

2016 TRACKER BUDGET

The Phase 2 tracker project consists of three sub-projects:

- Forward Pixels (FPIX) - 402.02.03
- Outer Tracker (OT) - 402.02.04
- Track Trigger (TT) - 402.02.05

Each of these has their own budget for R&D in 2016, discussed in turn in the following sections:

Critical R&D for Forward Pixels in 2016

The FPIX will be the NSF flagship project for the MREFC. The scope of this project, however, is still to be defined, both nationally and internationally, and R&D is urgently needed to inform this process. USCMS will build at least 1 m² of pixels, including some/all of the disks and may also build some radial layers - covering ~2.5 m in z, and pseudorapidities from ~1.4—4.0. The physics requirements vary significantly over this volume, ranging from “traditional” pixel detector performance needs (p_T resolution, d_0 resolution) to more novel criteria (z vertex association, pile-up mitigation). These requirements (plus practical considerations like radiation hardness) should drive the FPIX design (sensors, ROC, layout) and their relative importance for the US scope of the project must be understood as soon as possible.

Even though the design requirements are not yet fully specified, given the long lead time of the technological development needed to produce a suitable ROC, the forward pixel project must continue to pursue ASIC R&D in 2016. Options for the eventual final ROC include a chip expected to result from the CERN RD53 collaboration that will be used in the BPIX, a chip from R. Horisberger (PSI) to be developed from the phase-1 ROC, and a RD53 variant (FCP) being pursued at FNAL. In 2016 USCMS contributes to RD53 efforts on analog blocks for the common ATLAS/CMS RD53 demonstration chip and advances FCP development. While work on the ROC is advanced, mechanical engineering efforts are just beginning. Since complete conceptual designs will be needed for the TDR, the necessary mechanical engineering R&D must occur in 2016. This work will continue at FNAL where it has started, but also begin at Cornell, where it should ramp up in preparation of their anticipated role as the module integration center. Sensor R&D evaluating small-pitches, slim edges and implant choice will continue in 2016.

The requested budget for 2016 would exceed available funding by a significant margin. A 2016 budget has been proposed that enables the critical R&D, while fitting into the overall tracker and larger phase 2 upgrade funding envelope. Cost savings were achieved mainly through reduction in ASIC design at FNAL. Mechanical engineering costs were increased from the request reflecting the ramp up at Cornell. This is a short-term increase due to dual site costs in the period where knowledge/activity is being transferred from FNAL.

USCMS PHASE 2 TRACKER

FPIX Budget

Task	Type	Funding Request (k\$)	Total Budget (k\$)	KA25 Budget (k\$)	Ops Budget (k\$)
Sensor R&D - Cornell Layout & Testing	Labor	100	0	0 (?)	0
ROC R&D - chip submissions <i>RD53 + FCP065</i>	M&S	282.2	185	(125*1.8)	185
ROC R&D - FNAL EE <i>ASIC development</i>	Labor	975	500	500 (0->120*0)	0
ROC R&D - testing <i>RD53 + PSI</i>	M&S	0	20	0	20
ROC R&D - Ohio State/UNL <i>physicist evaluation</i>	Labor	0	0	0	0
Mechanics R&D <i>materials for conceptual design</i>	M&S	40	40	0	40
Mechanics R&D - Cornell ME <i>engineering for above</i>	Labor	250	303	0	303
Mechanics R&D <i>thermal tests</i>	M&S	0	6	0	6
Mechanics R&D - Purdue <i>UG labor for above</i>	Labor	0	4	0	4
Electronics R&D <i>service elec., power, optolinks (VL)</i>	M&S	20	20	20 (?)	0
Electronics R&D - FNAL EE <i>engineering for above</i>	Labor	125	125	125(?)	0
FPIX Total	0	2,222	1,243	645	598

FPIX 2016 Deliverables

- Sensor prototype fabrication, irradiation, characterization; n-in-n (SINTEF) and n-in-p (CMS common order)
- RD53 65 nm test structures (design, test, irradiation, characterization)
- FCP ASIC: in 130 nm (fabrication & testing) in 65 nm (design)
- Complete conceptual design, with engineering drawings, of mechanics
- Electrical integration for conceptual design (powering, services, optical links)

USCMS PHASE 2 TRACKER

- Detailed simulations needed to demonstrate physics case, resolve open design issues including but not limited to p_T vs. z resolution, pixel size, number of layers cylindrical vs. conical geometry, etc.
- New test beam telescope setup (2 copies) from UNL. RD53 test stands at OSU & UNL, PSI46 test stand at OSU.
- **Milestones:**
 - February 1, 2016: FPAAP report
 - February 8-12, 2016: Physics simulation studies reported at CMS Physics Days
 - May 9-12, 2016: Conceptual design presented at CMS TK Phase 2 Days

N.B. simulation efforts are not budgeted for, despite their critical needs since it is assumed that the physicist labor necessary for these tasks is funded by the research grants that the PIs from the university groups hold.

Critical R&D for Outer Tracker in 2016

The construction of the Outer Tracker (OT) is a high priority item for the U.S for several reasons. A performant tracker is crucial for CMS to realize its physics goals for HL-LHC and the current tracker will be beyond end of life. Equally crucial for CMS is the ability for the upgraded tracker to produce trigger primitives but without an OT, this is not possible. Finally, as was the case for Run 1, the construction of the OT requires the involvement of the significant facilities and experience in the US for the project to succeed

The minimum scope of US involvement is that USCMS will build half the PS modules, about 4000. We may be called upon to produce more, and production of 2S modules is also a possibility. Consequently, at least two production lines will be needed. One of these will be in the Northeast with mechanical assembly/testing at Brown and wire bonding/testing at Rutgers/Princeton. The other production line will include Fermilab, Davis, and Rochester. R&D includes assembly techniques, tooling, bump bonding, dummy modules and various mechanical & electrical tests.

USCMS groups will test & evaluate prototype sensors to qualify vendors including HPK, Infineon, and Novati (a US based company). USCMS is responsible for developing the MaPSA-lite test assemblies and subsequently testing the MPA-light chip, which is a prototype of the front-end of the MPA chip. These tests will evolve into QA/QC testing procedures for the PS modules. Beam tests in 2016 will establish the viability of the formation of track stubs from coincident hits in both sensors. USCMS will design the rods for the flat part of the barrel section of the phase 2 outer tracker and must carry out associated R&D towards this in 2016 as well.

The requested budget for 2016 exceeds available funding by a significant margin. A 2016 budget has been proposed that enables the critical R&D, while fitting into the overall tracker and larger phase 2 upgrade funding envelope. Cost savings were achieved mainly through the delay of purchase of a gantry system for automated module production until 2017.

OT Budget

Task	Type	Funding Request (k\$)	Total Budget (k\$)	KA25 Budget (k\$)	Ops Budget (k\$)
Sensor R&D <i>CMS common + irradiation/testing</i>	M&S	175.5	175	0((10)	175
Sensor R&D - Brown + Rochester <i>characterization, testing protocol</i>	Labor	90.8	90	0 (10)	90

OT Budget

Task	Type	Funding Request (k\$)	Total Budget (k\$)	KA25 Budget (k\$)	Ops Budget (k\$)
MAPSA R&D <i>MAPSA-lite testing</i>	M&S	36	36	0	36
MAPSA R&D - Rutgers EE, <i>firmware for test board</i>	Labor	23	25	0	25
PS Module R&D <i>Dummy modules, thermal tests, assembly jigs</i>	M&S	71	70	0	70
PS Module R&D - Brown + UCD tech, Brown + Princeton engineer	Labor	184.5	180	0	180
PS Module R&D - Brown + UCD UG	Labor	22	20	0	20
PS Module R&D <i>ASIC engineering, design/sim/ layout of HPK/novati sensors</i>	Labor	27	0	0	0
Module Assembly Tooling - Brown	M&S	162.5	62.5	0	63
Mechanics R&D - FNAL <i>Stave Assembly</i>	M&S	27	25	0	25
Mechanics R&D - FNAL ME <i>engineering for above</i>	Labor	385	340	0	340
System/Beam Tests - FNAL <i>test beam and system test equip.</i>	M&S	40	40	0	40
System/Beam Tests - FNAL <i>engineering for system testing</i>	Labor	120	120	0	120
OT Total	0	1,364	1,184	0	1,184

OT 2016 Deliverables

- Irradiate and characterize radiation damage for prototype sensors
 - proton irradiation at one of LANSCE, FNAL¹, UCD (or Europe)

¹ proposal to create 400 MeV beam from FNAL linac

-
- neutron irradiation at one of RINSC, UCD (or Europe)
 - 10 dummy modules to verify assembly procedures, carry out thermal, alignment, wire-bonding, HV tests
 - Qualify an industrial vendor for bump bonding
 - Build MaPSA-light test assembly, demonstrating hit correlation in test beam
 - Assemble system-level test stand with prototype rod and as complete readout as possible
 - **Milestones:**
 - March 1, 2016: 10 dummy modules to verify assembly procedures
 - July 1, 2016: Build MaPSA-light test assembly, demonstrating hit correlation in test beam

Critical R&D for Track Trigger in 2016

As noted above, the ability to trigger on tracks at L1 is critical for the success of CMS in HL-LHC; it is needed in order to maintain acceptable lepton trigger rates. Meeting the tight latency (~4 us) and huge data bandwidth (>100 Tbps) requires significant continued R&D in 2016. Like the OT, this is an area where the US will play a critical role. USCMS is leading the R&D on two of the three proposed track trigger (TT) implementations - ASIC+FPGA (AM) and pure-FPGA (tracklet). CMS has required that each of these implementations produce a “demonstrator” in 2016 that shows the technical feasibility of their approach (pre TDR) in order to inform the eventual technology decision. Consequently, 2016 TT R&D is focussed on the production of the AM and tracklet demonstrators. For the AM demo DS/PRB, PRB/PRM boards must be produced/tested and core firmware must be developed. For the tracklet demo, which runs on commercial Xilinx VC709 and Phase 1 Wisconsin CTP7 boards, first-pass firmware must be optimized. In addition to the demonstrators, R&D on high pattern density AM chips (both generic and CMS specific ProtoVIPRAM series) will continue in 2016.

The requested budget for 2016 exceeds available funding by a significant margin. A 2016 budget has been proposed that enables the critical R&D, while fitting into the overall tracker and larger phase 2 upgrade funding envelope. Cost savings were achieved through reduction in AM firmware development at FNAL and the withholding of funds for dedicated software engineers to carry out simulations. As for the other sub-projects, simulation efforts are not budgeted for despite their critical needs since it is assumed that the physicist labor necessary for these tasks is funded by the research grants that the PIs from the university groups hold. Other savings were achieved by reducing COLA for CERN-based personnel, reducing undergraduate support and M&S support for the tracklet group.

TT Budget

Task	Type	Funding Request (k\$)	Total Budget (k\$)	KA25 Budget (k\$)	Ops Budget (k\$)
Tracklet Demo <i>Hardware setups at Cornell/ Rutgers</i>	M&S	30	20	0	20
Tracklet Demo <i>Run DEMO at CERN (COLA)</i>	M&S	29	16	0	16
Tracklet Demo <i>SWE</i>	Labor	22	0	0	0
Tracklet Demo - Rutgers,Cornell EE <i>firmware development</i>	Labor	202	202	0	202

TT Budget

Task	Type	Funding Request (k\$)	Total Budget (k\$)	KA25 Budget (k\$)	Ops Budget (k\$)
Tracklet Demo <i>UG</i>	Labor	25	10	0	10
AM Demo	M&S	210	210	0 (110*O)	210
AM Demo - FNAL EE <i>firmware development</i>	Labor	270	220	45	175
AM Demo - FNAL EE <i>ASIC development</i>	Labor	135	135	135 (140*O)	0
AM Demo - NWU EE <i>firmware development</i>	Labor	50	50	0	50
AM Demo - UF & TAMU SWE <i>simulation & algorithm</i>	Labor	100	0	0	0
TT Total	0	1,073	863	180 (250*O)	683

TT 2016 Deliverables

- Sub-sector AM and tracklet demonstrators and piecewise integration towards sectors
- Development of core AM firmware and optimization of tracklet firmware
- Integrated simulations in CMSSW (AM); studies for hardware optimization and emulation (tracklet & AM)
- Full Integration & operation of AM demonstrator at FNAL and tracklet demonstrator at CERN
- Continue to advance AM chip development towards needed pattern density
- **Milestones:**
 - March 2016: Cross-group synchronization of algorithm emulation on common data samples
 - Winter 2017: Demonstrate sector-level tracking in hardware

Tracker Summary for 2016

Task	Funding Request (k\$)	Total Budget (k\$)	KA25 Budget (k\$)	Ops Budget (k\$)
FPIX	2,222	1,243	645	598
OT	1,364	1,184	0	1,184
TT	1,073	863	180	683

Task	Funding Request (k\$)	Total Budget (k\$)	KA25 Budget (k\$)	Ops Budget (k\$)
Total	4,660	3,290	825	2,465