Comisión Nacional de Investigación Científica y Tecnológica – CONICYT

RESEARCH TEAM GRANTS IN SCIENCE AND TECHNOLOGY

FINAL REPORT

INSTRUCTIONS

1. The following report must be thoroughly filled up indicating the general and specific results of the Research Team Grant.

2. Reviewers' suggestions on the previous report must be referred to.

3. The signatures of Main Researchers currently abroad may be included digitalized in another page.

4. Include all appendices you consider necessary to show the outcomes of the project which must be sent to the Program in a digital version only.

   Concerning publications remember to include in the digital appendices the letters or email messages confirming reception or acceptance, as well as the corresponding digital copies. Only published works that declare acknowledgements to this project will be considered as resulting products from this grant.

   Concerning theses (undergraduate, master's and/or PhD's) resulting from the project, remember to include in the digital appendixes the cover pages and executive summaries of each one of them.

   Concerning courses, seminars, conferences, workshops where members of the project took part presenting results, dissemination events or others organized by project members, remember to include in the digital appendices the copies of the corresponding programs, if available.

5. Once completed, the current report must be sent in printed and digital version to the following address:

   Programa de Investigación Asociativa – CONICYT
   Moneda 1375 – Santiago

For further information and/or inquiries please contact: Karol Campos Gavilán **– kcampos@conicyt.cl.**

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RESEARCH TEAM GRANTS IN SCIENCE AND TECHNOLOGY

FINAL REPORT

I. PROJECT PRESENTATION

PROJECT TITLE	CODE
AtlasAndino: Physics at the LHC and its Applications	**ACT1102**
PROJECT DIRECTOR	**SIGNATURE**
Marco Aurelio Díaz	
MAIN INSTITUTION	
Pontificia Universidad Católica de Chile	
ASSOCIATED INSTITUTIONS	
PERIOD INFORMED	
Nov 15 2012 to Mar 15 2016	

a) Main researchers' information

MAIN RESEARCHER (Complete Name)	**SIGNATURE**
Jorge Alfaro Solis	
WORKING ADDRESS	**EMAIL**
Pontificia Universidad Católica de Chile **Faculltad de Física** **Av. Vicuña Mackenna 4860, Santiago, Chile**	**jalfaro@puc.cl**

MAIN RESEARCHER (Complete Name)	**SIGNATURE**
Maximo Bañados Lira	
WORKING ADDRESS	**EMAIL**
Pontificia Universidad Católica de Chile **Facultad de Física** **Av. Vicuña Mackenna 4860, Santiago, Chile**	[redacted]

MAIN RESEARCHER	**SIGNATURE**
Benjamin Koch	
WORKING ADDRESS	**EMAIL**
Pontificia Universidad Católica de Chile **Facultad de Física** **Av. Vicuña Mackenna 4860, Santiago, Chile**	**bkoch@fis.puc.cl**

II. RESUMEN EJECUTIVO

Esta sección no deberá extenderse más allá de 2 páginas. Resuma los logros del proyecto considerando los objetivos específicos del Instrumento, tales como:

- La realización de investigación científica y tecnológica de alto nivel y alcance internacional.
- El entrenamiento de investigadores recientemente formados y la formación de estudiantes de pre y postgrado ya sea a través de la participación activa del equipo de investigadores del proyecto en programas de postgrado ya consolidados o en su formación, tutorías a estudiantes de todas las categorías, cursos específicos en carreras o programas de pre y postgrado, etc.
    - El establecimiento de redes internacionales de cooperación con otros equipos de investigación similares, Centros de investigación extranjeros, agencias internacionales, programas de estudios de instituciones extranjeras, etc.
    - Desarrollo de actividades de comunicación destinadas a sensibilizar a la sociedad chilena, al sector público y privado y a sectores productivos entre otros, sobre la importancia del quehacer de la Ciencia y la tecnología y su inserción en todo aspecto de la vida cotidiana de la sociedad chilena.

Dado que este resumen debe ser asequible a aquellas personas que no son necesariamente expertas en el área, le solicitamos el uso de un lenguaje relativamente simple o explicaciones cuando términos técnicos así lo requieran.

El Anillo ACT1102 ha realizado investigación a un nivel internacional, apoyado por muchos artículos con arbitraje, en los siguientes aspectos:
(A) en teoría, cuantización de la gravedad con el modelo de gravedad-delta; modificación de la gravedad que podría explicar la Materia Oscura (bi-gradedad); y gravedad con “cosntantes” fundamentales que cambian con la escala;
(B) en teoría, compatibilidad con mediciones experimentales de modelos con supersimetría o con bosones de Higgs extra a través de campos triplete de Higgs; compatibilidad de modelos supersimétricos con violación de la Paridad-R con observaciones de Materia Oscura y del incremento de positrones desde los rayos cósmicos; reconciliación entre mediciones de Daya Bay del ángulo de mezcla θ_{13} de neutrinos con modelos que predicen masas y ángulos de mezcla de neutrinos;
(C) entendimiento del sistema de Trigger de Tau del Detector ATLAS, que nos ayuda a identificar un leptón tau; determinación de las posibilidades de medición del acoplamiento de Yukawa del quark top con el Detector CLIC; determinación de las posibilidades de medición del acoplamiento triple de Higgs con el Detector ATLAS; medición con el Detector ATLAS de las propiedades del bosón de Higgs similar al del Modelo Standard con masa de 125 GeV; medición de indicaciones de la existencia de una nueva partícula con masa de cerca de 750 GeV; determinación del ángulo de mezcla de neutrinos θ_{13} con el Detector Daya Bay.

También hemos realizado trabajo pionero en Computación Grid. Hemos creado una Organización Virtual para Chile comenzando con nuestra Universidad (PUC-VO). Por el momento contiene sólo dos nodos (sitios): uno en Astronomía y otro en Física, y los usuarios son miembros de nuestro grupo. Los dos nodos estan certificados por ROC-LA (Centro de Operaciones Regional - Latino America), y la VO esta siendo monitoreada por EGI (Iniciativa Europea de la Grid). Un tercer nodo está preparado para ser conectado (en la Facultad de ingeniería), el cual necesita de la certificación de ROC-LA. Es muy simple añadir nodos extra. Por el momento los usuarios son miembros de nuestro grupo, y tienen que elegir el nodo donde el trabajo será ejecutado. Será necesario añadir un WMS para que el trabajo sea ejecutado en un nodo elegido automaticamente. Será muy fácil añadir nuevos usuarios. En resumen, la VO está operacional.

Estamos participando, junto a colegas de CERN, Canadá, China, Israel, y Rusia, en la mejora del espectrómetro de muones del Detector ATLAS, más especificamente las “Thin Gap Chambers”

(TGC) de las “Small Wheel” (SW). El compromiso chileno incluye 32 cámaras (cuadrupletes) y serán construidas en su mayor parte en la UTFSM de Valparaiso. La eficiencia de las cámaras terminadas será medida con rayos cósmicos en el laboratorio que llamamos HEPLAB1, que está en su mayor parte terminado. Necesitamos terminar el sistema de Adquisición de Datos. Antes del testeo, soldaremos los “Adapter Boards” a las cámaras. Eso será hecho en el HEPLAB2, que necesita ser acondicionado. Nuestra participación en el proyecto “New Small Wheel” ha sido financiado en parte por el Anillo, y el trabajo continuará más allá de su término, también financiado por Conicyt.

Hemos hecho un esfuerzo conciente para mejorar el entrenamiento que damos a los estudiantes de pregrado, graduados y postdoctorandos de la PUC. Un conjunto de cursos más coherente se está ofreciendo. Un programa de seminarios muy rico, con un presentador cada semana desde Chile o desde el extranjero, se ha organizado. Participación en Conferencias y Escuelas han sido financiadas con el Anillo, donde presentaciones y posters han sido incentivados, pero no requeridos. Estadías en CERN y otros Institutos han sido financiadas y co-financiadas para estudiantes, postdoctorandos, y jovenes investigadores. Visitas de investigadores desde el extranjero y desde otros centros de investigación en Chile han sido financiadas y co-financiadas, de modo de exponer a los investigadores locales a las últimas ideas en nuestro campo. Finalmente becas postdoctorales y para estudiantes han sido financiadas por el Anillo.

En el área experimental, hemos reforzado nuestra cooperación dentro de la Colaboración ATLAS. Ésta es una colaboración grande, con cerca de 5000 investigadores de cerca de 180 instituciones. Chile es parte de la Collaboración con dos Universidades (UTFSM y PUC) en Valparaiso y Santiago, con 10 autores. En este momento estamos participando en la mejora del Spectrómetro de Muones, tal como se describe más arriba. El Anillo financió y co-financió la visita de varios investigadores, trabajando en áreas tales como Trigger, Spectrómetro de Muones, Computación Distribuida, y Análisis. También formamos parte de la Colaboración CLIC, donde hemos contribuido al estudio de componentes electrónicos del detector, y al análisis que determina el acoplamiento Yukawa del quark top con el bosón de Higgs. CLIC es un experimento propuesto donde electrones y positrones serán acelerados linealmente y colisionados, con la intención de estudiar hipotéticas resonancias con una masa de algunos TeV o menores. Nuestro grupo es también parte del Experimento Daya Bay (y de su sucesor Juno). Daya Bay midió el ángulo de mezcla de los neutrinos θ_{13} y nuestro grupo está contribuyendo a la exploración del rompimiento de la simetría de Lorentz y de CP. Estamos muy interesados en el CTA (Cherenkov Telescope Array). Principalmente, los investigadores del Anillo están interesados en la posibilidad de contribuir a la electrónica y a la identificación de la Materia Oscura.

En el área teórica, la cooperación está formada con un número mucho menor de investigadores. Tipicamente unos pocos. De este modo, el Anillo nos ha ayudado a reforzar la cooperación teórica con visitas de investigadores a nuestro Instituto y con visitas de nuestros investigadores a otros paises. Por ejemplo, hemos reforzado (o iniciado) cooperación con investigadores en paises Latino Americanos, en Norte América, en Europa, en África, y en Asia.

Finalmente mencionamos actividades de diseminación. Han ocurrido varias conferencias en Chile donde los investigadores del Anillo han presentado sus resultados mediante presentaciones profesionales o posters: Afunalhue, Concepción, Valparaiso, Antofagasta. También han habido conferencias en otros paises donde investigadores del Anillo recibieron ayuda financiera para presentar sus resultados, y enterarse de los últimos avances. Pero también muy importante, han habido muchas ocasiones donde nuestros investigadores han dado presentaciones a público en general, o explicado un fenómeno científico a través de una entrevista con los medios. Mencionamos aqui la “Master Class”, una actividad dirigida a profesores de Enseñanza Media y estudiantes del último año de colegio, donde aprenden sobre física de partículas y analizan datos reales del LHC.

III. EXECUTIVE SUMMARY

This section should have no more than two pages. Summarize the project's achievements considering the specific objectives of this grant, such as:

- To conduct high-level scientific and technological research with an international scope.
- To train recently graduated researchers as well as undergraduate and postgraduate students through their active participation in the project's research team in postgraduate programs already consolidated or under creation, tutoring students in all categories, specific courses in degrees or under- or post- graduate programs, etc.
- To establish international cooperation networks with similar research teams, foreign research centers, international agencies, study programs in foreign institutions, etc.
- To develop communication activities aimed at raising awareness within Chilean society, the public and private sectors, and productive sectors, among others, regarding the importance of the work on Science and Technology and its inclusion in all aspects of Chilean society's daily life.

As this summary should be affordable to non-experts in the area, please use relatively simple language or explanations for technical terms.

The Anillo ACT1102 has performed research at an international level, supported by many articles with referee, in the following aspects:
(A) theoretical quantization of gravity with the delta-gravity model; theoretical modification of gravity that could explain Dark Matter (bi-gravity); and gravity with fundamental "constants" that change with the scale;
(B) theoretical compatibility of experimental measurements with models with supersymmetry or with extra Higgs bosons through Triplet Higgs fields; compatibility of supersymetric models with bilinear R-Parity violation with observations of Dark Matter and positron enhancement from cosmic rays; reconciliation between the Daya Bay measurement of the neutrino θ_{13} mixing angle and models that predict neutrino masses and mixing angles;
(C) understanding of the Tau Trigger system of the ATLAS Detector, which help us to identify a tau lepton; determining the prospects of measurement of the top quark Yukawa coupling with CLIC Detector; determining the prospect of measurement of triple Higgs coupling with ATLAS Detector; measurement with the ATLAS Detector the properties of the SM-like Higgs boson with mass 125 GeV; measurements of hints for a new particle with a mass of about 750 GeV; determination of the θ_{13} neutrino mixing angle with Daya Bay Detector.

We have also done pioneering work on Grid Computing. We have arranged a Virtual Organization for Chile starting with our University (PUC-VO). For the moment it contains only two nodes: one in Astronomy and one in Physics, and the users are members of our group. The two nodes are certified by ROC-LA (Regional Operating Centre - Latin America), and the VO is being monitored by EGI (European Grid Initiative). A third node is about to be connected (in the Engineering Department), it needs ROC-LA certification. It will be very easy to add more nodes. The users are for the moment members of our group, and have to choose the node where the job will be performed. We need to add a WMS and the node will be chosen automatically. It will be easy to add more users. In summary, the VO is operational.

We are participating, together with partners in CERN, Canada, China, Israel, and Russia, in the upgrade of the muon spectrometer of the ATLAS Detector, more specifically on Thin Gap Chambers (TGC) from the Small Wheel (SW). The Chilean assignment include 32 chambers (quadruplets) and will be mostly constructed at the UTFSM in Valparaiso. The efficiency of the finalized chambers will be tested with cosmic rays in the Laboratory we call HEPLAB1, which is mostly ready. We need to finish the Data Acquisition system. Previous to the testing, we will solder the Adapter Board to the chambers. That will be done in HEPLAB2, which need to be conditioned for that. Our participation

on the New SW project has been financed in part by the Anillo, and the work will continue beyond its end, also financed by Conicyt.

We have made an conscious effort to improve the training of PUC undergraduate and graduate students and postdoctoral fellows. A more coherent set of courses for our students has been offered. A rich seminar program, with a speaker every week from Chile and from abroad, has been organized. Participation in Conferences and Schools have been financed for our students with the Anillo, where talks or posters have been encouraged, but not required. Visits to CERN and other Laboratories have been financed and co-financed for students, postdoctoral fellows and young researchers. Visits of researchers from abroad or from research centres in Chile have been also financed or co-financed, in order to expose our trainees to the latest ideas in our field. Finally, postdoctoral fellowships and studentships were financed with the Anillo.

In the experimental area, we have strengthen our cooperation within the ATLAS Collaboration. This is a large Collaboration, with around 5000 researchers from about 180 institutions. Chile is part of the Collaboration with two institutions (UTFSM and PUC) in Valparaiso and Santiago, with near 10 authors. At the moment we are participating in the Muon Spectrometer upgrade, as described above. The Anillo financed and co-financed visits to several researchers, working in areas like Trigger, Muon Spectrometer, Computing, and Analysis. We are also part of the CLIC Collaboration, where we have contributed to the study of electronic components in the detector, and to the analysis determining the top quark Yukawa coupling to the Higgs boson. CLIC is a proposed experiment where electrons and positrons are going to be linearly accelerated and collided, to study hypothetical heavy resonances present at a few TeV of energy or less. Our group is also part of the Daya Bay Experiment (and its successor Juno). Daya Bay measured the neutrino mixing angle θ_{13} and our group is contributing to the exploration of Lorentz and CP violation. We are very interested in CTA (Cherenkov Telescope Array). Mainly, the researchers in the Anillo are interested in the possibility of contributing to the electronics and to the identification of Dark Matter.

In the theoretical area, the cooperation is formed with a much smaller number of researchers. Typically just a few. In this regard, the Anillo has helped us to strengthen the theoretical collaboration with visits of researchers to our Institute and visits of our researchers to other countries. For example, we have solidified (or initiated) cooperation with researchers in Latinamerican countries, in North America, in Europe, in Africa, and in Asia.

Finally we mention dissemination activities. There have been several conferences in Chile where researchers of the Anillo have presented their results using professional talks or posters: Afunalhe, Concepción, Valparaiso, Antofagasta. There have been many other conferences abroad where researchers from the Anillo have receive financial help to present their findings , and learned about the latest developments. But also very importantly, there have been many instances where our researchers have given presentations to general public, or explain a scientific phenomena via an interview with the media. Here we mention the Master Class, an activity directed to high school teachers and last year high school students where they learn Particle Physics and analyze LHC Data.

IV. ACTIVITIES

This section should have five pages as maximum. Indicate the activities performed considering those commitments stated by the team researchers in the Original Proposal and stated in the last Annual Activities Plan. Each activity should have a headline and 2-3 explanatory lines including if they have been performed and if not indicating why.
Please consider **the specific objectives of this grant**.

Objective O1: Undergraduate Training.
This objective was fulfilled in the sense that we contributed to undergraduate teaching and introduced students to research. This activity was strengthen with the Anillo because with it we could attract and finance more undergraduate students. Also as a result, there are several younger undergraduate students interested in our group that will do their mini-thesis or Engineering Memoria with us. In this sense, the effects of the Anillo will be felt beyond its end. We also participate every summer (January) in a PUC program where undergraduate students are introduced to research. The Anillo did not contributed to increase the number of undergraduate courses offered, but did contributed to offer a more coherent set of courses since we met to do precise that. **A1.1: Undergraduate Courses.** In the first year we reported 22 undergraduate courses, 27 in the second year, and we have a similar number for the third and final year of the Anillo. As an example we mention Introduction to Particle Physics, Theomodynamics and Kinetic Theory (mainly for physicists), Electronics (mainly for engineers), and Relativity and Gravitation (mainly for physicists and astronomers). **A1.2: Supervision of Undergraduate Thesis.** In the first year of the Anillo we reported 1 Licenciatura in Astronomy mini-thesis, in the second year we had 3 Licenciatura in Physics mini-thesis, 1 in Astronomy, and 1 Memoria for Engineering. In the third and last year of the Anillo we directed the mini-thesis of a similar number of students. As an example for Licenciatura in Physics we mention Sergio Carrasco directed by Máximo Bañados, and Felipe Zepeda for Licenciatura in Astronomy directed by Andreas Reisenegger.

Objective O2: Graduate Training.
This objective was fulfilled since we have greatly improve the education and training of our graduate students, financing and co-financing with the Anillo a healthy seminar programme, attendance to Schools and participation in Conferences. The Anillo allow us to give a more coherent set of graduate courses, and expose our students to top science and technology through seminars and stays in laboratories. **A2.1: Graduate Courses.** In the first year of the Anillo we reported 9 graduate courses, and 10 reported for the second year. As for the previous case, we have a similar number for the third and final year. As an example we mention Quantum Field Theory, Design of Analog Integrated Circuits, and General Relativity. **A2.2: Supervision of Magister and Doctorate Thesis.** In the first year of the Anillo we reported 17 graduate thesis (10 Magister and 7 Doctorate, in Astronomy, Engineering, and Physics, 8 of them current). In the second year we reported 18 graduate thesis (12 of them current). In the third year we have a similar number. As an example we mention Dr. Nicolas Rojas and Dr. Pablo Gonzalez, who finished their Doctorate in our group. **A2.3: Student stays at CERN or other Facilities.** In the first year we reported a stay at CERN by Giovanna Cottin (Magister in Physics student), working on Tau Lepton Trigger and Data Quality. In the second report, we mention a stay at CERN by Pablo Walker (Magister student in Engineering) working on Thin Gap Chambers, and by Sylvain Blunier (Doctorate in Physics student) working on Grid issues (WebDav). In the third year, our graduate student Sylvain Blunier also went to CERN, continuing his work on Grid. We mention also Marilyn Cruces (Magister in Astronomy student) who went to several countries in Europe to participate in different conferences and on the ASTRON/JIVE Summer Student Programme 2015 in The Netherlands. **A2.4: Seminar Program in HEP.** Our seminar programme is called “gravitículas” and is organized by Prof. Benjamin Koch. In the first year of the Anillo we reported 31 seminars, about half the time from scientist working in Chile and the other half from abroad. In the second year we reported 27, and a similar number for the third year of the Anillo. The program is essential for the local scientist (Professors and Students) to maintain current on the latest developments,

and are also useful for initiating or continuing international cooperation. **A2.5: Contribution to Conferences and Attendance to Schools.** In the first year of the Anillo we mentioned 7 attendance to Schools and Conferences from graduate students, highlighting here the 2013 CERN School in Peru, and the XVIII Simposio Chileno de Fisica, Sochifi" in Chile. In the second year we reported the participation by S. Blunier in the ATLAS Software week, and the participation by several graduate students to the 2014 Afunalhue workshop organized by Prof. J. Alfaro. In the third year we financed also the stay of a student in the CERN-Latinamerica School and mention the participation of several graduate students in the 2016 Afunalhue workshop.

Objective O3: Professional Development.

This objective was successfully fulfilled with several stays, mainly at CERN, by young postdoctoral researchers, and technicians. **A3.1: Training at CERN or other HEP Facilities.** In the first year of the Anillo we reported on visits to CERN by E. Carquin and M. Vogel, working on ATLAS Tau Trigger and on the CLIC Collaboration. In a similar way, in the second year of the Anillo E. Carquin visited CERN working on the Tau Lepton Trigger and analysis on the triple Higgs coupling, G. Leal also visited CERN working on the Muon Spectrometer upgrade, and M. Vogel also visited CERN working on ATLAS Tau Trigger and on CLIC analysis. For the third year, we highlight a trip to CERN by P. Walker related to the ATLAS Muon Spectrometer upgrade. **A3.2: Postdoctoral Hiring Process.** As reported in the first year of the Anillo, the main hiring process culminated with the contract of postdoctoral scientists Drs. Edson Carquin and German Gomez. They worked in Experimental and Theoretical Particle Physics respectively until Nov 15 2015. As temporary postdoctoral researchers, B. Panes, R. Avila, N. Viaux, and N. Rojas worked financed by the Anillo for usually 6 months.

O4: Scientific exchange.

We fulfilled this objective because the Anillo was able to finance more visits from our scientists to centers of knowledge like CERN and other Institutions. Without the Anillo, the visits would have been smaller in number and shorter in time. These visits are very useful to initiate or continue cooperation between our scientists and partners elsewhere. **A4.1: Visiting scientist to PUC.** In the first year of the Anillo we reported 10 visits from abroad to Santiago. For the second year we mentioned 4 visits. In the third year we had a similar number of visits. Most of the time, these visits were for a week, include a seminar and many work conversations with local scientist that usually lead to cooperation. We mention here the visits by Alessia Platania from Italy, and by Stefan Theisen from Max Planck, Potsdam, Germany. **A4.2: Visits to CERN or other HEP facilities abroad.** We have reported 3 visits to CERN by members of our group in the first year, and 2 visits to CERN and one to The Netherlands in the second year. A similar number of visits we have for the third year. We highlight here the visit to Universidad Autónoma de Madrid, Universidad de Barcelona, Universidad de Santiago de Compostela, in Septiembre 2015 by Prof. Jorge Alfaro, visit to University of Notre Dame in 2016 by Prof. Angel Abusleme, and the visit to the Institute of High-Energy Physics, Beijing, China, by Prof. J.P. Ochoa.

O5: Work in RLA

This objective was fulfilled because several studies where conducted by the three lines of work that comprise it. Most of these works were done in cooperation with (sometimes former) students and international partners. All of them published in scientific magazines with referees. **A5.1: Studies on Delta Gravity.** Delta Gravity was analyzed by Prof. Jorge Alfaro mainly in the first year of the Anillo, together with Dr. Pablo Gonzalez. In the second year of the Anillo the solution to quantization of Gravity called Delta Gravity was presented in Conferences by the mentioned researchers. As a continuation of the cooperation, Prof. Alfaro changed attention to the problem of a Lorentz Violating Theories together Dr. Ricardo Avila called Very Special Relativity. Both, Drs. Gonzalez and Avila were financed by the Anillo, first as Doctorate students and later with postdoctoral work with Prof. Alfaro. The three of them studied later an electroweak model that included Very Special Relativity. **A5.2: Studies in Bi-Gravity.** In the first year of the Anillo two works were mentioned in the report, done by Prof. Máximo Bañados in cooperation with then students M. Pino and D. Cohen. In the second year three works were highlighted, done by Prof. M. Bañados in cooperation with former students Macarena Lagos and Sebastián García, together with Prof. P. Ferreira from Oxford. In the last year of the Anillo, the attention of Prof. M. Bañados (Dean

of Faculty of Physics at PUC) was switched to high spin objects, line of investigation from which two articles materialized. **A5.3: Studies in Exact Renormalization Group.** The studies of the Exact Renormalization Group by Prof. Benjamin Koch and his group has span the three years of the Anillo. In the first year we reported on an article done in cooperation with former student Paola Rioseco. In the second year we reported on works done in cooperation with collabotrator Prof. Frank Saueressig, from The Netherlands. In the third year he continued analizing that problem, mentioning a work with Paola Rioseco published in Class. Quant. Grav. **A5.4: Periodical meetings with students.** The three groups, lead by Profs. Alfaro, Bañados, and Koch, and including mostly graduate students, meet periodically during the whole duration of the Anillo. These meetings were very useful for the training of the students, solving problems in communion and presenting advances. **A5.5: Publications.** We reported for the first year 9 publications in the three lines of work just mentioned. For the second year we mentioned 11 publications. A similar amount of publications corresponds to the third year. He mention here two of them that involves more than one main researcher in this Anillo: “Constraints to Dark Matter from Innert Higgs Doublet Model”, by M.A. Díaz, B. Koch, and S. Urrutia, and “Can Schwarzschild Black Holes Be Accelerators of Spinning Massive Particles?”, by C. Armaza, M. Bañados, and B. Koch. We menton here that a group of researchers in Chile have jointed CTA Collaboration, and that a member of the Anillo, Prof. Reisenegger, is the representative of this group.

O6: Work in RLB

This objective was also fulfilled. Several articles were published, many of them involved graduate students. The Anillo financed these students, including visits to foreign Centres and Laboratories, attendance to Conferences and Schools, and visits for foreign scientists to Chile. All of this increased the output in this Research Line. **A6.1: Studies on Higgs bosons.** In theoretical studies, Prof. M.A. Diaz's group is looking into the implications of a SM-like Higgs boson with a mass of 125 GeV, and a potential extra Higgs boson at 750 GeV. In the first year it was mentioned the work in collaboration with former students G. Cottin and N. Rojas where a SM Higgs of 125 GeV is considered. In the second year a work together with Prof. B. Koch and student S. Urrutia was mentioned, where the SM Higgs doublet is enhanced with an extra and inert Higgs doublet. The research continues with a triplet Higgs field, together with student S. Blunier and E. Castillo, where an extra scalar could have a mass of 750 GeV. In experimental studies, the SM Higgs boson was discovered, an extra Higgs boson could have been observed by ATLAS and CMS Collaborations at 750 GeV, and triple SM Higgs couplings (work by Dr. E. Carquin) has a cross section too small to be observed by now. The top quark Yukawa coupling could be measured at CLIC (work by Dr. M. Vogel). **A6.2: Studies on supersymmetric models.** In theoretical studies, Prof. M.A. Díaz's group is working out the consistency of a supersymmetric model with experimental results. In the first report a work done in collaboration of Prof. M. Rivera and former student N. Rojas was presented. In the second report we mentioned first steps of a work where the Gravitino as Dark Matter was confronted with other astrophysical measurements. This work was published during the third year of the Anillo. In experimental studies, supersymmetry has not been observed. Dr. M. Vogel initiated work with the supersymmetry with R-Parity violation group. **A6.3: Studies on neutrino physics.** In theoretical studies Prof. M. Rivera studied a mechanism to generate neutrino masses together with collaborators in Europe. This work was mentioned in the first report. We highlight two other models reported for the second year: a neutrino mass generation mechanism in connection with neutrino-less double beta decay, by M. Rivera and collaborator, and supersymmetry with violation of R-Parity, by M. Rivera, N. Rojas, and M.A. Díaz. Supersymmetric and non-supersymmetric models that generate mass to the neutrinos coninue to be studied in the third year of the Anillo. In experimental studies, Prof. J.P. Ochoa, and Drs. Y. Malyshkin and N. Viaux belong to the Collaboration Daya Bay, where we mention the measurement of the (very elusive) θ_{13} neutrino mixing angle. **A6.4: Weekly meeting between researchers and students.** All the groups mentioned above held periodical meetings that included Professors, Postdoctoral Fellows, and Students. **A6.5: Publications.** Associated to this Research Line there are 4 articles reported for the first year of the Anillo, and another 4 for the second year. For the third year there are a similar number.

O7: Work in RLC

This objective was fulfilled. We contributed strongly to the tau Lepton Trigger associated to the ATLAS Detector, and to analysis related to the Higgs boson. **A7.1: Work on tau trigger validation and sofware.** This line of work was developed mainly by Drs. E. Carquin and M. Vogel. We highlight here the study of the Tau Energy Scale by Dr. Carquin. The work by Dr. Vogel earned him the ATLAS authorship. The involvement of these two researchers in Tau Lepton Trigger continued through the three years of the Anillo, until the end ef 2015. **A7.2: Periodic tau trigger meeting, local and remote.** We held periodical local and remote meetings during the Anillo. The local meeting had as an objective to introduce the students to the workings of the ATLAS Trigger system. The remote meetings were the usual ATLAS group meetings where mainly E. Carquin and M. Vogel report their findings. **A7.3: Work on Higgs and/or supersymmetry analysis.** Originally this line of research was oriented to analysis with ATLAS Data, where Dr. Carquin studied the measurement of the triple Higgs coupling. But with time the analysis extended also to CLIC, where Dr. Vogel studied the measurement of the Higgs Yukawa coupling to the top quark, and to Daya Bay, where n. Viaux studied CP and Lorentz violation seen with neutrino oscillations. We also mention the initial involvement of Dr. Vogel in supersymmetric phenomena when R-Parity is not conserved. **A7.4: Periodic Higgs and/or supersymmetry meeting, local and remote.** We also had periodical meetings on analysis. The local meetings had the objective to introduce the students to the analysis methods and tools. The remote meetings were the usual ATLAS analysis group meetings, but also independent meeting associated to CLIC and Daya Bay Collaborations. **A7.5: Publications.** There were several publication mentioned in previous reports, including a large amount of ATLAS publications although our group was not the main contributor.

O8: Work on RLD

This objective was fulfilled. The Virtual Organization (VO) is working as described below. The two operational nodes (Physics and Astronomy) include the software necessary to analyze ATLAS data (and other software as well). **A8.1: Hardware installation of new HEP-PUC Grid node.** The necessary hardware is installed, forming the HEP-Grid node. This includes a Computing Element (CE), a BDII, a Storage Element (SE), and several Working Nodes (WN). **A8.2: Grid software installation in new HEP-PUC Grid node.** The HEP node is working properly with all the software that makes it a Grid node, and certified by ROC-LA. **A8.3: Set up HEP-PUC cluster as ATLAS Grid node.** The HEP node is working as a Grid node. The first step was to be certified by ROC-LA (Regional Operating Centre in Latin America). It contains all the software necessary for an ATLAS annalist to run local code for debugging. To be done: to connect to ATLAS as a site. **A8.4: Creation of PUC VO.** The Virtual Organization, PUC-VO, is working. The VO is defined with all the requirements of the Grid. It is being monitored by ROC-LA and has been certified by EGI. The VOMS is working, which can accept new members for the VO. The users can use a proxy with their personal certificate and send works to the nodes subscribed to the VO. To be done: To work out the WMS which allows the user to send a job without specifying the node. **A8.5: Set up Astronomy Grid node connected to PUC-VO.** The Astronomy node is connected to PUC-VO. The first step was to be certified by ROC-LA as a Grid node. **A8.6: Hardware installation of Engineering cluster.** The hardware is installed in the Engineering Faculty. **A8.7: Grid software installation at Engineering Grid node for PUC-VO.** This is mostly done but still has some work to do. The node is not yet certified as a Grid site. To be done: to obtain the certification from ROC-LA for this third node of the PUC-VO. **A8.8: Operation of HEP-PUC ATLAS node.** The site is already equipped with the necessary hardware and software to be an ATLAS node. For the moment, a user that wants to run and debug a code to be used for an analysis of ATLAS data can do it. We have not try to become an official site for ATLAS yet because Chilean international bandwidth is insufficient. **A8.9: Operation of PUC-VO.** The PUC Virtual Organization is operational. For the moment it is tiny, it include just two sites and the users are people from our group. It will be very easy to add more nodes, the third one that is very advanced is in Engineering. The next steps will be to include more users and more nodes. **A8.10: Weekly meetings for HEP cluster.** We have had weekly meetings with the group working on the Grid node. This group was lead by System Manager Juan Veliz and Prof. M.A. Díaz. It include also Dr. M. Vogel, Doctoral student S. Blunier, and undergraduate students Vicente Santibañez and Andrea Torrealba. **A8.11: monthly meetings for PUC-VO.** The meetings related to the Virtual Organization were melted with the meetings for the Cluster described above.

O9: Work on RLE

This objective is fulfilled. We have worked the preliminaries related to the working of the Thin Gap Chambers (TGC), like characterization and aging. We have advanced steadily on the preparation of the HEP Laboratories in order to test the chambers to be built in Valparaiso. Equipment and training of personnel have been financed by the Anillo. The work will continue, financed by the NSW Conicyt-PUC grant. The chambers from Valparaiso will arrive regularly (32 quadruplets) starting sometime at the middle of 2016. The testing and shipment to Geneva will be completed in 2017. All the testing sites organized the first International Meeting in Canada, and Prof. Ochoa was there. **A9.1: Set up of TGC detector and trial measurements by thesis student.** This was done by former student Gonzalo Leal. See report for year 1. **A9.2: Set up of TGC experiment on aging. Measurements with different gas flows.** An aging study was done, identifying the chemical composition of gas depositions in the wires. The work at PUC was directed by Prof. U. Volkmann. Measurements with different gas flows was considered secondary, and all efforts were directed to the testing of the small Thin Gap Chambers (sTGC) for the New Small Wheel (NSW), including the soldering of the Adapter Boards. **A9.3: Experimental studies on the new technology to be agreed upon.** The sTGC to be produced almost finished at UTFSM in Valparaiso (soldering of Adapter Boards to the chambers will be done at PUC) will be tested in Santiago. The HEPLAB1 which includes the Hodoscope that will test the sTGC with cosmic rays is almost ready. Missing is the adaptation of the Data Acquisition (DA). This is being done mainly by Prof. A. Abusleme and his student Pablo Walker, who designed and built the interface card between the scintillators and the DA equipment. The HEPLAB2, where the soldering will be performed, needs more work, which includes the system that will extract the fumes. Dr. Viaux is looking into those details, in both laboratories. **A9.4: Weekly local meetings, and periodic meeting with TGC group abroad.** We have had local meetings on the subject since the beginning of the Anillo. We also attend the remote meetings with our collaborators in Canada CERN, China, Israel and Russia. Recently we set up a meeting with our partners in Valparaiso. All of the above meetings have a weekly frequency. Last month, we attended ATLAS Collaboration Meeting (Prof. Díaz) and Testing Meeting in Montreal (Prof. Ochoa).

O10: Dissemination

This objective was also fulfilled, with many professional international and national talks. Also many talks to General Public. We highlight the organization of “Master Class”. These activities received financial help from the Anillo, and certainly not all of them would have been possible without the Anillo. **A10.1: Contributions at Conferences and other seminars.** The number of professional and General Audience talks by members of the Anillo has been numerous, with 23 and 7 respectively in the report for the first year, for example. In the last three years Prof. Alfaro has co-organized the Workshop in Afunalhue, Chile, directed to local researchers. In February-March 2016 Prof. Koch organized the “Master Class” for a third consecutive year, directed to School teachers and last year High-School students. The Anillo financed the attendance to the International Conference and School in Valparaiso for some students and postdocs.

V. OUTPUTS

In this section refer to the results of the project related to each of the specific objectives of the grant and based on the three year productivity reported in the website: http://portaldelinvestigador.cl/en/pia_reportes.

Do not provide lists of outputs but refer to the total outcomes during the development of the project explaining relevant aspects of the processes behind the results.

It could be considered any of the following fields required in the Productivity System: indexed Publications, Books, awards, Organization of scientific events, Participation in Scientific Events, Collaboration, thesis, Postdoctoral Fellows, Outreach Activities, Patents.

The objectives for the Anillo are: O1: Undergraduate Training; O2: Graduate Training; O3: Professional Development; O4: Scientific exchange; O5: Work in Research Line A (theory in Gravity); O6: Work in RLB (theory in Higgs, Beyond SM, neutrinos); O7: Work in RLC (Trigger and Analysis); O8: Work on RLD (Distributed Computing); O9: Work on RLE (Hardware); O10: Dissemination.

All the objectives were fulfilled (see previous section for details).

The output of the proyect is in the described web-page. There is something important that I could not upload, and that is related to the postdoctoral felows. Therefore, I mention it here. Two posdocs were hired full time and for the whole duration of the Anillo. They are Dr. Edson Carquin and Dr. Germán Gómez. Dr. Carquin was hired as the experimentalist. His work was related to the ATLAS Collaboration, in analysis of data it order to determine the triple Higgs coupling. He also did work on the Tau Lepton Trigger, more specifically investigating the Tau Energy Scale. In the case of Dr. Gómez, he was hired to work in theory. He is very knowledgeable in Astrophysics, working this time mainly in the identification of Dark Matter. He has been efficient in our interest to contribute to the Cherenkov Telecope Array proyect.

Another important issue related to productivity is that there should be at least two articles with at least two Anillo main researchers among the authors. Profs. Alfaro, Bañados, Díaz, and Koch are the Anillo main researchers. The two articles are:

1) “Constraints to Dark Matter from Inert Higgs Doublet Model” by Diaz, Koch, and Urrutia, accepted for publication in Advances in High Energy Physics on January 28th 2016.

2) “Collisions of spinning massive particles in a Schwarzschild background”, by Armaza, Bañados, and Koch, accepted for publication in Classical and Quantum Gravity on March 10th 2016.

The two acceptance letters are included.

VI. HIGHLIGHTS

In no more than three pages, indicate the main outcomes and/or activities which must be considered the most significant results of the project. Please consider the specific objectives of this grant.

There are three issues that we would like to highlight.

1) The Anillo has improved the education of the students associated to our area, and improve the training of postdoctoral fellows and young researchers. There are several ways this has happened. First, the fact that the members of the Anillo met almost every week implied that through conversations the set of under-graduate and graduate courses offered has became more coherent. For example, we have defined a group of core courses that should be offered every semester, and we have learned of courses in Engineering that can be followed by students in our Faculdad. Second, Prof. Koch organized a series of weekly seminars that, by definition, helped with the education of our students and exposed all the researchers to the latest developments of the field. The Anillo contributed to the organization of the seminars financing different items. Third, several visitors, either from other institutions in Chile or from abroad, came to our Institute financed or co-financed by the Anillo, and created contacts for current or future cooperation. Fourth, several visits of our students or young researchers to other Laboratories or Institutes were financed by the Anillo, greatly improving their education or training.

2) We have created a Virtual Organization for Chile. For the moment it is small, and thus incipient: with only two working sites, Physics and Astronomy, and with users that for the moment are members of our group. The sites are certified by ROC-LA and the VO is being monitored by EGI. The expansion and professionalization of the VO involve the following steps. First, the WMS has to be working. This service will allow the users to send their job without specifying the site where it should run. Second, more sites should be added. Since the VO is already configured, this step is easy. The next site to be added will be one we already have almost completed in the Computing Science Department at PUC. We will added to the VO once the site is certified by ROC-LA. Other sites can follow. Some could be at PUC, later we could add some sites outside PUC. Third, users should be added, for which we will do advertisement and will install the necessary code. In addition we mention that among the code it is installed, is the ATLAS code that an ATLAS analyst needs to send a job and run over a limited set of data, destined for debugging. In this sense, the Physics site is ready to contribute to ATLAS.

3) Together with partners at Canada, CERN, China, Israel, and Russia, the two Chilean Institutions associated to the ATLAS Collaboration, UTFSM in Valparaiso and PUC in Santiago, are participating in the upgrade of the Muon Spectrometer. More specifically, muon detectors called Thin Gap Chambers form the so-called Small Wheel. The increase in luminosity expected after the Long Shutdown force the replacement of the old TGC. Most of the construction of the Chilean share (32 quadrupoles) is going to be perform in Valparaiso. At PUC we will terminate the construction soldiering the Adapter Boards to the chambers. The finalized chamber will be tested, and its efficiency will be measured with the almost completed Hodoscope. The Anillo helped finance the conditioning and equipment for the two Laboratories at our disposal. The tested chambers will be shipped to Geneva for further tests and installation in the ATLAS Detector. The work will continue with financing from other Conicyt grants.

VII. LESSONS LEARNED

The following section can be used in case of available information related to the possible difficulties, inconveniences or similar issues in the management of the project within the host institution, between CONICYT and the host institution, institution and researchers or any other combination of participants and activities involved. Information provided in this section must be concise, stating all variables involved and outcomes. Do not extend further than two pages.

This information could be used to improve the practices in future initiatives.

There were two difficulties worth mentioning, that we overcome.

1) The grant National Laboratory for High Performance Computing (NLHPC) had an administrative delay. This in turn caused a delay in the delivery of computing hardware to our group. Finally, this caused a delay in the Research Line D related to Distributed Computing. At the end the equipment arrived, but we had for months to advance without this hardware in the creation of the VO and the preparation of the site in Physics for ATLAS software. We created the VO on time with the help of small amounts of equipment obtained with the Anillo itself, but with the help of other grants as well. The preparation of the sites with ATLAS software was done in the last year of the Anillo. In this way, an ATLAS analyst can run its code in our site, but with limited access to data. Thus, debugging is the main application (not to be considered a small part). After this, the code would have to be run in ATLAS Grid with access to the whole data set. To be done in the future is to connect to ATLAS Grid, but that has the problem of a not adequate bandwidth from Chile to abroad. Lesson Learned: If important delays come along, alternative mitigating paths should be found.

2) The second issue we mention is related to the fact that theoretical cooperation is usually done with a much smaller number of researchers, when compared to large experimental collaborations. Also new cooperation between theoreticians is a slow process, but fruits can be obtained with time and patience. This has impact on one basic objective of an Anillo grant: to increase cooperation among members. And this affects one of the Anillo rules: there should be at least two articles with at least two Anillo main researchers. In the Anillo ACT1102 we have a large cooperation between one main researcher with associated researchers and other members of the Anillo. The main researchers are four, 3 pure theoreticians and 1 mixed between theory and experiment. Frequent collaboration was present in the Anillo from the start between one main researcher and associated researchers. Work between main investigators was scarce, and special attention was given to this situation. At the end, the effort was successful. Lesson Learned: pay attention to this issue from the beginning, since creating new cooperation is a slow process.

VIII. COMMENTS TO PREVIOUS EVALUATIONS

Refer to the observations and/or suggestions stated by the reviewers in the last evaluation. Explain how the research team worked on those comments and/or suggestions. Please do not extend further than two pages.

A comment from one of the referees should be mentioned here. The Anillo has a theoretical section and an experimental section. The relation among them may not seem immediately clear. The referee points to precisely that, he/she does not see a clear interaction between the two sections.

Writing with more details, Research Line A was devoted to the study of gravity, through topics like bi-gravity, gravity quantization, Lorentz violation, and running of fundamental constants. One connection that was developed during the last year was that Lorentz violation was studied both via theory with the work of Prof. Alfaro in Research Line A, and via experiments, where the Daya Bay Collaboration led by Prof. Ochoa analyze neutrino data looking for Lorentz violation effects, within Research Line C.

Nevertheless, one could also argue a bit deeper. Physics is a science where experimental observations are modeled by theory in such a way that it can predict other phenomena. Our Anillo had a large number of meetings, where theorists and experimentalists talked in a fruitful way. The interaction went in both directions where one group devised experiments motivated by theory, and where the other group changed or proposed theories motivated by experimental observations. What is the connection in our Anillo? The topics were close enough for experiments to look for effects predicted by theory. Through the meetings mentioned earlier, this interaction was passed to students via presentations or conversations. We believe the education of our students has improved by showing this interaction between theory and experiment.