Opportunities of Si-microstrip LGAD for next-generation space detectors

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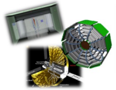
Low Gain Avalanche Diode (LGAD) is a consolidated technology developed for particle detectors at colliders which allows for simultaneous and accurate time (<100 ps) and position (tens of μm) resolutions. It is a candidate technology that could enable **5D tracking in space** using LGAD Si-microstrip tracking systems. The intrinsic gain of LGAD sensors may also allow to decrease the sensor thickness while achieving signal yields similar to those of Si-microstrips currently operated in Space. In this contribution we discuss the possible applications and breakthrough opportunities in **next generation large area cosmic ray detectors and sub-GeV gamma-ray detectors** that could be enabled by **LGAD Si-microstrip tracking detectors** in Space. We propose the design of a cost-effective **instrument demonstrator on a CubeSat platform** to enable and qualify the operations of LGAD Si-microstrip detectors in space.

Silicon Microstrip detectors in space

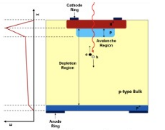
Most of space detectors for charged cosmic ray and γ-ray measurements require **solid state tracking systems based on Si-microstrip (SiMS) sensors.**
SiMS detectors are the only solution to instrument **large area detectors** with larger number of electronics channels coping with the **limitations on power consumption in space**

Operating Missions						
	Mission Start	Si-sensor area	Strip-length	Readout channels	Readout pitch	Spatial resolution
Fermi-LAT	2008	$\sim 74\,m^2$	38 cm	$\sim 880 \cdot 10^3$	228 μm	~66 μm
AMS-02	2011	$\sim 7\,m^2$	29–62 cm	$\sim 200 \cdot 10^3$	110 μm	~7 μm
DAMPE	2015	$\sim 7\,m^2$	38 cm	$\sim 70 \cdot 10^3$	242 μm	~40 μm

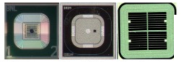


Future Missions						
	Planned operations	Si-sensor area	Strip-length	Readout channels	Readout pitch	Spatial resolution
HERD	2030	$\sim 35\,m^2$	48–67 cm	$\sim 350 \cdot 10^3$	~242 μm	~40 μm
ALADInO	2050	$\sim 80\text{-}100\,m^2$	19–67 cm	$\sim 2.5 \cdot 10^6$	~100 μm	~5 μm
AMS-100	2050	$\sim 180\text{-}200\,m^2$	~100 cm	$\sim 8 \cdot 10^6$	~100 μm	~5 μm

Tracking with Low-Gain Avalanche Diodes



LGAD sensor layout


LGAD sensors from 3 different producers

LGAD: standard Si sensors with intrinsic gain layer typical of APD devices
- High E-field region allows carrier multiplication and provides gain
- Moderate gain (10~70) increases the signal-to-noise ratio (SNR)
- Provides accurate timing resolution down to tens of ps

Developed for pixel sensors for HL-LHC detectors. **LGAD SiMS detectors and readout FEE require dedicated R&D for space qualification and power consumption**

LGAD is the most suitable, mature enough, candidate technology to enable 5D tracking and have very thin but efficient SiMS detectors in Space.

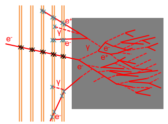
"5D tracking"

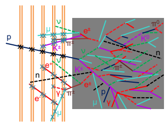
high accuracy position, charge and timing measurement for each hit in a high rate environment

Possible experimental opportunities enabled

IMPROVED TRACK FINDING	REMOVE "GHOST" HITS
Hit timing information improves track reconstruction on high rate environments and identifies back-scattering hits from downstream calorimeters	**Separating tracks in time can mitigate the ambiguity of "ghost" hits in SiMS with strips running in perpendicular directions**
TIME OF FLIGHT	**PARTICLE ID**
Hit timing resolutions of ~ 100 ps enable ToF measurements with SiMS complementary to scintillators with fast light readout	**Track timing identifies slow low-energy particles backscattering from downstream calorimeters for primary hadronic particle crossings**

Different **backsplash timing signatures** in upstream tracker from primary $e^{+/-}$ or hadrons





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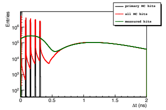
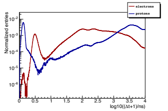


100 ps resolution allows to separate hits from primary particles and from secondary backsplash

Prospects for **improved tracking efficiency**



Different timing signatures from p and $e^{+/-}$ showers

Prospects to use in MVA **classifiers for e/p separation**

PARTICLE ID

A detailed discussion on possible advantages from 5D tracking in space astroparticle experiments is available at M. Duranti, V. Vagelli et al., Instruments **2021**, 5(2), 20

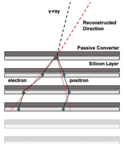
Sub-GeV γ-ray detectors

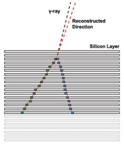
Opportunity for improved PSF below 1 GeV

Thin high signal Si sensors: the LGAD intrinsic gain improves the SNR for thin sensors and allows for reduced active material budget tracking planes

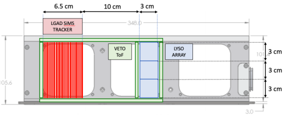
The PSF of γ-ray experiments (Fermi-LAT, DAMPE, ...) is degraded at low energies by Coulomb MS in materials (passive converter and Si-sensors)

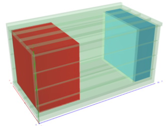
- **Remove passive materials**
- **Use thin active detectors**
- **Increase number of active layers to boost the GR conversion probability** (approach first proposed in [5])





A CubeSat demonstrator for the Space qualification of LGAD microstrip detectors in space





A conceptual design of the demonstrator compatible with the constraints in weight, volume and power budget of a CubeSat platform hosted in 2 units of a 3U CubeSat, with one additional units dedicated to the FEE and DAQ of the demonstrator.

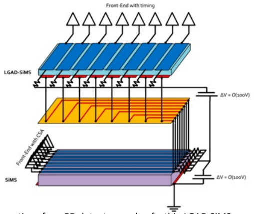
LGAD SiMS Tracker
40 layers of 150 μm thick SiMS LGAD sensors
readout pitch: 150 μm --> expected Δx ~ 15μm
Target timing resolution ~ 100 ps

Veto / Time of Flight system
0.5 cm thick Sci-paddles
SiPM readout using commercial FEE. Δt ~ 30 ps

Electromagnetic Calorimeter
3x3x3 cm^3 array of LYSO crystals
SiPM readout using commercial FEE
Feasibility to add another stack of LYSO array under study

Weigth < 3 kg Power < 20 W

Simulation of the detector performances is ongoing
FEE power mitigation techniques under investigation



Possible connections for a 5D detector made of a thin LGAD SiMS sensor for timing and moderate resolution coordinate measurement coupled with a thicker standard SiMS sensor for charge and high resolution coordinate measurement. This layout drives the main investigation in the context of the project.

R&D activity to increase LGAD SiMS TRL for space from TRL=2 to TRL=5 funded by italian MUR (PRIN 2022)
PTSD – Penta Tracking Space Detector
Institutes: INFN, ASI and FBK:
1. Proto-instrument requirement identification
2. Design and production of LGAD SiMS sensors with large actove area optimized for 5D-tracking measurements in space
3. Development of SiMS sensor assembly procedures in a large area detector
4. assembly of a breadboard laboratory model for verification of requirements, functionalities and space qualification

Funding and activities planned to start in Fall 2023