb} and V_{ub} [8].

In 1995 Shipsey established a new facility, the Purdue Particle Physics Microstructure Detector Laboratory (P3MD) which has been described by DOE reviewers as "a national treasure". Between 1996 and 2000 he led the construction in P3MD of the CLEO silicon vertex detector (Si3) [9], having previously led the novel mechanical and thermal design of the detector. Si3 was the largest and most sophisticated silicon vertex detector ever constructed by a consortium consisting solely of universities without the benefit of national laboratory participation. It operated at the heart of the CLEO III detector from 2000-2003.

II. The Search for new physics with CMS (2001-15). The CMS experiment is one of the two general-purpose detectors at the Large Hadron Collider (LHC) at CERN, the European Laboratory for Nuclear Research in Geneva Switzerland. Shipsey joined CMS in 2001 after completing the construction of Si3. Using the facilities of P3MD, he led the design and development of the production process for all the silicon-sensor pixel detector modules (14 million pixels) for the forward pixel detector of CMS [10]. The pixel detector took data at CERN from the start of LHC operations until the end of 2016 and performed extremely well. For the replacement silicon pixel detector inserted in 2017, Shipsey with an engineer developed a design for the production of the pixel modules that included novel use of robotic automated assembly.

In 2010 Shipsey served as co-convener of the CMS quarkonia group. He led the first measurement of the Upsilon production cross section at the LHC [11] an important test of non-perturbative QCD in a new kinematic regime, and produced an eye-catching plot that simultaneously shows many SM particles, from the eta to the Z, that became an international icon of the first LHC running. In 2011 Shipsey and his student found the first evidence of upsilon suppression in heavy ion collisions [12] - a smoking gun for the production of the long-sought Quark-Gluon Plasma. The paper was Editor's Choice in PRL in July 2011. This was followed by the Observation of upsilon suppression in 2012 [13]. From 2012, Shipsey turned his attention to the search for new physics that may explain the origin of mass and the particle nature of dark matter. Shipsey with his students and post docs formed one of two independent CMS teams that made the first observation of the process where a strange B meson decays to a di-muon pair. This process, which has been sought since 1984, is exquisitely sensitive to new physics beyond the SM, especially Supersymmetry, which can enhance or suppress the rate relative to SM expectations. The CMS measurement [14] was consistent with the SM, thereby ruling out a large swathe of Supersymmetry parameter space. Increased precision was achieved by a combination with a measurement by the LHCb experiment [15]. In two papers, Shipsey searched for other new physics with vertices displaced from the interaction point, a theoretically well-motivated signature [16]. In addition, Shipsey served as Chair of a number of internal CMS analysis reviews, including evidence for the Higgs boson at 125 GeV in $H \rightarrow ZZ \rightarrow 4l$ (2011-12).

In late-2009 Shipsey was chosen by the US community and funding authority to co-coordinate (co-lead) the LHC Physics Center (LPC) at Fermilab. The LPC provides an intellectual and physical home for data analysis and instrumentation activities for U.S. scientists working on CMS at the LHC who are unable to spend extended time at CERN. Shipsey's leadership was so successful that he was asked to continue for a second term in 2012 by which time the LPC was regarded as a jewel in the crown of CMS.

In February 2012 Shipsey was elected Chairperson of the CMS Collaboration Board for 2013-2014. During his tenure he was able to improve the overall coordination within the experiment, helping to enable it to handle the triple challenge of analyzing the LHC Run 1 data, preparing for LHC Run 2, and preparing for the detector upgrade. He also strengthened the education and training opportunities provided by CMS, designing and establishing the CMS Data Analysis School and co-designing CMS Instrumentation Upgrade School.

III. The search for new physics with ATLAS (2015-). Upon joining Oxford at the end of 2013, Shipsey developed the specifications and oversaw the design, installation and commissioning of a major new facility, the Oxford Physics Microstructure Detector Laboratory (OPMD) which came online in December, 2015. Using OPMD, with experience garnered on CMS, he and an engineer have developed a design for the production process of the ATLAS silicon strip and silicon pixel modules for LHC Phase II (commencing approximately 2025) that includes novel use of robotic automated assembly. Shipsey is also working on HV/HR CMOS technology sensors as an alternative to traditional planar sensors for LHC Phase II. These offer advantages of less mass and lower cost if they can be demonstrated to be radiation hard; promising results are being obtained. With his first Oxford students and post docs, Shipsey is working on measurement of the Higgs boson width and searches for the Higgs to di-muons, additional Higgs particles and Higgs decaying to dark matter. Other than the second, these analyses are performed simultaneously since they have the same experimental signature: two leptons and missing energy. He is a member of the ATLAS Advisory Committee to the Collaboration Board (2018-2019).

IV. The characterization of dark energy with LSST (2008-). The discovery of dark energy in 1998 implies that either three quarters of the energy density of the Universe is of a completely unknown form – dark energy – or General Relativity breaks down on cosmological scales and must be replaced with a new theory of gravity. By studying the expansion rate history of the Universe with better precision by several techniques, key questions can be addressed. Is the dark energy density constant or evolving over cosmic time? Are the different manifestations of dark energy consistently described in the framework of General Relativity, or is the framework wrong?

LSST (survey starts 2022) will offer a revolutionary new astronomical view of the universe. A ground-based 8.4-meter, 10 square-degree field-of-view telescope, LSST will conduct an optical survey of faint astronomical objects across the entire sky every three nights enabling precision dark energy measurements and opening a movie-like window on objects that change or move on rapid timescales. Shipsey's interest is the measurement of the equation of state of dark energy using weak gravitational lensing. At the heart of LSST is a 3 Giga pixel CCD digital camera, the largest ever constructed for astronomy. Obtaining images of sufficient quality to study dark energy using weak-lensing requires that the alignment and focus system of the camera performs extremely well and that CCD performance is well understood. Joining LSST in 2008, Shipsey established a DOE-funded lab to characterize the part of the LSST camera that determines if the telecope+camera is in focus (wave-front sensing) which is crucial to achieve LSST science goals. His group developed wave-front reconstruction algorithms in collaboration with NOAO, based in part on Shipsey's novel design of a test stand. Three papers describe the work for example [17]. At Oxford, in 2016 Shipsey established a CCD characterization station to study the novel thick full-depletion LSST CCDs to enhance science reach. Thick CCDs have greater quantum efficiency for 700 nm < λ < 1.1 μm but the photo-charge is subject to the perturbing influence of lateral electric fields for a longer time interval than in traditional thin CCDs, introducing novel image artefacts that hinder precision determination of the positions, fluxes, and shapes of astronomical objects. Studies of these effects in Oxford form part of the work of the LSST-Dark Energy Science Collaboration (DESC) Sensor Anomaly Working Group.

An early proponent of LSST in the U.S. particle physics community, Shipsey helped make the case for LSST to the U.S. Department of Energy (DOE) and recruited U.S. particle physics groups to the project. He currently assists the LSST Project with sensor vendor e2v; in 2015-16, Shipsey and his group worked closely with e2v to address technical problems with the sensors which are now in full production. He is Chair of the LSST DESC Advisory Board, charged by DOE with making the definitive LSST dark energy measurements. He brings a unique perspective to the LSST:UK consortium of currently 42 universities, as the only consortium member who is also a member if the US-led LSST Project. He was chosen to give one of the three key talks at the review that led to STFC approval of UK LSST participation. He is PI for the STFC-funded LSST:UK sensors work package, and spokesperson of the fledgling LSST:UK particle physics community (nine institutions). He was the LSST Corporation (LSSTC) representative for Purdue (2008-13) and Oxford (2014-present), initiating LSSTC membership at both institutions and a LSSTC Executive Board Director (2009-12, & 2017-21). In 2011, he initiated and co-organized an internal review of LSST that identified a number of significant project vulnerabilities that were subsequently corrected. The review is widely credited as a key preparatory step for a critical, and successful, NSF Final Design Review of LSST. He has presented the LSST project on Capitol Hill and given over thirty LSST colloquia/seminars/conference talks. As a member of the LSSTC Operations Taskforce he successfully made the case for the UK to have a permanent seat on a new standing Corporate Operations Committee thereby giving the UK guaranteed input to the scientific strategy and observing schedule of LSST.

V Other instrumentation (1992-): Between 1992 and 2005 Shipsey led an internationally recognised program in gas microstructure detector development that had extensive student involvement. Twelve papers span this period; a representative example is [18]. Shipsey was first to build a working microstructure gas detector in the U.S. from e-beam and UV lithography to thin-film deposition. He developed detectors that held the record for the highest gas amplification, the first ion-implanted kapton substrate, the first 2-D readout plastic detector operating in a beamline, and performed extensive studies of radiation hardness. With a Chicago group, Shipsey achieved the first mass production of Gas Electron Multipliers using a standard industrial reel-to-reel process from 3M Corp, and subsequently the first mass production of a MicroMEshGAS detector. At Oxford, OPMD will support sensor development for a range of science. Several successful new initiatives include a beam test at DIAMOND light source of an ultra-low-dead-space Medipix pixel hybrid array, enabling improved diffraction pattern measurements intended for photon-science applications. He has co-initiated a new collaboration (Oxford Physics, RAL and Open University) to develop CICADA (Continuous Imaging Camera with Advanced Digital Architecture) a very high-speed hybrid pixel X-ray imaging system, optimised to operate at FEL facilities such as LCLS-II at SLAC to individually image X-ray diffraction patterns at intervals as short a 1 micro-second. He also received STFC funding to lead the effort to build sensor modules for ultra-low-mass silicon trackers for the Mu3e experiment at PSI, which will search for the forbidden process muon to three electrons, a sensitive and distinctive probe for new physics. Shipsey has long been concerned with the application of particle physics instrumentation to other areas; this is covered in a review co-authored with Demarteau, Lipton, and Nicholson [19].

VI Early physics: Shipsey was the first Ph.D. on the CERN NA31 experiment which found evidence for the long-sought direct CP violation - a difference in the way matter and anti-matter decay [20]. Shipsey's thesis determined one half of the double ratio used to determine ε'/ε, which is a measure of the amount of direct CP violation. The controversial NA31 measurement was subsequently confirmed with higher precision by the NA48 and KTeV experiments. The NA31/48 collaborations and their Spokespersons shared the EPS Europhysics Prize in 2005.

VII Community Leadership: As the elected Chair of the Division of Particles and Fields of the American Physical Society, Shipsey designed and oversaw with McBride, Rosner and Ramond the year-long U.S. community study *"Planning the Future of U.S. Particle Physics (Snowmass 2013)"*. The community chose Shipsey to deliver the keynote address summarizing the study that closed the process in August, 2013. He reprised and extended that address as the summary speaker at the International Conference on High Energy Physics, in Chicago, in 2016.

VIII Summary: Shipsey has developed several world-leading particle detectors whose experimental deployment has been highly significant in making some of the most important discoveries and precision measurements of recent decades in particle physics. He has not only developed experimental techniques, he has also been a leader in the analysis of the data making several important discoveries and precision measurements that elucidate the physics of heavy quarks.

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