FY2026 NPP LDRD Type B Pre-Proposal

Development of a Generic 4D Telescope Platform

Principal investigator:

Gabriele D'Amen [Physics Department]

Shaochun Tang [Physics Department]

FY2025 NPP LDRD Type B Pre-Proposal

Proposal title:

Development of a Generic 4D Telescope Platform

Primary Investigators:

Gabriele D'Amen   (PD)
Shaochun Tang   (PD)

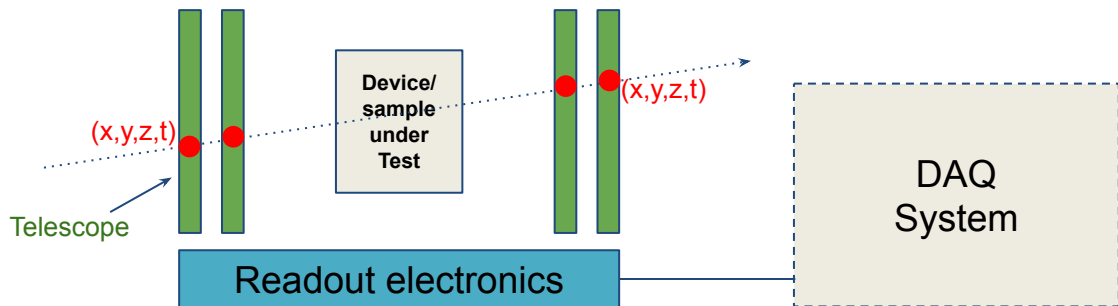**ECA eligibility:**

Gabriele D'Amen   (PhD in 2018)

Proposal Term:

From: 10/1/2025   To: 9/30/2027   (2 yrs)

Annual funding:

FY26: 250k   FY27: 250k

Motivation

Telescope

(x,y,z,t)

Device/
sample
under
Test

(x,y,z,t)

Readout electronics

DAQ
System

Fermilab FTBF telescope

DESY Adenium telescope

CERN SPS Malta telescope
(now decommissioned)

- **Particle telescope:** multiple layer detector for reconstruction of particle **3D position (+ Time-of-Arrival/Time-of-Flight) = 4D dimensions**

- Characterization of **components, sensors, samples, devices** limited by availability and cost of particle detectors
  - *Resources, time and personpower spent on 4D reconstruction*

- Telescope systems sometimes installed **permanently or semi-permanently at beam facilities** (cost M$)
  - *Often based on leftovers from CERN experiments…*
  - *Wide heterogeneity of capabilities, costs, availability, interfaces with user…*
  - *Limits already scarce choice in feasible testbeam facilities*
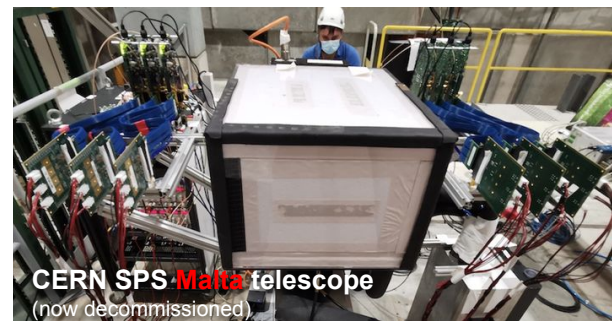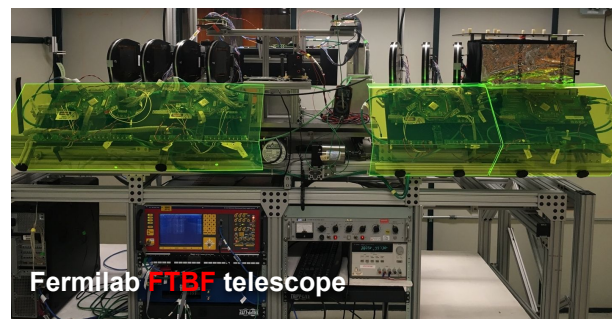
Technological concept

Main Goal

Design a powerful, portable, and affordable (<20kUSD/layer) **general purpose particle telescope** capable of provide **high time-(<50ps) and space-(<10um) resolution (4D) particle detection** in laboratory and at test beams

AC-LGADs
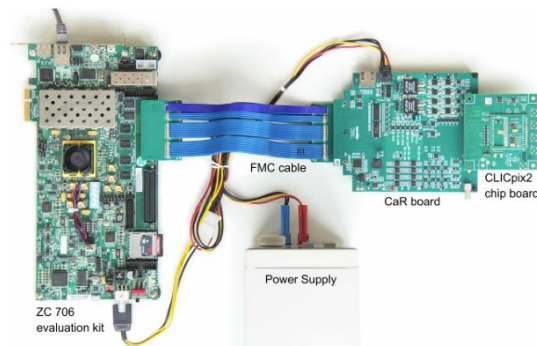
sensors with excellent 4D performances

- Sensors and expertise **already available at BNL**
- **Time resolution**: ~30ps
- **Space resolution**: < 10um
- **Signal sharing** requires **new readout electronics**
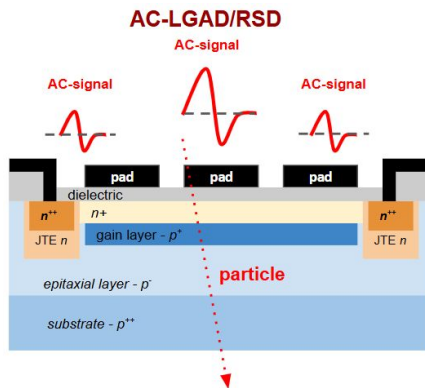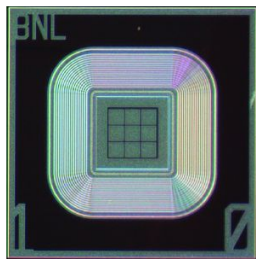
CaRIBOu

general purpose readout system

- Expertise **already available at BNL**
- **Open source technology**
- **Software and Firmware easily extendable**

AC-LGAD/RSD

Methods to achieve the goals
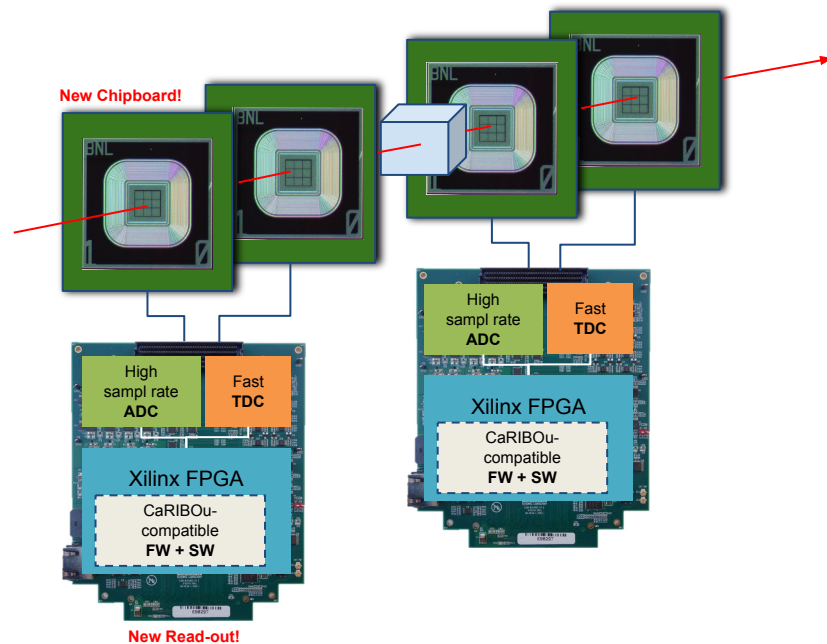

Deliverable

We will design and develop a new hardware platform (**chipboard + readout**) for readout of Ultra-fast 4D sensors compatible with CaRIBOu software and firmware
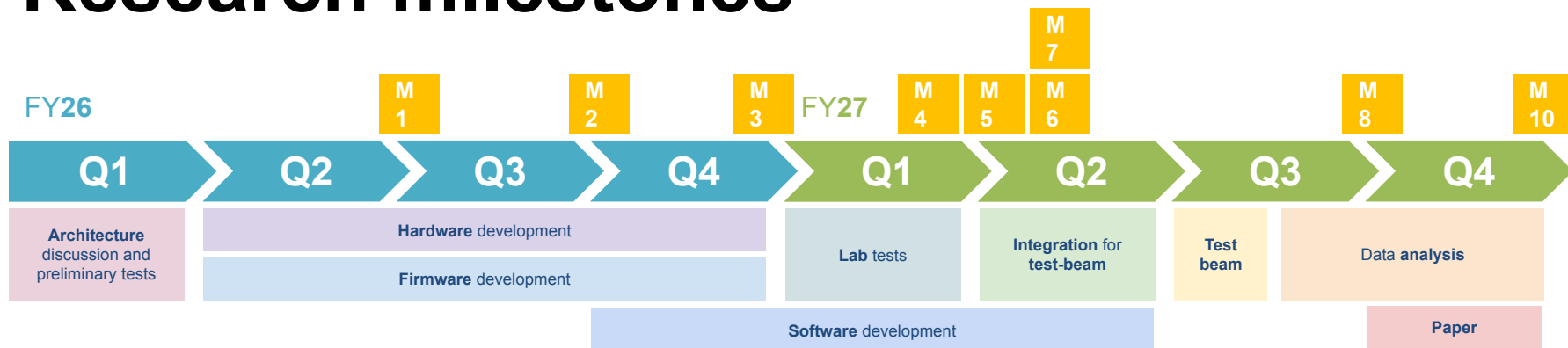
Chipboard:

- Based on experience as developers and users of LGAD and AC-LGAD readout boards

Readout system:

- Readout hardware equipped with:

  - **Xilinx FPGA**
  - High sampling rate (>= 10 GS/s) **ADC** channels to sample amplitude of AC-LGAD signals
  - **Fast TDC** for particle Time-of-Arrival measurements

- Made with **off-the shelf components**

- Provide **robust data acquisition** capabilities

- By adapting **CaRIBOu software and firmware environment**, this platform will provide a **plug-and-play way to add 4D tracking capabilities to a wide range of experiments and applications**

New Chipboard!

High sampl rate **ADC**   Fast **TDC**

Xilinx FPGA

CaRIBOu-compatible **FW + SW**

New Read-out!

High sampl rate **ADC**   Fast **TDC**

Xilinx FPGA

CaRIBOu-compatible **FW + SW**

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Research milestones

- ○ *Milestone 1 – FY26/Q2:*   sensor characterization, first prototypes of chipboards
- ○ *Milestone 2 – FY26/Q3:*   readout system demonstrator
- ○ *Milestone 3 – FY26/Q4:*   complete readout chain
- ○ *Milestone 4 – FY27/Q1:*   system test with injected fast electrical pulses
- ○ *Milestone 5 – FY27/Q1:*   system test with minimum ionizing particles
- ○ *Milestone 6 - FY27/Q1:*   measurement of time resolution using minimum ionizing particles
- ○ *Milestone 7 – FY27/Q1:*   calibration of AC-LGAD response vs particle position using laser
- ○ *Milestone 8 – FY27/Q3:*   measurement of tracking capabilities
- ○ *Milestone 9 – FY27/Q4:*   paper detailing results

Personnel & Procurements

Personnel

- *Shaochun Tang*
  - Effort: 0.1 FTE + 0.05 FTE (0.15 FTE total)
  - Hardware & Firmware design

- *Gabriele D'Amen*
  - Effort: 0.05 FTE + 0.1 FTE (0.15 FTE total)
  - Software development & Characterization in lab & test-beam

- *PostDoc*
  - Effort: 0.7 FTE/yr (1.4 FTE total)
  - Firmware, Software development and system integration

- *Technician*
  - Effort: 0.05 FTE (0.05 FTE total)
  - Sensor characterization

Procurements

- *Xilinx FPGA*
  - Biggest requisition, O(10^5) USD/board

- *ADCs & TDCs*
  - O(10^3) USD

- *PCBs:*
  - Multiple design tests of AC-LGAD chipboard

Additional costs

- *Test Beam* (NSRL or Tandem)
  - ~60k USD

Potential future funding

Indirect ROI

- Saves **resources O(10^4-10^5 USD)/time/personpower** for projects requiring precise 4D tracking (HEP, NP, Medical…)
- Leads to new collaborations within RDC3/RDC5 (US) and DRD3/DRD7 (EU)
- Strengthen BNL position as one of the leaders of both fast-timing silicon technology and readout electronics for HEP/NP applications

Direct ROI

- PI is eligible for Early Career Award (next slide)
- Adding 4D telescopes to existing BNL test-beam facilities (Van de Graaf, NSRL, …) can:
  - Attract **DOE operation grants**
  - Attract **additional users** interested in exploiting their 4D measurement capabilities
  - *Opportunity!:* **Scarcity of available characterization test-beams** in the upcoming years (FNAL and CERN not available)
  - Based on AIDA telescope (CERN): 30 wks in 2018 for characterization of fast timing silicon sensors; additional revenue in the order of **2-6 M$/yr** (not including lab overhead)
  - (Does not include private users/industry interested in **high-precision material characterization, medical studies** (radioteraphy/radiodosimetry)**, etc**.)
- Potential for BNL to produce the device (think of FELIX…)

How this LDRD benefits ECA application

- Co-PI *Gabriele D'Amen* received his **PhD in 2018** (eligible until 2028) and will submit an Early Career Award proposal for FY 2026

- His application will focus on the usage of **Neuromorphic Computing techniques** to improve the **tracking capabilities** of future High Energy Physics experiments by exploiting timing and the **4D capabilities of modern silicon detectors**

- The construction of the Generic 4D Telescope will give him a platform to study the **impact** of these Neuromorphic reconstruction techniques **on on-line tracking using real data** acquired at test-beams

Alignment with the Laboratory Mission and Vision & Names of Suggested BNL Reviewers

Alignment with BNL Mission & Vision

- Synergy with **R&D efforts for EIC** (ePIC AC-LGADs)
- Enables **Sensor R&D for FCCee** and other Higgs Factories (P5 report)
- Allows real-data studies of **AI-on-hardware** implementations

Suggested BNL Reviewers

- Alessandro Tricoli   [Physics, 4D reconstruction]
- Jin Huang   [Physics, application]
- Gabriele Giacomini   [IO, 4D detectors]
- Jack Fried   [IO, electronics]

Summary Slide

Motivation

- Widespread need (especially looking towards EIC/FCC/Muon Collider) for reliable, powerful, user-friendly **4D tracking system**
- 4D tracking at test-beams and lab expensive and time-consuming (We don't want to **re-invent the wheel** every time)
- Existing setups based on **older technologies**
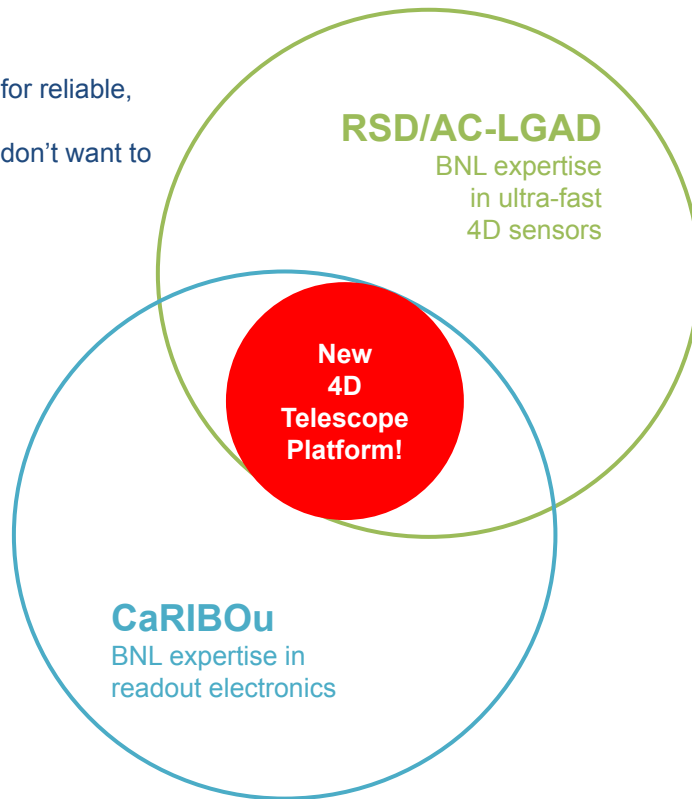
Return-on-Investment

- Saves resources/time/personpower
- Leads to new collaborations within RDC (US) and DRD (EU)
- Strengthen BNL position as leader of fast-timing detectors & readout electronics
- Potential for BNL to produce the device (think of FELIX…)
- PI is eligible for Early Career Award

Deliverables

The blueprint for a plug-and-play 4D telescope, including:
- PCB/hardware design
- Firmware
- Data Acquisition software

Present the work at international conferences

RSD/AC-LGAD
BNL expertise
in ultra-fast
4D sensors

**New
4D
Telescope
Platform!**

CaRIBOu
BNL expertise in
readout electronics

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Backup