# Light-driven detector concept — power and data transmission

Mengqing Wu

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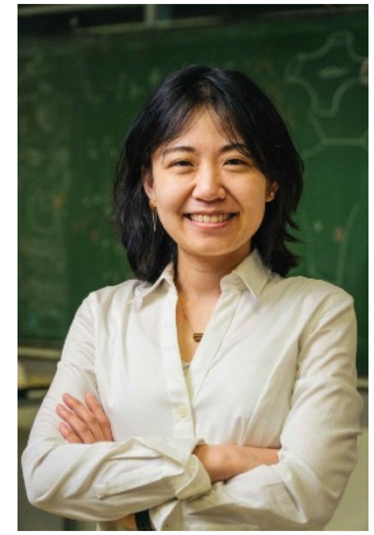
Nikhef

Radboud University

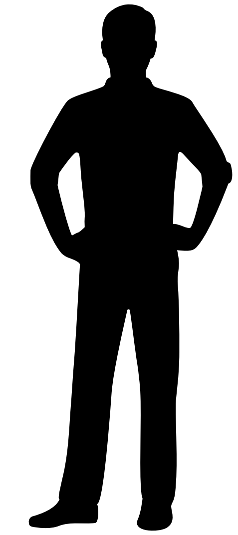
# Brief introduction

## The team & the status

- Optical powering is a small project I started in 2022 with my engineer at RU
- After years of interests in optical data transmission using integrated photonics, I start to initiate a project within the Netherlands, and with collaborators in DRD7 at CERN
- Ultimate goal: reduce detector complexity & material budget, realising ultra-compact detector design - ideal for vertex and tracker
- Inside the NL: common interests in the Nikhef and its partners in optical power and integrated photonics readout solutions



Brief about me:
- trained in physics & engineering
- detector R&D (ATLAS HGTD, DRD3 and DRD7), physics analysis (ATLAS exotics)

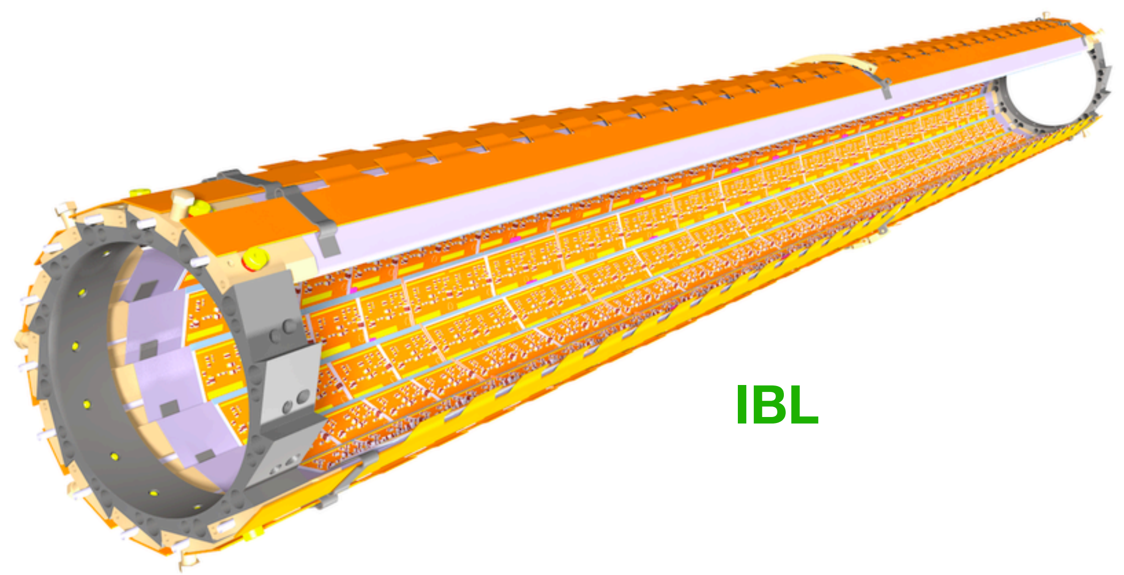


Mengqing Wu
Assistant Prof.

D. Szálas-Motesiczky
Engineer

# Vertex detector

- Beloved features:
  - Low mass, low noise, good spatial/time resolution, good coverage
- A complex system requiring intense engineering care on:
  - Grounding and shielding
  - Power circuit (parallel -> series to support that many channels, generating the so-called AC powering scheme)
  - Signal acquisition
    - digital signals bi-directional in the chain: ASIC <-> cable <-> end-of-stave PEB <-> (lp)GBT <-> VTRx <-> FELIX <-> server
- Integrated photonics has a good prospects at system level to release bottlenecks to build a vertex detector with all the wanted features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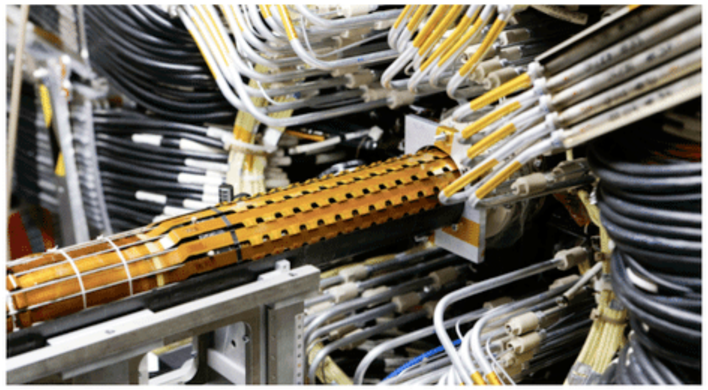
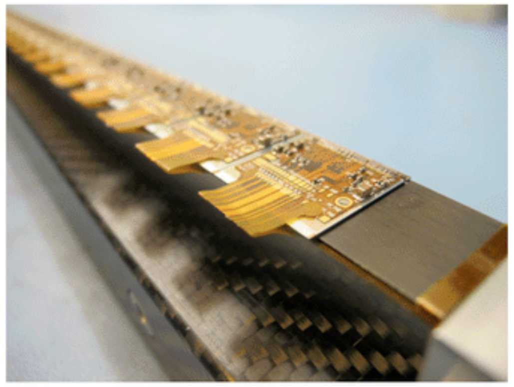

(a)

IBL insertion


(b)

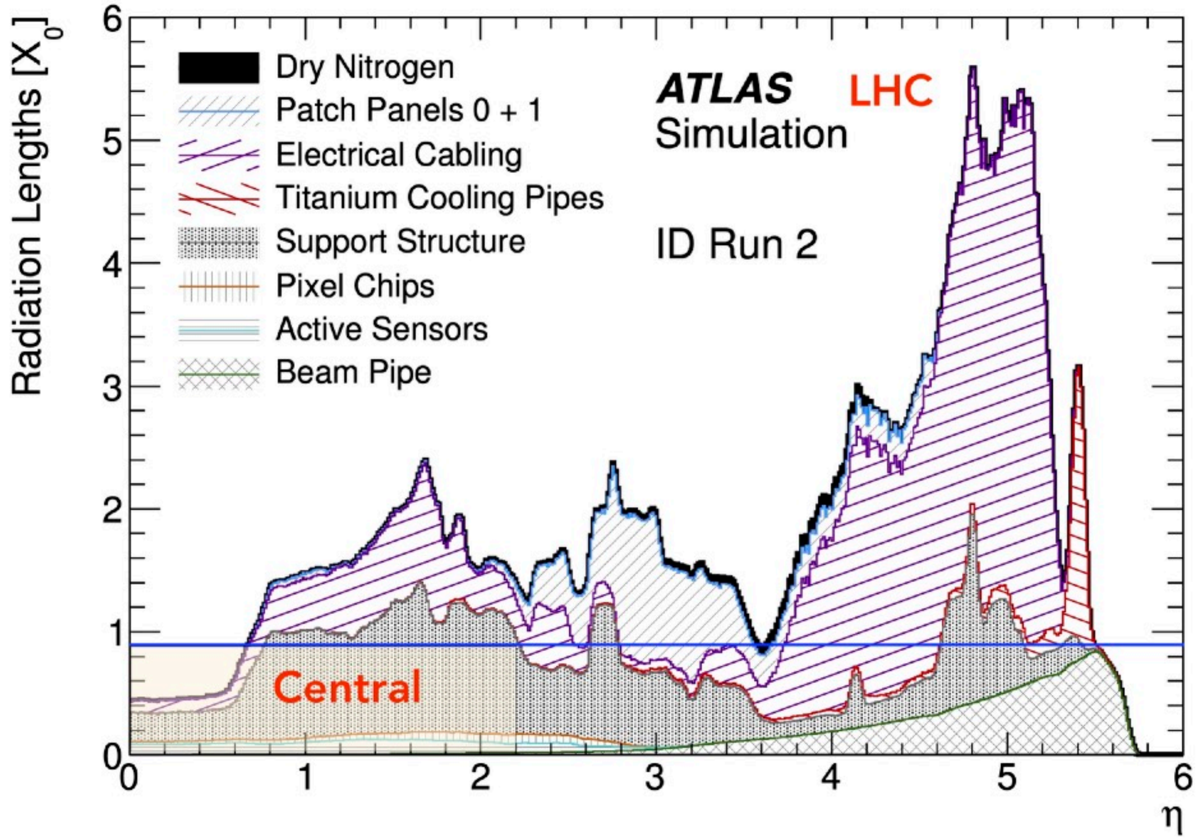
IBL stave

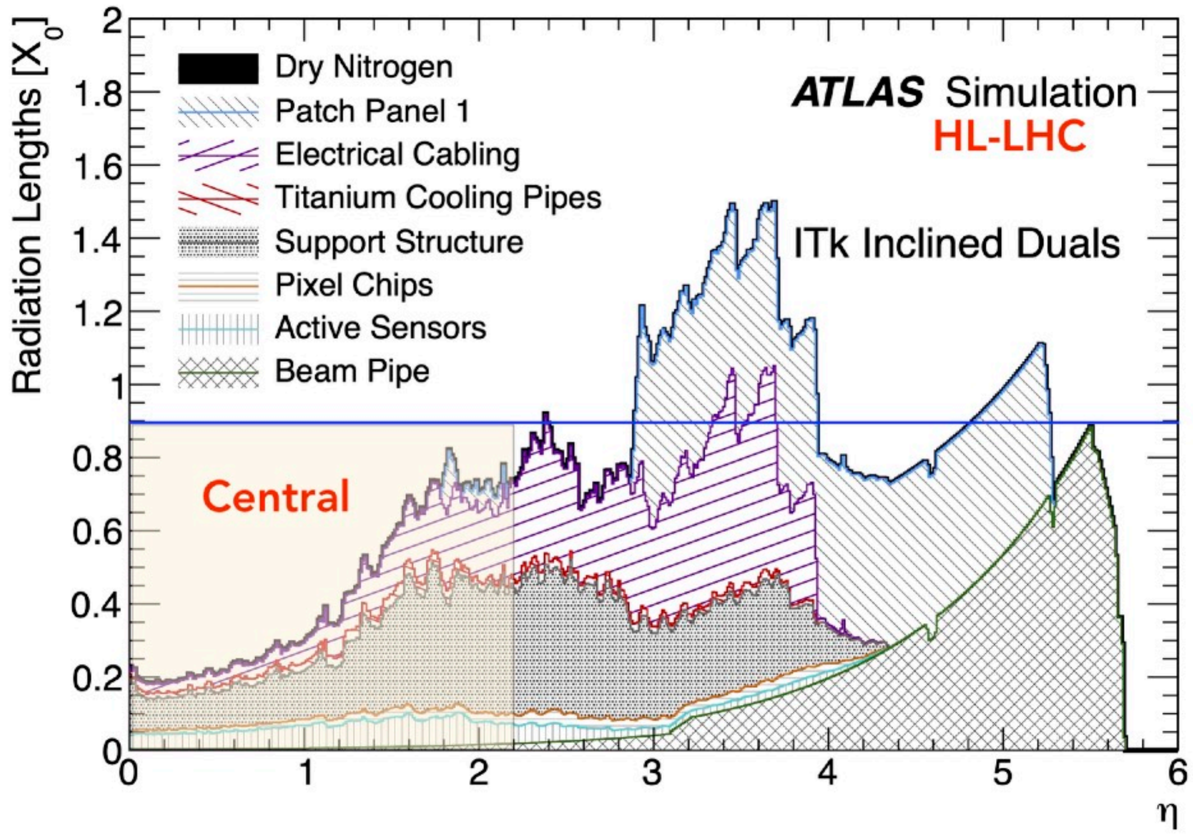
Silicon photonics/fibre
electronics/copper

# High-granularity & low-mass

## Wanted features

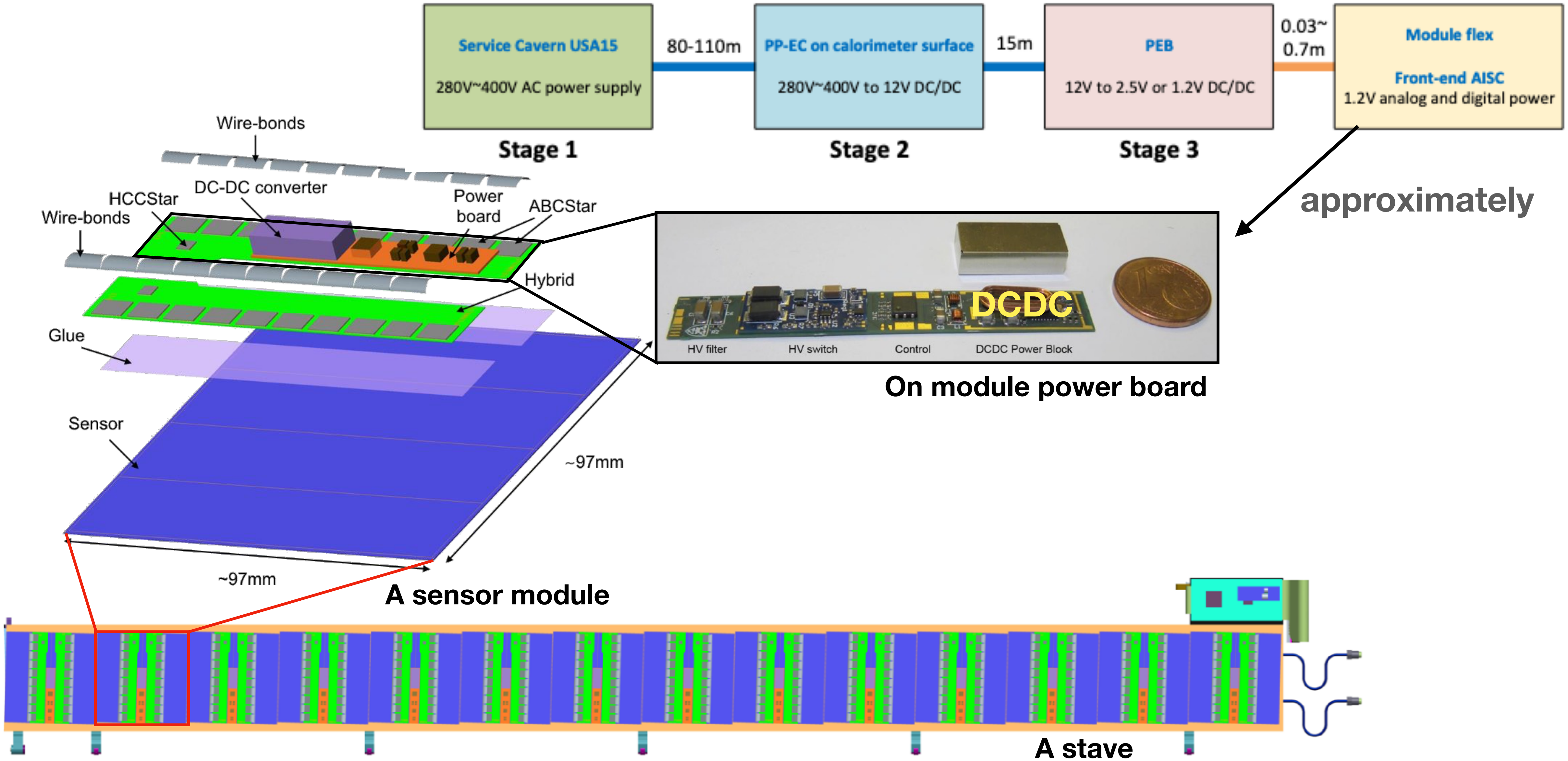
ATLAS-TDR-030




- the “new” series powering scheme helps to reduce the material to a large extend, though not exclusively

# Current Powering scheme




- Long cables length from wall power plugs to the powering targets - sensor, ASIC and peripheral electronics (incl. lpGBT/GBT, VTRx)
- Power dropping — trade-off with extra coppers

# Data Transmission with MZM

- MZM - interferometric structure - radiation hard, reliable data transmission
- **Topic in DRD7** (under new link techniques)
  - Ring modulator dev at CERN is chosen to be focused on
- At Nikhef: Allied with my Nikhef colleague Ernst-Jan Buis *(optical sensing expert)*, who has a pattern on ring modulator sensor, with which we wish to build a detector together

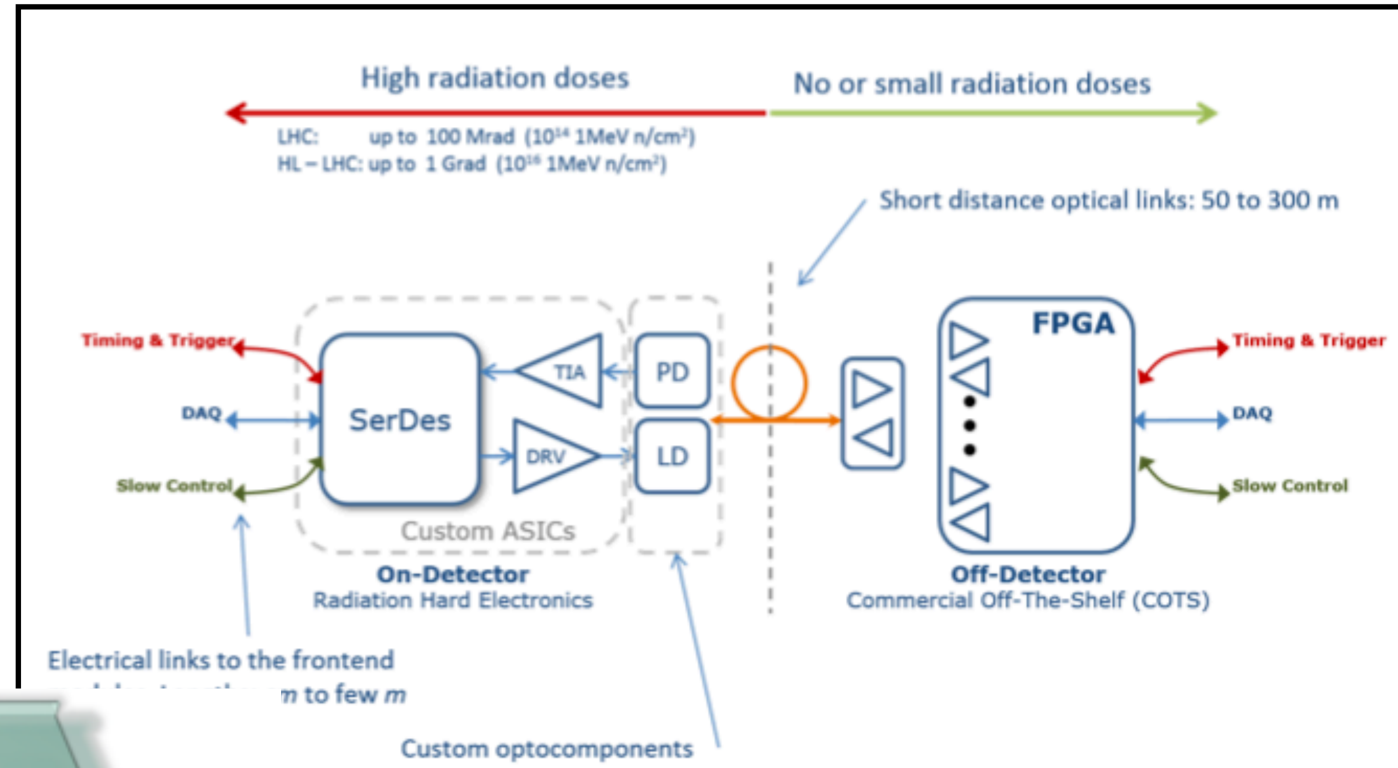




Figure 5: Typical HEP link architecture [6].

[lpGBT documentation]

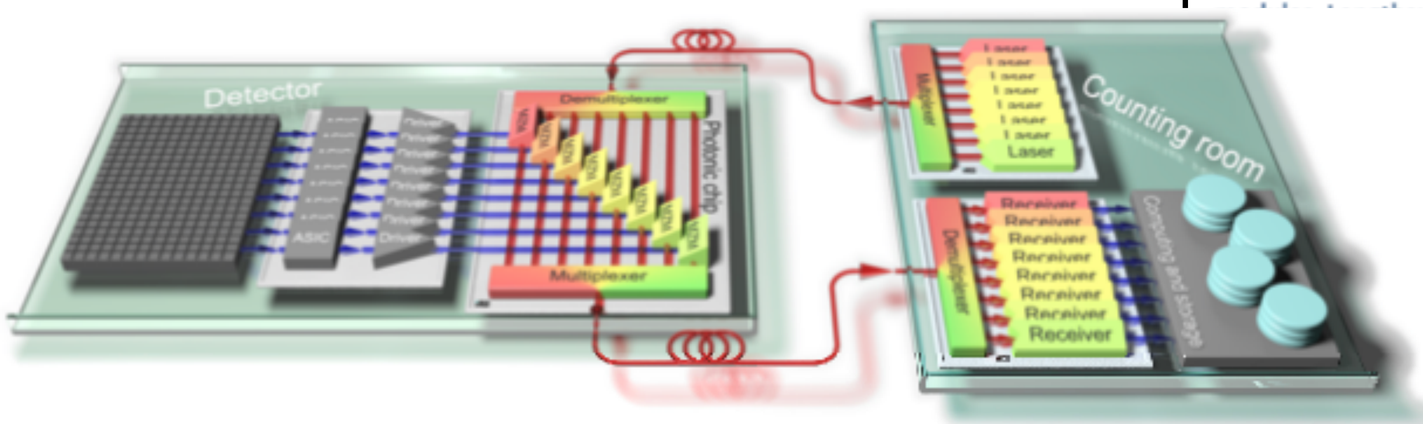



Figure 6: Schematic view of a MZM based system concept for detectors [10].

[PoS(TWEPP2019)053]

# An optical power scheme

## Example ripple requirement & efficiency comparison

| Power block | Version 1 | Version 2 | Version 3 |
|---|---|---|---|
| bPOL12V | V5 | V6 | V6 |
| Length /mm | 22.5 | 22.5 | 22.5 |
| Width /mm | 15 | 15 | 11.5 |
| Shielding height /mm | 8 | 5 | 5 |
| Output Ripple (peak to peak) at 1.2V, 3.0A, 20℃ | 11. 1~15.9 mV | 5.6 ~ 7.4 mV | ~ 7 mV |
| Efficiency @ 1.2V, 3.0A, 20℃ | 55%~ 60 % | 52 % ~ 55% | 55%~ 57% |

**Table 3.3:** Input power supply requirements for the PEBs.

| | Min. | Typ. | Max. |
|---|---|---|---|
| Input voltage range | 5.5 V | 10 V to 12 V | 12 V |
| Input current per channel (half of PEB) | 0.3 A | 4.6 A to 12.2 A | 16.0 A |
| Input ripple and noise @ full load (0-20 MHz bandwidth) | - | - | 20 mVpp (peak-to-peak) |

**Table 3.1:** Front-end electronics power supply requirement

| | Min. | Typ. | Max. |
|---|---|---|---|
| Voltage range | 1.14 V | 1.2 V | 1.26 V |
| Analog current per ASIC | - | 0.42 A | - |
| Digital current per ASIC | - | 0.58 A | - |
| Ripple and noise @ 1.0 A (0-20 MHz bandwidth) | - | - | 5 mVpp (peak-to-peak) |

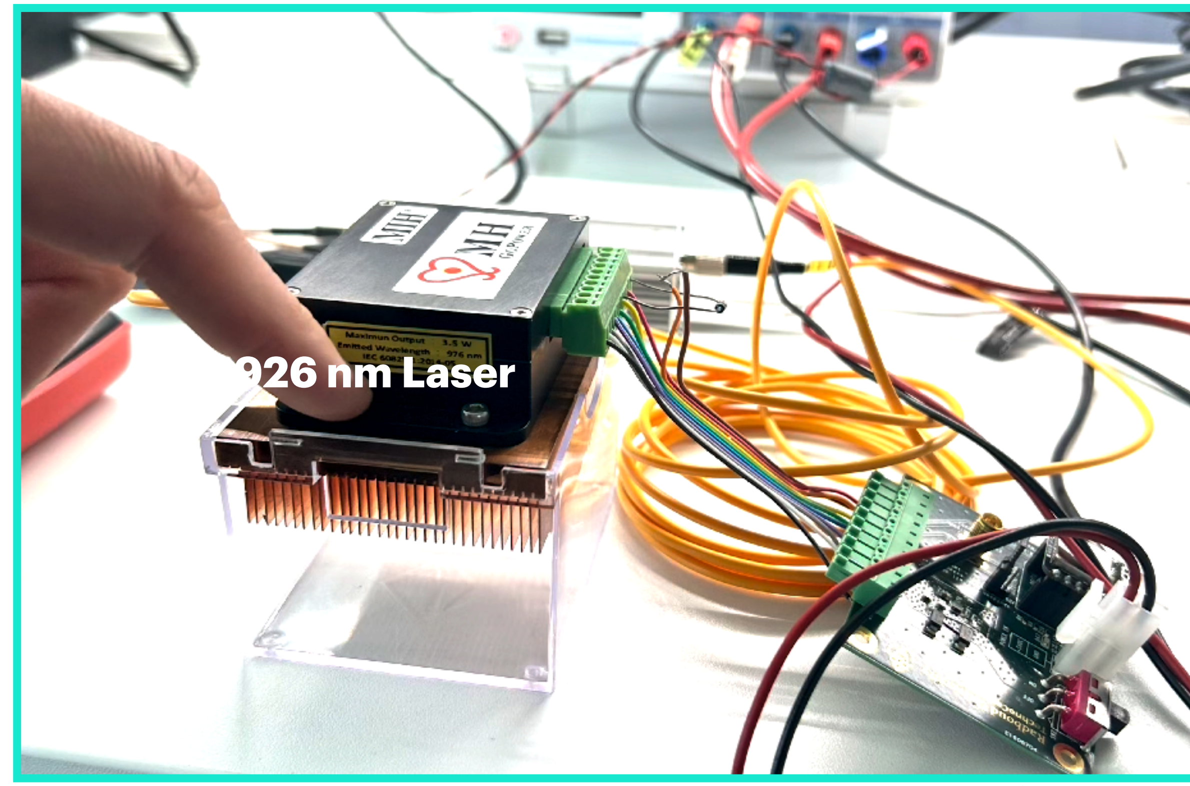
- To power the electronics: it looks like we fit
  - DCDC converter at stage3: bPOL12V - ripple required **20mV pp**
  - LV DC to power ASIC on sensor: ripple required **5mV pp**
- Our current ripple: **~4-5mV pp**
- So to meet requirements for a final detector: okay for now

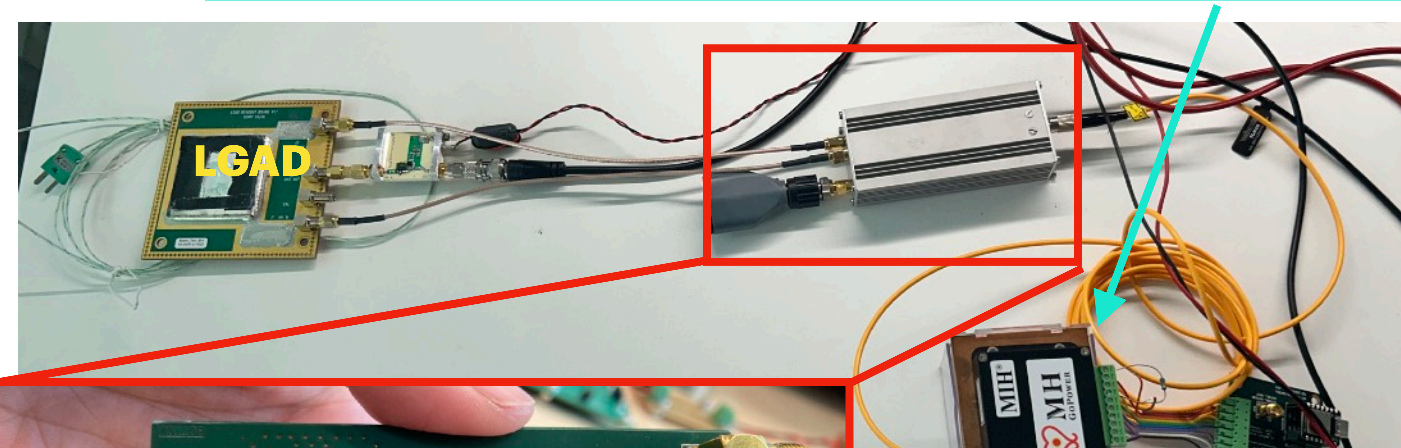
| | Copper power system | | Optical power system |
|---|---|---|---|
| AC/DC converter | 80-90% (HV) 60-70% (LV) | Light sources | 50% |
| Cable loss/ interconnects | 38% [17] | Optical fiber | negligible |
| DCDC converter | 72% (3 A, –30 °C) | PV cell | 50% (highest at 68.9% [18]) |
| Total | 30% | Total | 25% |

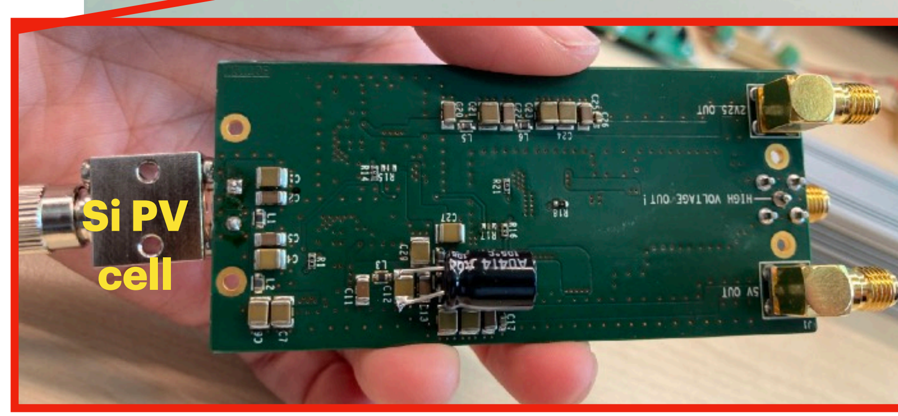
Table 1: Typical efficiency for the basic components of the conventional copper-based and this proposal target optical based power systems. The copper system reflects either the latest technology choice (such as the latest radiation hard bpol12V DC-DC converter is used here) or the ATLAS strip detector system operated at a nominal load [17]. Optical system reflects either the state-of-the-art PoF technologies [19, 18].

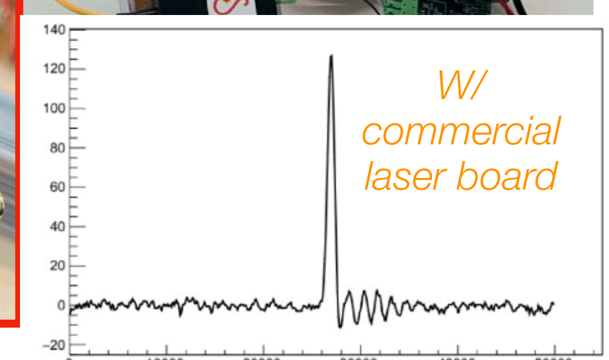
# Lab Demonstrator Status

- Goal: compact, lightweight but high performance detector - starting point on marrying photonics technology to detector
- Split into two directions:
  - Power-over-fiber *(project started)*
  - Integrated photonics in DAQ *(project incubating)*
    - NB: strong interests in wireless data transmission - but very limited experience on this.
- Current prototype:
  - In-house laser driver board
  - In-house PV-cell carrier board
  - Both laser and PV-cell off-shelf
  - Good single point data seen in oscilloscope
    - Comparable to data collected with a commercial laser



# Moving to III-V PV cells

## Collaborating with material physicist

- **August/September 2025:** initial collaboration with assoc. Prof. Schermer on group III-V PV cells (GaAs, GaInP) - so far highest efficiency (~68% in lab) PV cell, however, band cap may cause concern on radiation hardness
  - The latest DUNE PoF project opted also to GaAs PV cells (for cold and warm electronics)

| Parameter | Value |
|---|---|
| 808nm Broadcom laser power per unit | tunable up to 2 W |
| Max OPC Efficiency (Optical-to-Electrical) | ~51% (~45% at room temperature) |
| Output voltage per OPC | 3-38 V [1] |
| Output current per OPC | up to 100 mA |
| Output power per OPC | up to 600 mW |

Table 1: PoF system capability at LN2 temperature.

FERMILAB-PUB-24-0265-AD-ETD-LBNF

- **Oct/Nov 2025:** received some first samples to try out
  - **Plan:** RU AMS department has a fully equipped lab incl. crystal growth capabilities, if first demonstrator works out, we aim to work out a radiation-hard and efficient cell together for HEP application.