Addendum to the Expression of Interest of REDTOP

Y. Alexahin, A. Pla-Dalmau, J. Dey, V. Di Benedetto, B. Dobrescu, E. Gianfelice-Wendt, E. Hahn, D. Jensen, C. Johnstone, J. Johnstone, J. Kilmer, G.Krnjaic, T. Kobilarcik, A. Kronfeld, K. Krempetz, M. May, A. Mazzacane, N. Mokhov, W. Pellico, V. Pronskikh, E. Ramberg, J. Rauch, L. Ristori, G. Sellberg, G. Tassotto

Fermi National Accelerator Laboratory

J. Comfort, P. Mauskopf, D. McFarland, L. Thomas

Arizona State University

I. Pedraza, D. Leon, S. Escobar, D. Herrera, D Silverio

Benemerita Universidad Autonoma de Puebla

A. Alqahtani

Brown University, Providence, Rhode Island

F. Ignatov

Budker Institute of Nuclear Physics – Novosibirsk

P. Sanchez-PuertasPresent address: IFAE - Barcelona

Institute of Particle and Nuclear Physics – Charles University Prague

C. Gatto*

Istituto Nazionale di Fisica Nucleare – Sezione di Napoli and Northern Illinois University

W. Baldini

Istituto Nazionale di Fisica Nucleare – Sezione di Ferrara

R. Carosi, A. Kievsky, M. Viviani

Istituto Nazionale di Fisica Nucleare – Sezione di Pisa

W. Krzemień, M. Silarski, M. Zielinski

Institute of Physics, Jagiellonian University, 30-348 Krakow

S. Pastore

Los Alamos National Laboratory

M. Berlowski

National Centre for Nuclear Research – Warsaw

G. Blazey, M. Syphers, V. Zutshi, P. Chintalapati, T. Malla, M. Figora

Northern Illinois University

M. Pospelov

Perimeter Institute for Theoretical Physics, Waterloo

Y. Kahn

Princeton University, Princeton

A. Gutierrez, B. FabelaPresent Address: Vanderbilt University , M. A. Hernadez-Ruiz

Universidad Autonoma de Zacatecas

L. E. Marcucci

Universita' di Pisa and INFN

C. Siligardi, S. Barbi, C. Mugoni

Universita' di Modena e Reggio Emilia

M. Guida

Universita' di Salerno and INFN – Sezione di Napoli

J. Konisberg

University of Florida

S. Gardner, J. Shi, X. Yan

University of Kentucky

R. Rusack

University of Minnesota

A. Kupsc

University of Uppsala

(The REDTOP Collaboration)[†]

[*] Email gatto@fnal.gov

[†] Homepage: http://redtop.fnal.gov

I. THE REDTOP COLLABORATION

REDTOP Collaboration has been forming since the year 2015 and, at present, it counts 67 members from 23 institutions. A list of the participating scientists is found at the beginning of this addendum.

II. INTERESTED COMMUNITY

REDTOP main goal is to search for physics beyond the standard model in the MeV-GeV energy range, with a next-generation tracking and calorimetric techniques. The interested community is, therefore, the High Energy Physics (HEP), non-Collider community as well as those research groups involved in the development of nuclear and HEP detector to be operated with a high intensity beam. The dual-readout technique can also be exploited in high precision, compensating hadronic calorimetry, with possible application in a future collider (either hadronic or leptonic) at high energy. Finally, the technique of directly coupling a light sensor to Pb-glass and plastics tiles can be extended to medical imaging applications and/or hadron therapy, where the expensive, crystal based, radiation monitoring would be replaced by an ADRIANO2 module..

III. TIMELINE

The Collaborations has estimated that about two years of detector R&D are necessary to finalize the layout of the detector. Since R&D on ADRIANO2 is ongoing and funded, the fiber tracker requires no R&D, the R&D timeline is completely dominated by the R&D on the Optical-TPC. Engineering time for finalizing a Technical Proposal is estimated at no more than 1 year and it could be achieved in parallel with the R&D on the Optical-TPC. Both activities, however, require that funding be already in place. The solenoid and most of the lead-glass required for the Cerenkov component of ADRIANO are readily available from INFN while the fibers for Tracker and the Scintillating component of ADRIANO2 are commercially available with short lead times. The low cost, Large Area Picosecond Photo-detectors (LAPPD) required for the O-TPC are becoming commercially available at Incom and the production of about 100 units for REDTOP seems not to represent a problem for the company. REDTOP will use commercial Silicon Photomultipliers (SiPM), commercial ASIC's for the Front-End Electronics (FEE) and Back-End Electronics (BEE) boards and and commercial Data Acquisition (DAQ) components. The design, test and production of the electronics board is estimated in about 1 year.

A full proposal will be presented to the SPSC immediately after the conclusion of the ESPP process (mid-2020). The construction and installation time for the, relatively small, REDTOP detector is estimated to be about two years. The Collaboration proposes two options responsive to the running schedules, depending on whether funding for detector R&D on the Optical-TPC becomes available before or after the approval process. In the former case, REDTOP would be ready to install in 2022 and run in 2023, one year before LS3. In the second case, the Collaboration proposes a less aggressive schedule, by installing in 2023 and start running in 2024.

The collaboration aims at integrating about 10^{17} POT at 1.8 GeV ($\eta-$factory) and 10^{17} POT at 3.5 GeV (η'$-$factory). These yields could be provided in one or multiple years, depending on the availability of such beam at the hosting laboratory.

IV. COSTING

The optimization of the detector layout is proceeding at at steady pace, taking advantage of the fact that a full simulation is already in place (see Sec. 5 of the Overview document). However, only a preliminary cost estimate could be done at this stage of the project. Costing of electronic components ans sensors (SiPM-LAPPD) is based on current (i.e., 2018) quotes from the vendors and it is expected to decrease by the time the actual purchase is made.

IV.A. Solenoid

The Collaboration intends to re-use the Finuda magnet[Bert99], currently stored at the *Laboratori Nazionali di Frascati* of INFN. A cost of about $ 0.2M has been estimated for refurbishing the Dewar vessel, dismantling and shipping the cryostat and the return yoke. Cryogenics (cooler+power supply) is expected to be available at the hosting laboratory.

IV.B. Supporting structure

The entire detector will be enclosed in a, 1 cm thick, cylindrical steel supporting vessel, held inside the solenoid by two longitudinal rails. The cost of the vessel and the fixtures, including engineering, has been estimate at about $ 1M.

IV.C. Target systems and beam pipe

The technology of the beam pipe and target systems is well established and requires no R&D. The low dissipated power (1.5 mW/foil) requires no heat removal systems. The total estimated cost for engineering, components and manufacturing has been conservatively assessed to be no more than $0.5M

IV.D. Fiber Tracker

A cost of the Fiber Tracker for REDTOP has been obtained by an educated scaling of the cost of the LHCb[LHCB2015-1] tracker. The active surface of the tracker in case of REDTOP is about 0.24 m^2 vs 360 $m^2$for LHCb. Cost of the material is scaled proportionally to the active area. In total, 36 mats are needed (vs 1,152 for LHCb), each having a surface corresponding to 24% than a LHCb mat. Expected cost for the mats is less than $ 10K. We conservatively cost the tooling integrally, in the unfortunate assumption that we would not be able to borrow them from LHCb. The cost of LHCb tooling is 450,000 CHF. A total of 144 SiPM's, each comprising 128 channels, are needed (assuming a two-side readout schema). Total readout channels is about 18,000 (vs 590k for LHCB's tracker) . Even in this case, the cost is scaled from LHCb estimates[LHCB2016][LHCB2015-2] and stands at about $ 100K for the SiPM array, including mounting, $120K for the FEE, and and $50K for the, ASIC based, back-end electronic board (which includes zero suppression). About $ 0.2 M is the cost of mechanics and cooling for the electronics.

IV.E. Optical-TPC

From the structural point of view, the O-TPC is just a gas-filled vessel with the external walls instrumented with optical sensors. A surface of about $7\,m^2$ needs to be instrumented. Two options are considered: either 175 LAPPD (commercially available from INCOM[INCOM]) or 280,000 SiPM's. The cost is estimated at about $ 6M for the LAPPD option and $ 2.5M for the SiPM array option. The cost of a fast (40 MHz), ASIC-based readout electronics for the 280,000 channels is obtained based on LHCb-upgrade costing and stands at $ 1.8M for the front-end and $ 0.7M for the back-end .

The cost of the vessel is estimated at $ 0.5M while the, 3 cm thick, aerogel is expected to cost about \$1M.

IV.F. ADRIANO2

About 70% of the SF57 Pb-glass needed for ADRIANO2 is available at the *Laboratori Nazionali di Frascati* of INFN from the, now completed, construction of NA62 apparatus. Cost of shipping of the twelve boxes is expected to be about \$25K. The remaining 30% (or 2.7 m^3) is commercially available from Schott at a cost of about \$1/cm^3. Regarding the scintillating plate, two options are being considered: cast and molded. The performance of the prototype under construction at NIU will indicate if we could opt for the, much cheaper, molded option. In the present document, we conservatively quote the cost of the first option (cast scintillator), corresponding to \$ 750K for the needed 750/m^3. The machining and coating of the 150,000 tiles is expected to cost no more that \$10/tile. The cost of the SiPM changes considerably with the size of the device. In order to contain costs, we will employ larger (i.e, 6mm x 6 mm - \$12 each for large quantities) units in the glass and smaller (i.e. 3mm x 3mm - \$5) for the plastic tiles, which have a larger light yield. In conclusion, we expect that the cost of the 600,000 sensors would not exceed \$ 6M.

The cost of the FEE is scaled from LHCb and is expected to be about \$ 4M, while the back-end electronics is estimated at \$ 1.5 M.

IV.G. Trigger

The L0 and L1 of the trigger systems are implemented completely in hardware and receive input from the almost 900K-channel back-end electronics board. The expected cost is of the order of \$ 1M. The L2 trigger is implemented in software, with a farm of 2000 CPU receiving data fro the L1 trigger. Since network requirements are not stringent, a 10G machine is sufficient. A conservative estimate for 20, dual socket 32 core EPIC AMD with "*hyperthreading*", equipped with 128 processors, each with 2GB of memory and a SSD, stands at about \$ 0.2M. These have 28% more computing power than needed, which can be used as backup or for the reconstruction /analysis of the data.

IV.H. DAQ

IV.I. Contingency

A contingency factor of 50% is included in the present cost estimate.

IV.J. Summary of costs

Table Isummarizes the costing discussed above. The total expected cost, including contingency, is about \$ 51M.

IV.K. Cost reduction

Along with the optimization of the detector layout, the Collaboration is exploring alternative solutions to reduce the overall costs of the experiment. The largest contributions to the cost of REDTOP (cfr. Table I) correspond to the sensors for the Optical TPC and ADRIANO2, the front-end electronics and the back-end electronics of ADRIANO2. While the number of SiPM's reading each 10cm x 10 cm tile cannot be reduced (or made smaller) without a proportional reduction in light-yield, we are considering techniques for ganging multiple tiles. This technique will reduce the number of read-out channels and the load on the L0 trigger. Passive and active ganging is rapidly becoming a cost-cutting resource in the latest large area detectors. The radial granularity of ADRIANO2 could easily support ganging multiple tiles of the same kind (i.e., glass or plastics), without loosing particle identification power. Studies have been planned to explore the effects of

Solenoid	**0.2**
Refurbishing, shipping	0.2
Supporting structure	**1.0**
Target+beam pipe	**0.5**
Fiber tracker	**0.93**
Fiber mats	0.01
Tooling	0.45
SiPM array	0.1
Front-end electronics	0.12
Back-end electronics	0.05
Mechanics and cooling	0.2
Optical-TPC	**10.0**
Vessel	0.5
Aerogel	1.0
Photo-sensors (LAPPD option)	6.0
Front-end electronics	1.8
Back-end electronics	0.7
ADRIANO2	**16.0**
Pb-glass	2.7
Cast scintillator	0.75
Tile fabrication	0.6
SiPM	6.0
Front-end electronics	4.0
Back-end electronics	1.5
Mechanics and cooling	0.5
Trigger	**1.2**
L0 + L1	1.0
L2 farm + networking	0.2
DAQ	**5.0**
Digitizer	
Networking	
Contingency	**17.0**
50% Contingency	17.0
Total REDTOP	**51.3**

Table I. Preliminary cost estimate for REDTOP

SiPM ganging on event pile-up, shower separation and muon-polarization measurements. A cheaper alternative (SiPM) is being considered for the sensors of the Optical-TPC. Studies are ongoing to verify if the, intrinsically noisier, SiPM's could be a valid replacement for the LAPPD.

V. COMPUTING REQUIREMENTS

The expected event rate outputted by the Level 2 trigger is about 100 Hz (cfr. Table II of the Overview). Assuming a raw-data size of about 5 kByte, the expected throughput is 500 kB/sec or 5 PB of raw data for the full η run at each of the two beam energies, corresponding to a total $1 \times 10^9\, \eta-$events and $1 \times 10^7\, \eta'-$events stored on tape for reconstruction and further analysis. The event reconstruction takes about 30 sec. Consequently, a total of 3,000 CPU is necessary for the reconstruction 1 year (10^7sec) of data taking in a similar amount of time. Grid computing could easily provide that. When not in use, the 2,000 CPU dedicated to the Level 2 trigger (plus the spare 560 cpu's from the EPIC) the can be used to partially fulfill that task.

[Bert99] M. Bertani *et al.*, Nuclear Physics B (Proc. Suppl.) **78** 553 (1999).
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