US CMS HL-LHC PROPOSAL for Calendar Year 2015
TITLE: Proof of Concept for Endcap Dedicated Timing Detector
DATE: August 8, 2014
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ABSTRACT

A pressing question to be addressed by CMS over the next year is whether precision timing can be used to significantly enhance CMS physics in the HL-LHC era. Our group has successfully, during 2014, put tools in place for CMS to address this question. Specifically, Sunanda Banerjee has worked effectively with us to implement a dedicated timing layer in CMSSW based on the technology that our group (footnote) has been working toward for the past 5 years.

In parallel with addressing this critical question a viable technology to accomplish this purpose must be identified. We have made significant progress in proof of concept for 2 technologies (Si-APD based and MicroMegas based). This R&D work must continue in order to arrive at a convincing case that we have a technical solution. A key aspect is the coverage (in eta) over which there could be something suitable.

CMS cannot afford to take the 2 questions (physics case and availability of technical solution) serially. Our group has worked aggressively to identify a technology for which there could be a credible cost and timeline.

It would be tempting to cast our proposed 2015 activity in terms of the downselect- ie which calorimeter technology would satisfy the timing spec. However, we are confident that neither of the 2 could achieve, intrinsically, the required time resolution on photons or jets. Instead a dedicated timing layer (either a layer in front of the calorimeter or embedded in the calorimeter) is needed to complement the chosen calorimeter. This proposal is relevant to either location for the layer.

So the time critical questions are: 1)does <u>any</u> technology exist for the timing detector which can survive the challenging CMS requirements- including the radiation environment? 2) What are the implications for choice of calorimeter technology?

1 R&D OVERVIEW

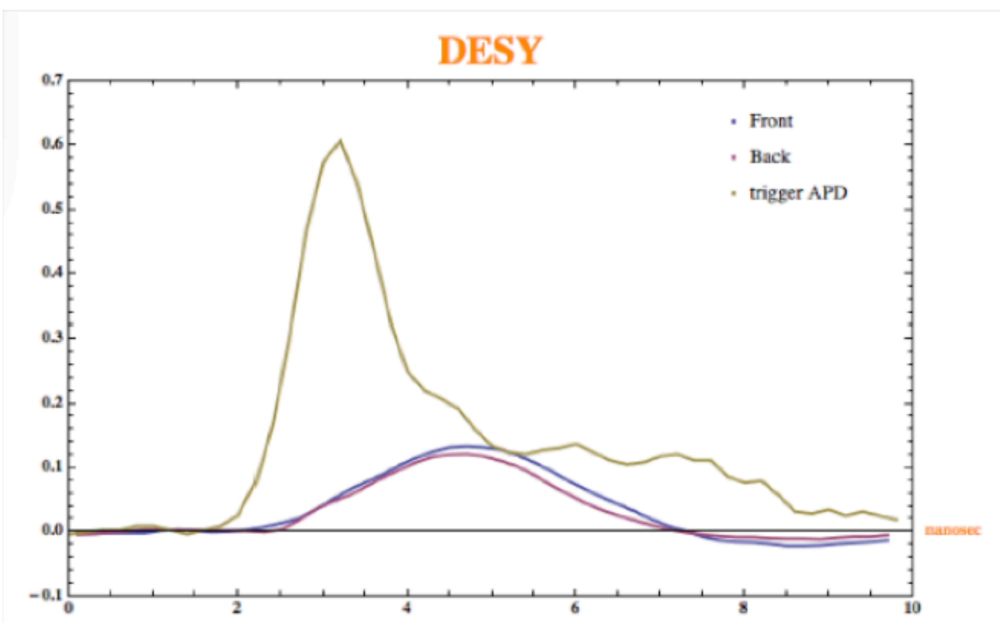
Of the 2 technologies which have been identified for precision timing (<~ 20 picosecond time jitter(ref. 1) to be associated with physics objects) the silicon based technology is the most advanced.

The Si-APD development has been carried out over the past 5 years in collaboration with RMD/Dynasil and Thomas Tsang of the BNL Instrumentation Division. In the past 2 years we have found a technical solution, which mitigates the primary factor limiting time jitter- weighting field uniformity- by constructing variants of the RMD Deep-Depleted APDs sandwiched between a sintered gold layer on the substrate and a capacitively coupled MicroMegas screen covering the HV terminal. This solution yields 10-15 picosecond jitter and acceptable transit time spread over the area of a 64 mm^2 pixel when tested using an infrared (~1000nm) femtosecond laser. This test methodology is a good model for signals produced by charged particles and has allowed a more rapid cycle of development and evaluation.

In parallel with laser characterization we have been carrying out a program of beam testing over the past 2 years- primarily at PSI but also several CERN beam lines as well as Frascati, DESY and, in Aug. 2014, a run at Fermilab. A significant aspect of the beam testing has been understanding of infrastructure issues that will be critical for proof of concept for inclusion in CMS Phase II- such as front end electronics, readout architecture, etc. We have worked, for example, with Stefan Ritt at PSI and Eric Delagnes at Saclay on evaluating their new technical solutions for waveform digitization and readout- DRS4(v5) and SAMPIC.

However the most significant aspect of beam tests over the past year has been the understanding of actual signal size from a well selected class of charged particles. Related to this is development of suitable front end electronics – for which we have put in place a contract with University of Pennsylvania.

Using these data we have been able to measure the number e-h pairs effectively contributing to the fast component of the signal that we use. Measurement of risetime and amplitude for MIPS, using commercially available 50-Ohm input impedance voltage amplifiers, led us to launch a development of a Si-Ge technology based high BW transimpedence amplifier with Mitch Newcomer at U. Penn. This amplifier (ref. 2), which is crucial for achieving the expected timing resolution with an appropriate pixel size (64mm^2) is needed because otherwise the large detector capacitance would (with a 50 ohm input amplifier) result in both signal loss and risetime degradation. The figure below shows the degradation of the signal relative to a small area/C_d "trigger APD" when using a larger area/C_d APD with conventional 50 ohm voltage amplifiers.



We have just completed the first round of prototyping these preamps. Though the results are encouraging (see Figure 1) further work is needed and possibly another prototype cycle before we have the electronics to demonstrate satisfactory performance of this timing concept. Following this we envision demonstrating a small system- eventually within CMS- of a few dozen channels.

Another significant outcome of the beam testing was the understanding of time jitter contribution from Landau-Vavilov fluctuations. The tails can be removed with only slight loss in efficiency so long as pulse height is also recorded in the data.

From an earlier paper (ref. 3), where we analyzed RMD data on radiation damage in the context of CMS scaling laws (developed for the ECAL project for treating APD readout options), it is likely that our silicon technology will maintain performance up to doses of several 10^14 n-eq/cm^2. We were unable, while participating in exposures parasitically with general CMS radiation damage studies at the CERN PS, to obtain data to confirm this at such high doses.

We need to proceed with dedicated damage tests of these devices- using either the Mass. General facility or the facility near Fermilab (Procure Center).

In the meantime 3 of us (Veenhof, White and Giomataris) have been simulating gas detector options for various gas mixtures and field configurations. Our simulation results show that a gaseous detector solution could be built that achieves the required resolution, using MicroMegas or MicroBulk for the MicroPattern gas detector in conjunction with a MgF2 radiator window and either a reflective or transparent photocathode. Beyond these initial simulations a basic measurement of photoelectron time jitter with a UV laser needs to be preformed. So we formed a collaboration, within RD51, to address this. Work has now begun at Saclay and CERN (the original Charpak group) to prepare chambers for testing in September 2014 at the Saclay Laser-matter Interaction Center (SLIC).

Although this is a critical first step, we feel that there are further critical steps to demonstrate that a suitable charged particle timing detector could be built using this concept in the CMS endcap. Among the open questions are: lifetime of the photocathode and other aging effects, suitability for the high rates and alternatives to resistive MicroMegas technology. Finally,detector capacitance issues, similar to the ones encountered in the Si solution can likely be approached in a different way- by proper design of the detector.

2 PARTICIPATING INSTITUTIONS AND PRINCIPAL INVESTIGATORS

Univ. Bologna- Crispin Williams
Boston University- Larry Sulak or Jim Rohlf (both are interested)
CEA, Saclay- Maksym Titov
CERN- Leszek Ropelewski
Fermilab- Jim Freeman

Instrumentation Division, BNL-Thomas Tsang
Princeton- Kirk McDonald
Rockefeller University- Sebastian White
IFCA, Santander, Spain- Marcos Garcia Fernandez
Texas Tech University-Richard Wigmans
Trieste- Andrea Vacchi

3 STATUS AND PLANS OF R&D IN CY2014

(See discussion in Section 1.)

The specific activities which have been funded under 2014 US-CMS support include the following:

1) A contract was started with University of Pennsylvania. Initial prototypes were built. They have been tested with our detectors and need further optimization. Production of next cycles of the preams tested on the detector on August 7 has already begun today (on the 8th). We should build a test stand for Mitch Newcomer to do this work most efficiently- ie optimizing with our detector under realistic conditions. This stand was not within the scope of the 2014 request but would be very useful. The figure below shows initial test output of the prototype amplifier tested on August 7.

2) RMD/Dynasil sent a quote for 10 detectors. We responded with a PO from the CERN team account. 2 detectors have already been received.

3) Several components have been purchased for beam tests under the CERN team account and S. White has travelled from CERN to US for upcoming Fermilab test.
4) Work on the MicroMegas technology laser tests has started under RD51 (at no cost to US-CMS).

4 TECHNICAL DESCRIPTION AND DELIVERABLES OF THE PROPOSED R&D IN CY2015

The work we propose for 2015, largely motivated by the aims described in section 1 can be broken down into 6 work packages. We start by listing the packages and the institutions involved. We do not list work undertaken by our collaborators for which we do not request US-CMS funds.

i)Amplifier Development –S.White contract w. University of Pennsylvania (with some support by Rockefeller on test setup with Si-APD test conditions and some for further testing by Princeton).
ii)Develop SiAPD technology to point of having demonstrator in CMS

a. Continued device testing-Rockefeller/Princeton
b. Packaging Development-RMD/Princeton
c. Production of Demonstrator- Princeton

iii)MicroMegas/MicroBulk development-Rockefeller/CERN/Saclay
iv) Rad Test of SiAPD devices-Boston University, Rockefeller University
v) Readout Electronics to Support Beam Tests and a demonstrator in CMS- Saclay, Fermilab and PSI(TBC)
vi) Travel, Test Equipment and MS

The continued Amplifier Development i) is expected to follow the 2014 model, under which it has been successful. The costing has been worked out in coordination with Mitch Newcommer.

We have not yet achieved the expected performance of the SIAPD ii) in beamtests and expect to continue testing and electronics optimization together with U. Penn. To continue into 2015 with further beam tests- most likely in the CERN SPS and PSI but possibly FNAL. In parallel Princeton will begin work with RMD to resolve the packaging issues as needed to have a detector suitable for CMS (this will require a PO to RMD for engineering time as well as ~6 detectors. It will also require ~20 hours of Princeton staff-Bert Harrup). Finally, work will start on design of a demonstrator to be readout in CMS.

Since the MicroMegas option iii) will by September will be roughly at the same stage in proof of principle as a particle detector as the SiAPD was over a year ago (having been characterized with lasers also) it is not difficult to list the steps required to bring it to the current state. We expect to do some initial work on beam testing within our RD51 program once the laser tests are complete. We request from US-CMS funds to build and test a dedicated charged particle timing detector suitable for use in the CMS endcap region during HL-LHC. Specifically we need to identify 1)a photocathode solution with adequate lifetime, 2) an electrical configuration of the mesh suitable for high rates which also provides low effective detector capacitance to the electronics. 3)detector designs suitable for test beam exposures and accelerated aging studies.

Much of our current program began with a 2011 DOE ADR&D grant generated by K. McDonald and S.White. For that grant we prepared cost estimates for Rad testing iv) in discussion with Mass. General Hospital irradiation Facilities. Our request is based on this costing. Although BU has expressed interest in taking on responsibility for these tests we do not yet know their costs for this activity. We are also discussing with our Fermilab Collaborators the possibility of using a facility near Fermilab. This would eliminate the facility irradiation costs and the budget instead would go to support FNAL radiation analysis of impact on detector performance(similar to our earlier work with N. Mokhov).

As mentioned in section 1, we have had a few years of contacts with Ritt Delagnes and Breton on their development of ultrafast timing readout systems v). Clearly for a demonstrator in CMS there is the challenge of adapting existing readout electronics (ie that CMS has developed for Phase I upgrade projects) to accommodate a digitizing scheme suitable for the 20 picosecond time resolution. Initial discussions indicate that the QIE10 experience could be relevant and so we have in mind collaborating with experts from this project.

Nevertheless, we view the 2015 activity as focused on isolated (ie beam) testing of the demonstrator- possibly with an option of something similar to CMS-TOTEM data merging. T. Tsang and S. White have experience designing clock distribution relevant for this level of timing precision.

Finally, we request funds to support testing and travel to test beams. Specifically we request funds (~$25k) for a suitable oscilloscope (similar to the quotation from TeledyneLecroy to S. White that recently circulated in US-CMS upgrade management). Travel from CERN to Fermilab testbeams would be supported from this request.

5 RELATION TO EXISTING EFFORTS

i)As mentioned above initial funding for work with RMD came under a DOE Advanced Detector R&D grant, which is now closed out.

ii)The work on a MicroMegas timing detector has been given a headstart under a recently started RD51 proposal. This will undertake the construction and testing of a small chamber for UV laser testing and possibly contribute an initial chamber for beam testing.

iii) We have worked with RMD/Dynasil to help them prepare a Phase I SBIR submission in the fall. The primary goal of this SBIR is to re-examine the production costs for our technology if the detector is produced in large quantity as a product- rather than as a modification of an existing product (which was designed for a completely different purpose). Realistic cost information could be valuable to CMS once the time comes to decide whether such an enhancement to CMS is realistic.

iv) We have started discussions with other institutions that would like submit a generic R&D proposal on readout architectures for precision timing. It is possible that over the next year this activity will help to inform decisions about the cost of timing in CMS.

v) Marcos is also on RD50 and there has been much interest in working together with their nascent R&D on timing in Silicon.

6 SCHEDULE AND MILESTONES

Amplifier Development

Start	Duration	Activity
January	2mo	4 prototype PCB amplifiers (iteration of work begun in FY14)
March	4mo	24 PCB amplifiers (for use in the SiAPD demonstrator module
July	6mo	ASIC version of the amplifiers

SiAPD Development

Start	Duration	Activity
January	2mo	Develop packaging for 24 SiAPDs for use in the demonstrator module
March	4mo	Fabrication of the demonstrator module.
March	4mo	Procurement and testing of a readout system for the demonstrator module
July	4mo	Bench tests of the demonstrator module
November	2mo	Beam tests of the demonstrator module

MicroMegas Development

Start	Duration	Activity
January	2mo	Procure prototype devices from CERN
March	8mo	Bench tests of the prototype devices
November	2mo	Beam tests of the prototype devices

Radiation Tests of SiAPDs

Start	Duration	Activity
January	2mo	Preparation of test modules for irradiation
March	1mo	Irradiation of the text modules
April	9mo	Cooldown, evaluation of the irradiated modules (+ possible 2^{nd} test cycle)

Readout Electronic Development

Start	Duration	Activity
January	2mo	Specify architecture of a fast time readout for use at CMS
March	4mo	Design of prototype readout boards
July	6mo	Fabrication and test of prototype readout

7 BUDGET AND BUDGET JUSTIFICATION FOR CY2015 (Fill out separate EXCEL spreadsheet)

This document presents a simplified budget summary in lieu of the detailed spreadsheet, which is still in preparation.

Simplified Budget Summary (burdened costs)

Institution	Activity	Labor	M&S	Travel	Total
Fermilab	Readout development	$30k	$10k		$40k
U. Penn	Ampli. Dev.	$80k	$30k	$5k	$115k
Princeton U.	SiAPD packaging	$10k			$10k
	Irradiation test modules	$5k			$5k
	SiAPD Demonstrator fab/test	$50k	$10k	$5k	$65k
	Micromegas beam test modules	$5k		$5k	$10k
Rockefeller	Micromegas bench/beam test	$10k	$15k	$15k	$40k
Boston U.	SiAPD irradiation tests	$10k			$10k
Mass. Gen. Hosp.	Irradiations		$30k		$30k
RMD/Dynasil	24 SiAPDs w/packaging dev.		$60k		$60k
PSI	DRS4(v5) readout modules		$10k		$10k
US vendor	Fast scope for DAQ at test beams		$25k		$25k
Total					**$420k**

9 FACILITIES, EQUIPMENT, AND OTHER RESOURCES (1 page)

Bench tests of SiAPDs can be performed at both U. Penn and Princeton U. The U. Penn high-energy-physics group has a dedicated electronics shop with a long history of production of modules for collider detectors. Princeton U. high-energy-physics group has dedicated mechanical and electronics shops.

Beam tests of SiAPDs and Mircomegas fast-timing detectors will be performed at Fermilab test beam in association within the T-1041 "CMS Forward Calorimetry Upgrade" collaboration. Alternatively, beam tests can be performed in the CERN H2 beamline, and/or in a PSI muon beam.

Device irradiations will be performed at the Mass. General Hospital facility, with physicist support from Boston U. Alternatively, we could use the PET cyclotron at the CDH Proton Center, A ProCure Center, in the proximity of the Du Page Hospital.

MicroMegas bench tests with an ultrafast laser will be performed at Saclay (in association with the present proposal)

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3) “Design of a 10 picosecond Time of Flight detector based on Avalanche Photodiodes” S. White, M. Chu, M. Diwan, G. Atoyan, V. Issakov- Jan. 2009 http://inspirehep.net/record/811206?ln=en