A Rest Gas Ionization Monitor for the PS

James Storey

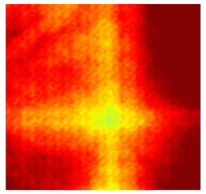
on behalf of the PS-BGI team:

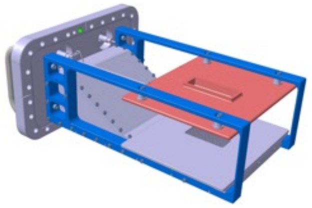
Swann Levasseur, Hampus Sandberg,
Kenichiro Sato, Gerhard Schneider & Bernd Dehning.

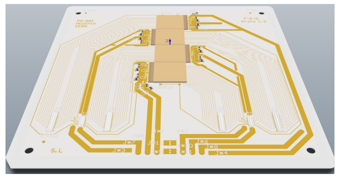
BI Day, 10th March 2016

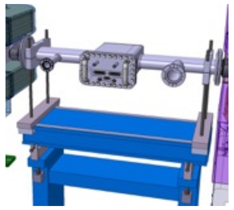
Outline.

Operational requirements & PS constraints. 

Motivation for a pixel detector. 

Technical design. 

Pixel detector readout electronics. 

Outlook. 

Operational requirements.

Measure transverse beam size with a relative error (systematic + statistical) = 1%.

e.g. for LHC beam with 25ns bunch spacing & 72 bunches, at 25 GeV the beam size = 3.7 mm → **detector resolution < 1mm.**

Readout modes:

1) **Basic mode:** Continuous measurement during the cycle average over all bunches @ 1kHz.

2) **Normal mode:** Continuous **bunch-by-bunch** measurement during the cycle @ 1kHz → **Time resolution < 25ns & measurement time > 1s.**

3) **Burst mode: Bunch-by-bunch and turn-by-turn** for 5000 turns at chosen moment of the cycle.

PS constraints: Vacuum pressure.

desirable
Gas injection not ~~possible~~ (problem for ions).

How many turns are needed to measure beam size of a **single bunch** with relative error = 1%?

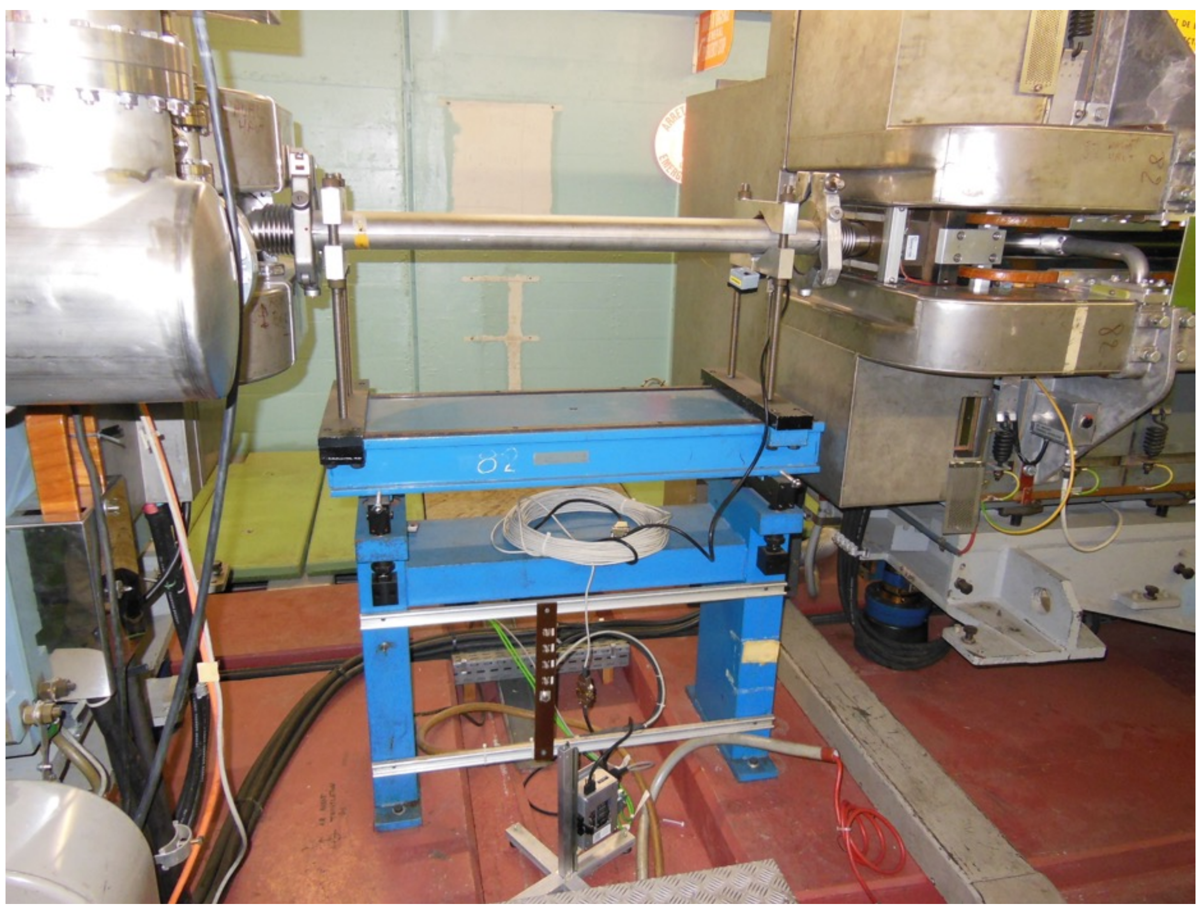
Assuming pressure = $1x10^{-9}$ mbar & gas = H_2
ionisation e- / ions per bunch per turn = 1

For beam size relative statistical error = 1% (5%) need to detect 12,000 (500) e-/ions (Federico Roncarlo CERN-THESIS-2005-082)

→ To measure beam size of **single bunch** with **1% (5%) relative error** requires **~12,000 (500) turns.**

PS constraints: Outgassing, radiation, mechanical.

- Vacuum: outgassing ≤ $1 \cdot 10^{-7}$ $mbar \cdot l \cdot s^{-1}$.
- Radiation: 10 kGy/yr at beam pipe, 1 kGy/yr at 40 cm.
- Mechanical:



80 cm

7.0 cm

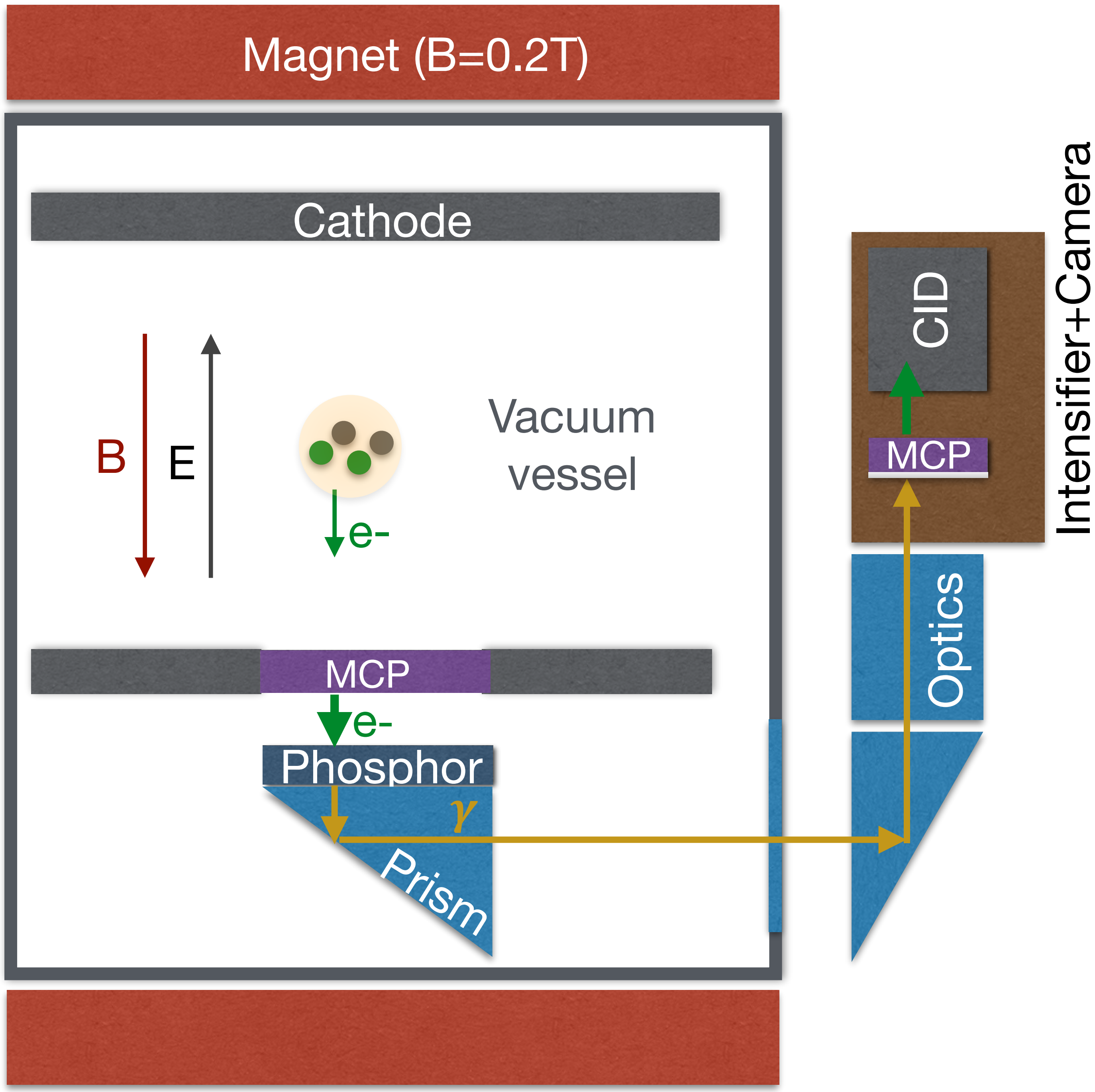
14.6 cm

Summary of requirements.

Detector resolution < 1mm.
Time resolution < 25ns.
Continuous measurement > 1s.

Does any existing IPM design meet all these requirements (+ outgassing, radiation & mechanical constraints?)

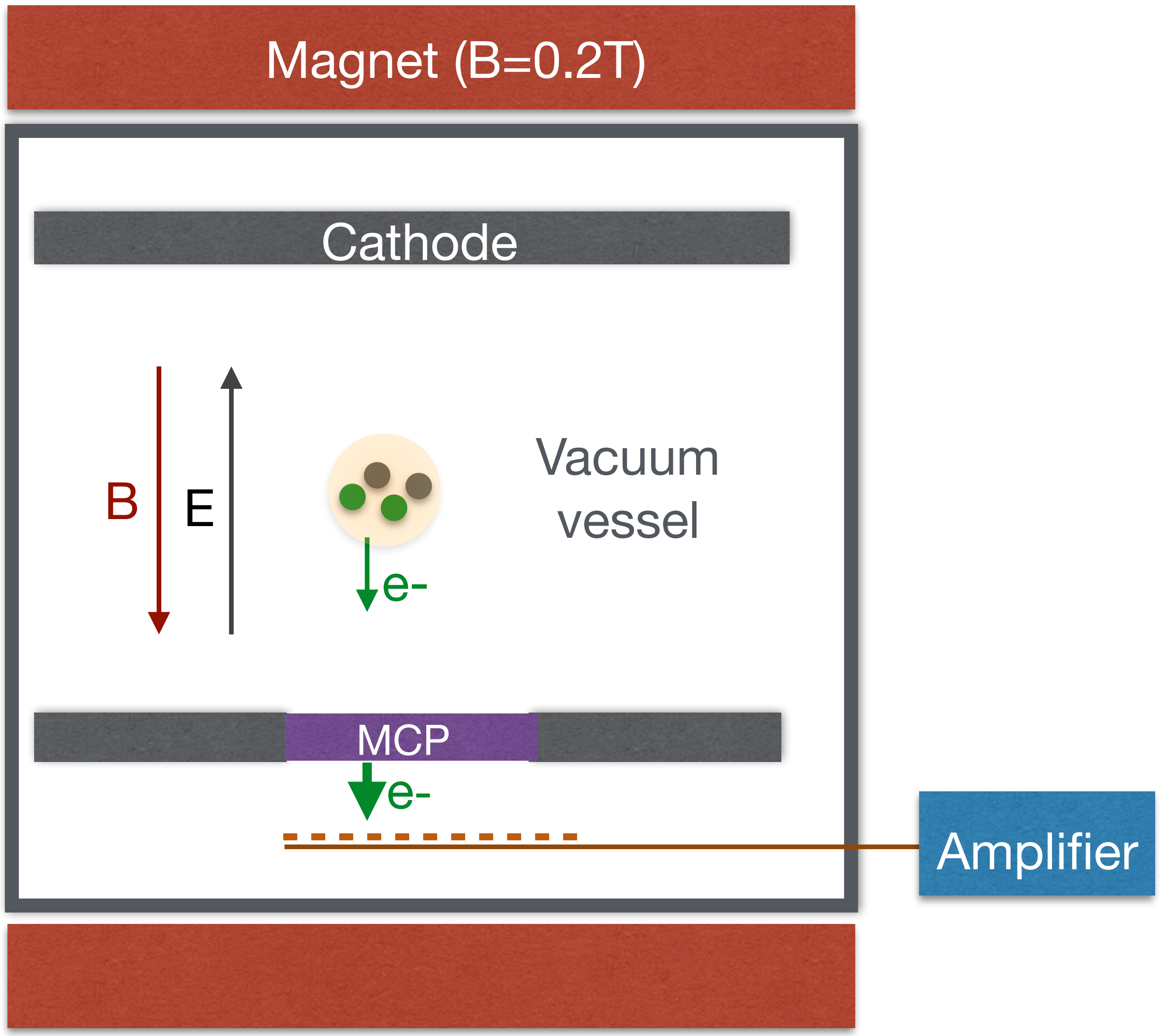
Rest gas ionisation monitors:
MCP + phosphor screen (CERN SPS/LHC).



Detector resolution ~100um.
(MCP + optics).

Time resolution ~10ms
(camera frame rate; lower
with intensifier gate).

Rest gas ionisation monitors: MCP + wire array (Fermilab / J-Parc).



Detector resolution >250um (anode wire pitch).

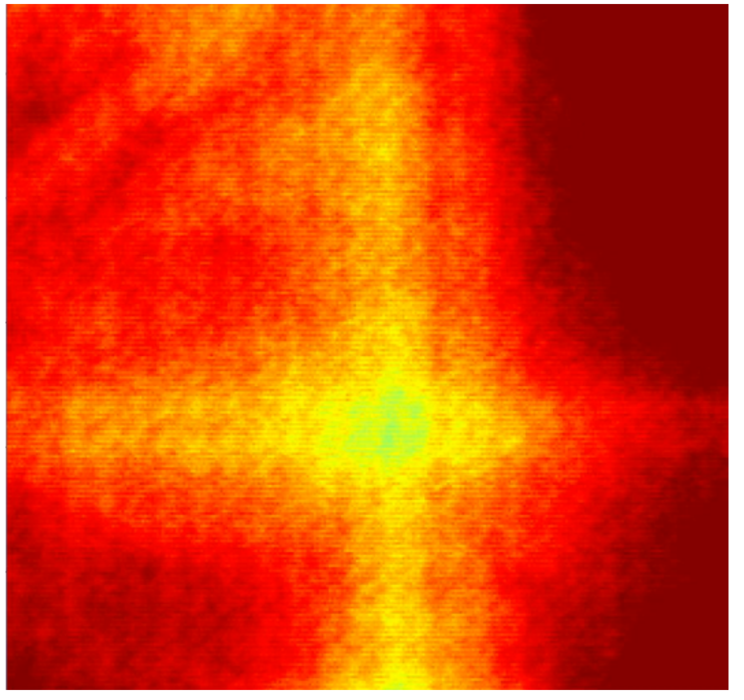
Time resolution > 100ns (cables + amplifier).

Common problem: MCP lifetime.

Gain of each MCP channel gradually reduced as it is it amplifies more and more electrons.

Gain of channels which “see” the beam reduced faster than those on periphery → **inhomogeneous MCP gain.**

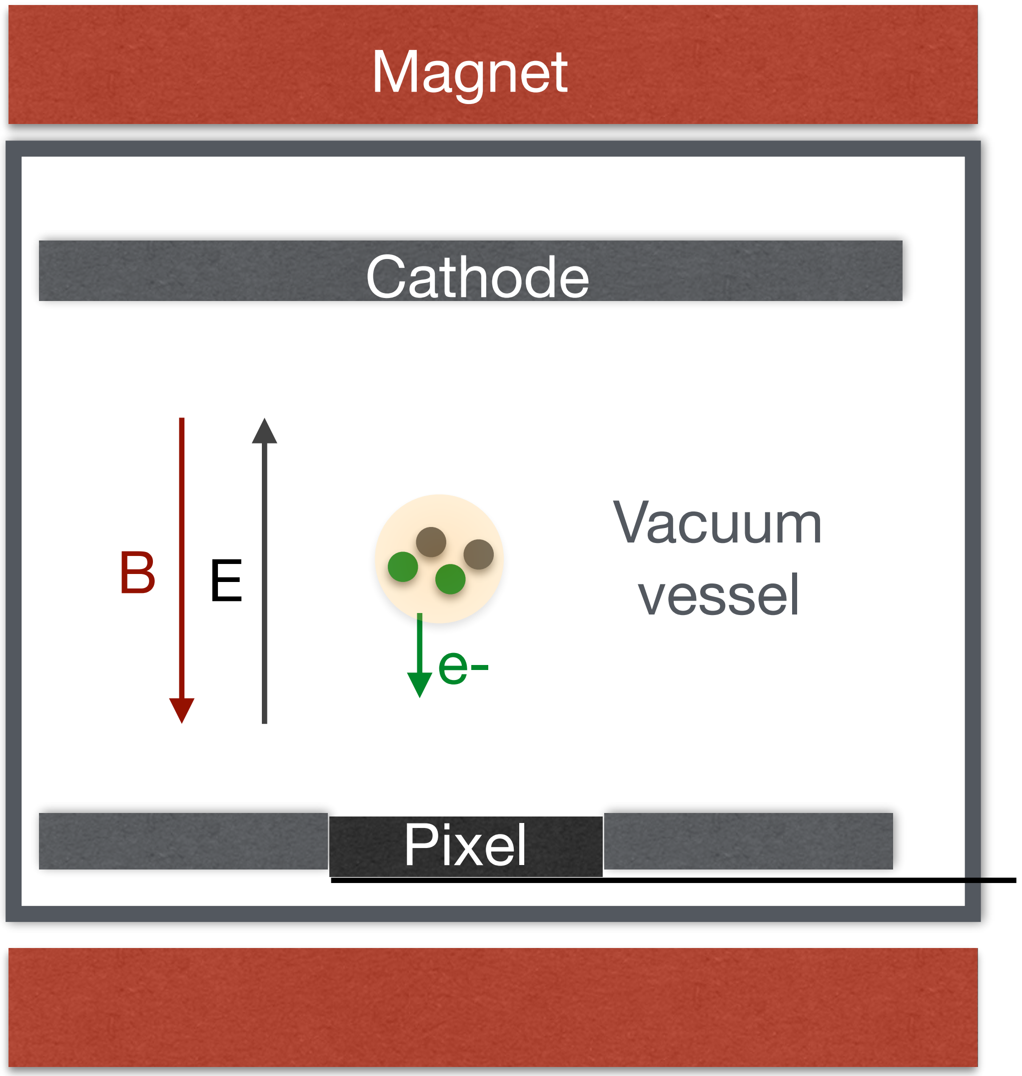
LHC B1H exposed to EGP.

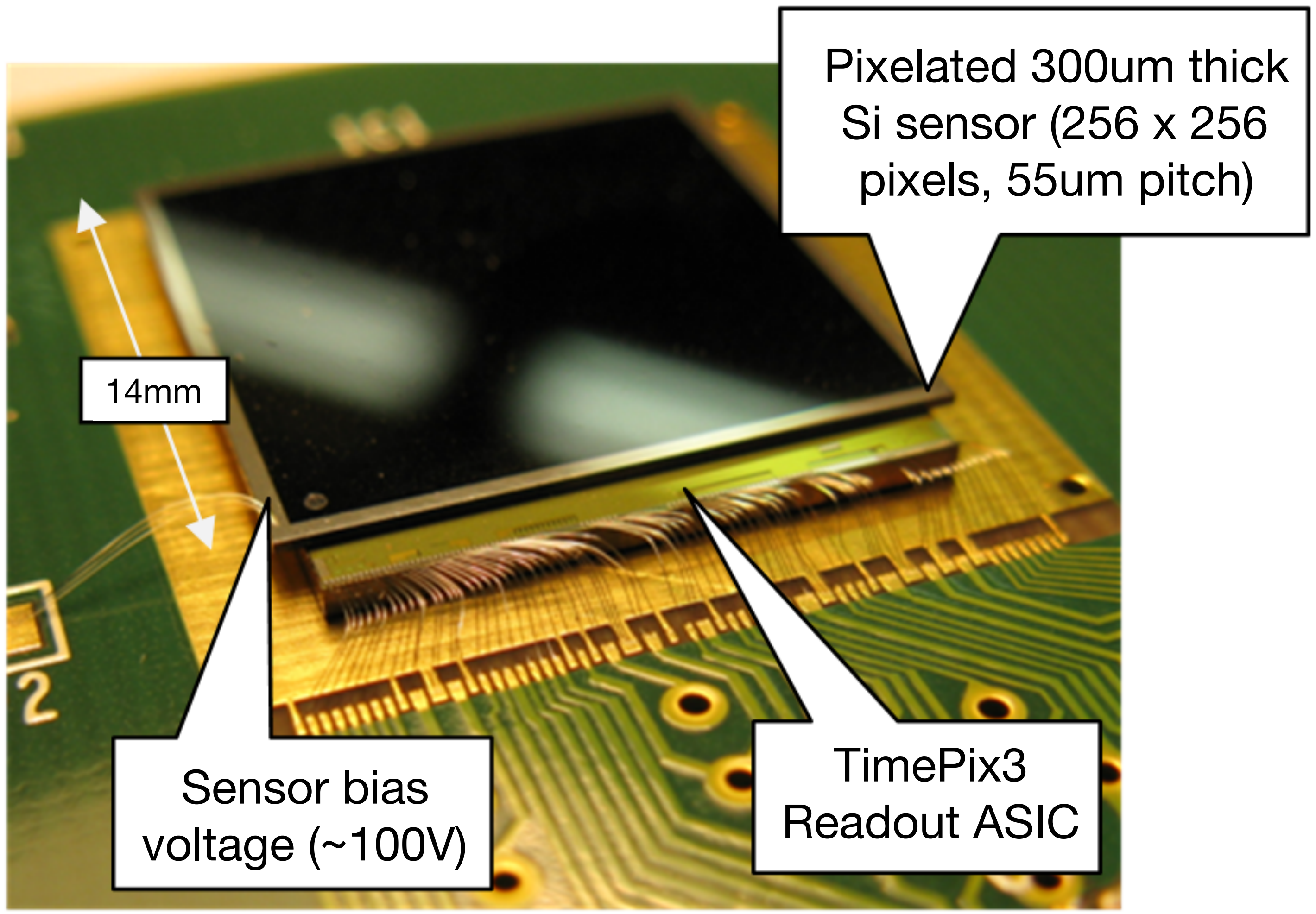


Some solutions:
- Calibrate with EGP (CERN LHC).
- Limit degradation by preventing electrons hitting MCP when monitor not used (Fermilab).

… but eventually MCP must be replaced (vacuum intervention, cost).

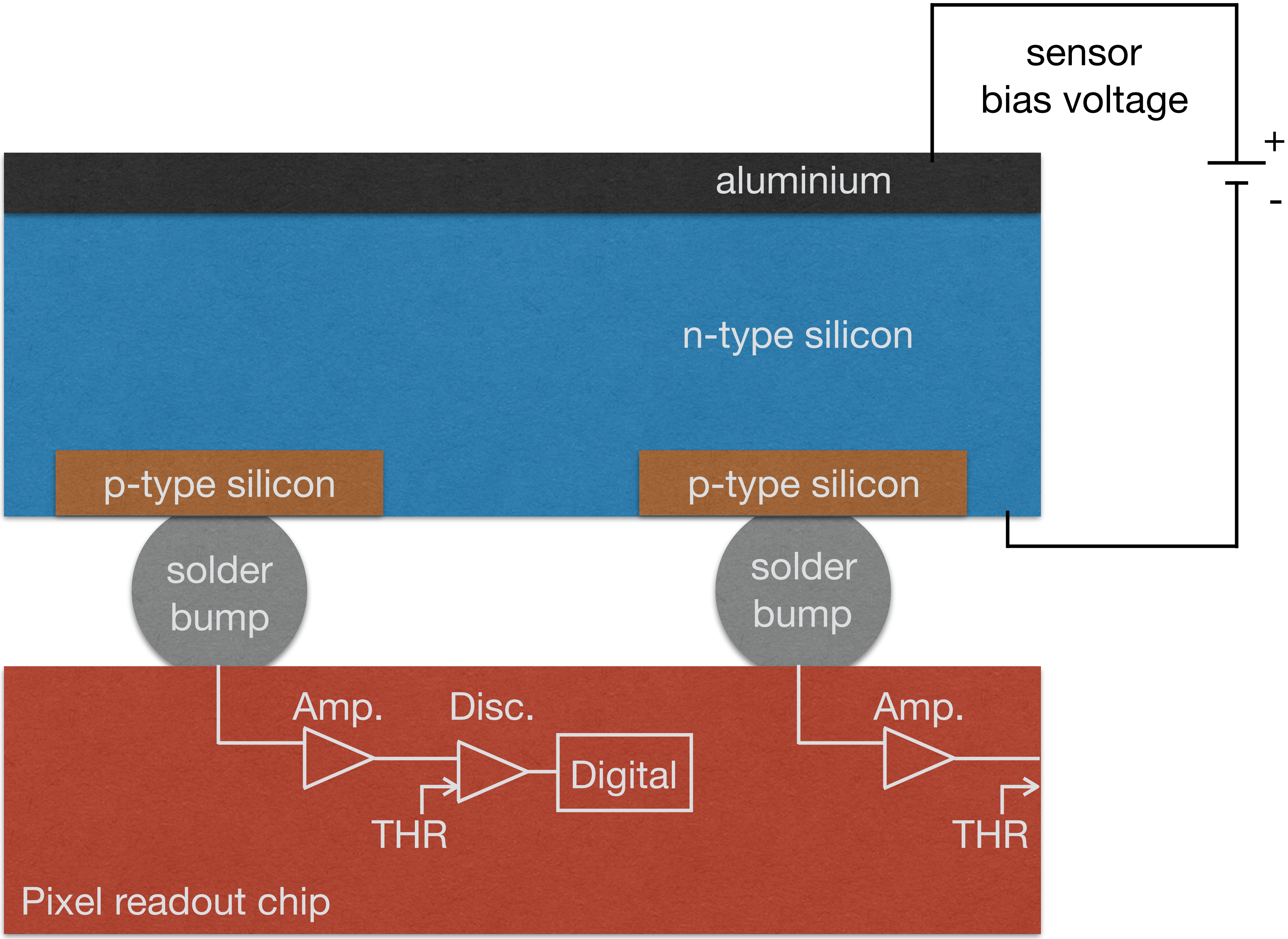
Idea: Replace MCP + Phosphor/Wire array with Hybrid pixel detector.



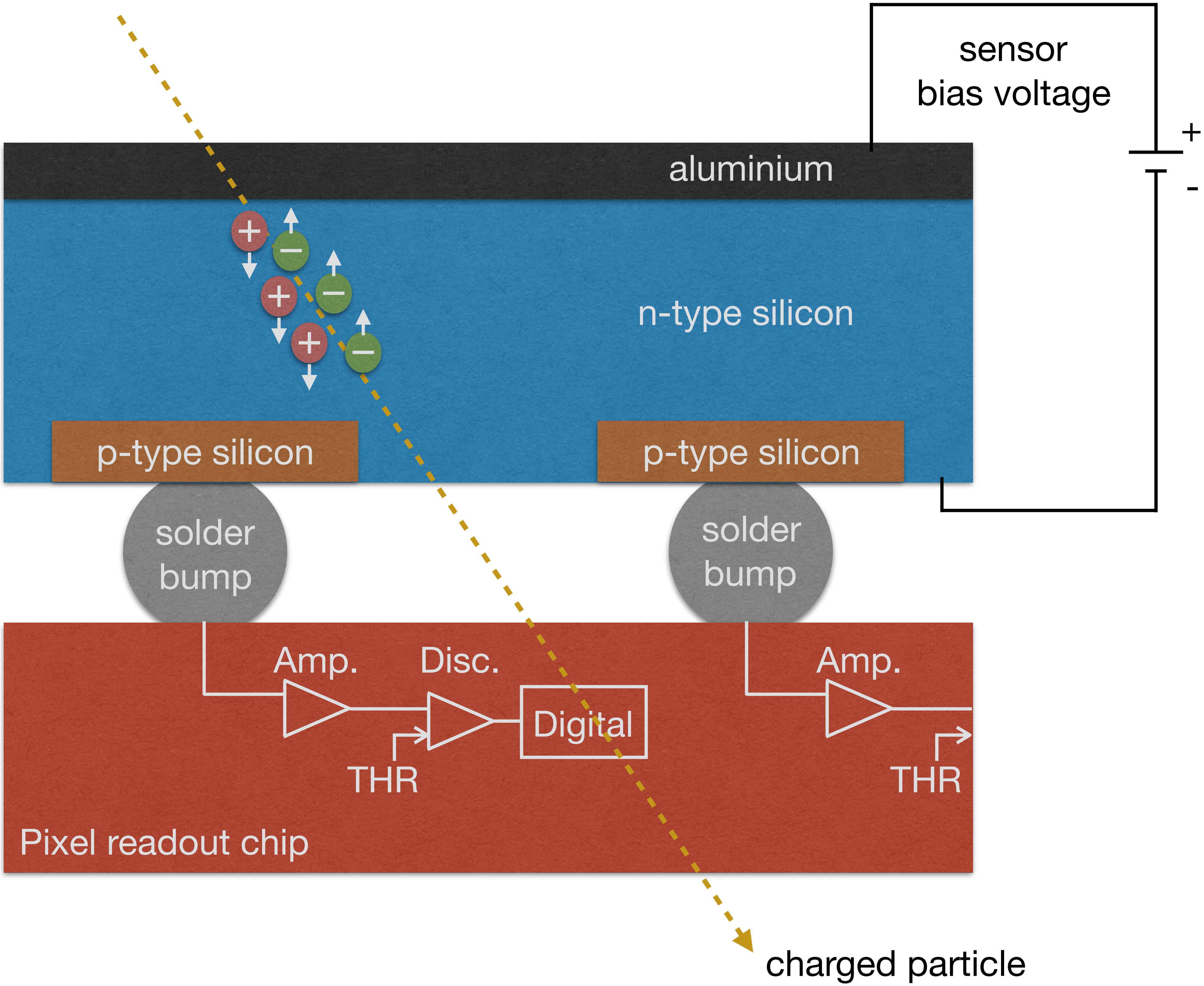


from Medipix collaboration.

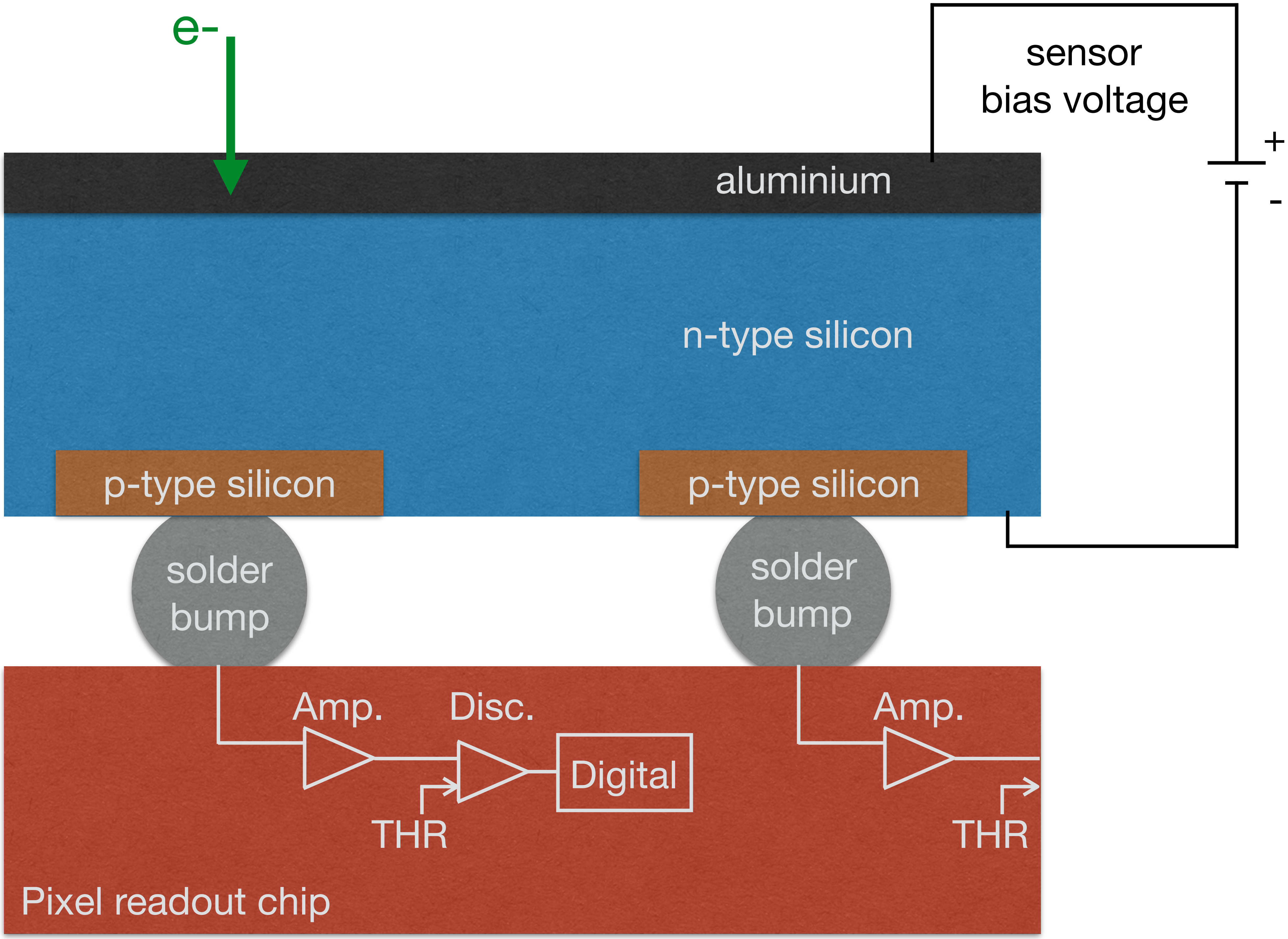
Hybrid pixel detector.



Hybrid pixel detector.



Hybrid pixel detector for ionisation profile monitor.



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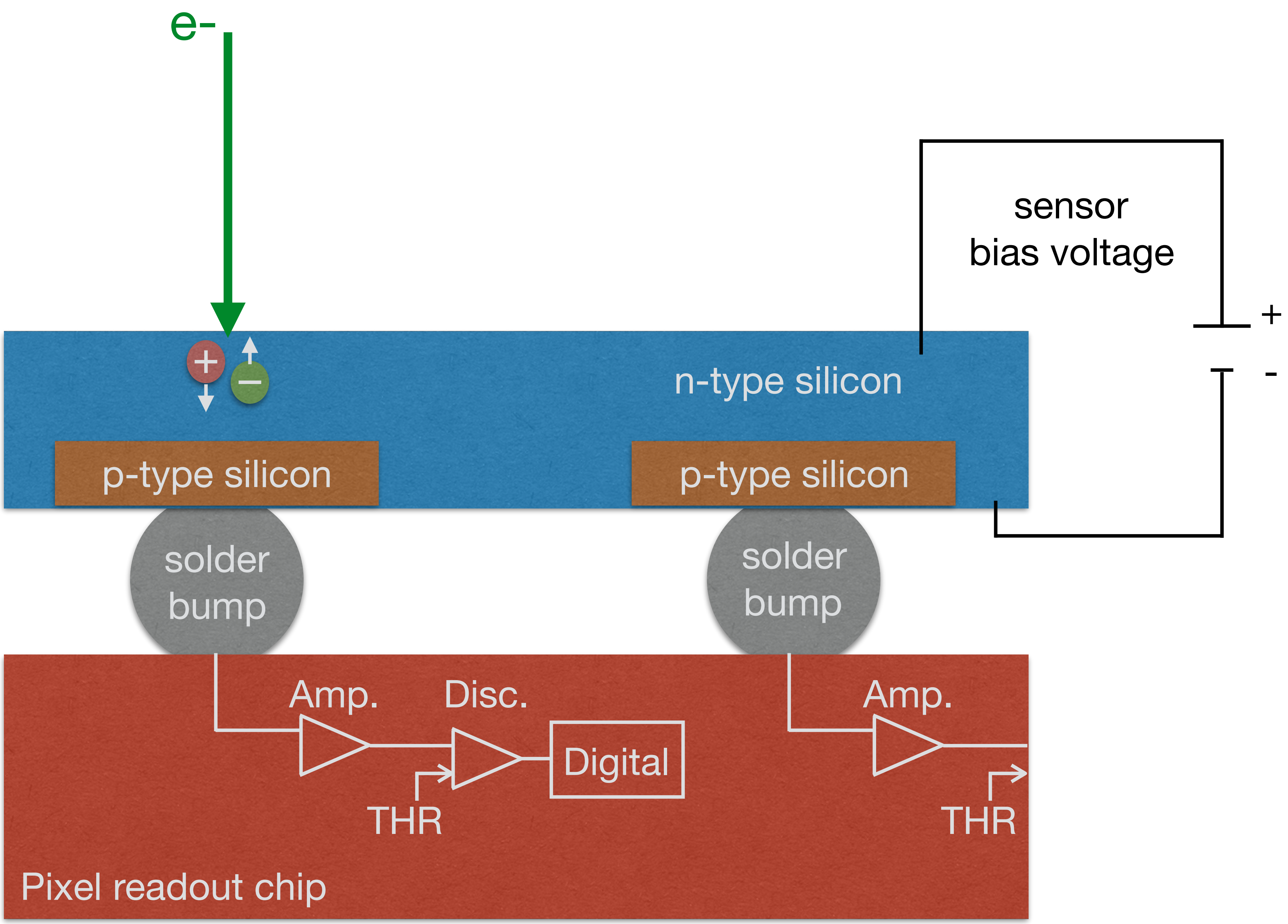


Hybrid pixel detector for PS-BGI: 100um silicon sensor bonded to a Timepix3 chip.

Timepix3 characteristics:

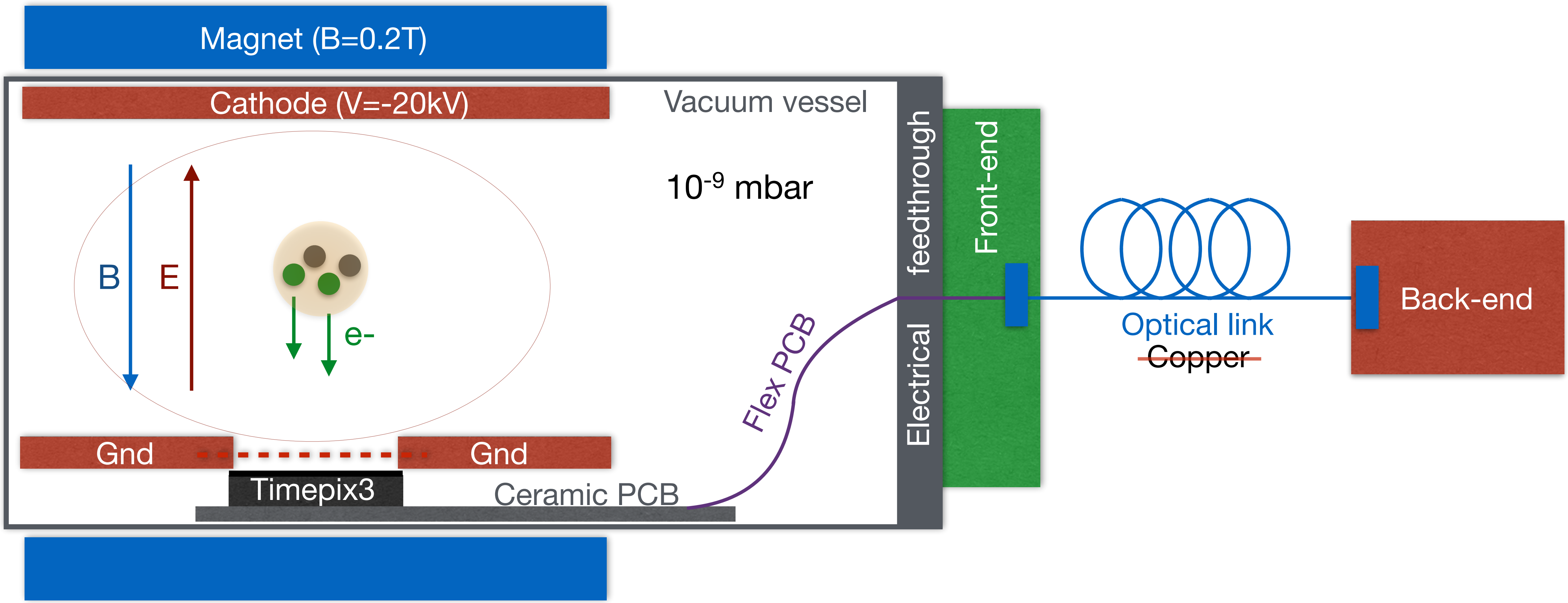
- **Detector resolution = 55um,**
- **Time resolution = 1.56 ns,**
- Radiation hardness < 2 MGy,
- Triggerless readout:

  Above threshold → Event(Time of Arrival + Time over Threshold).

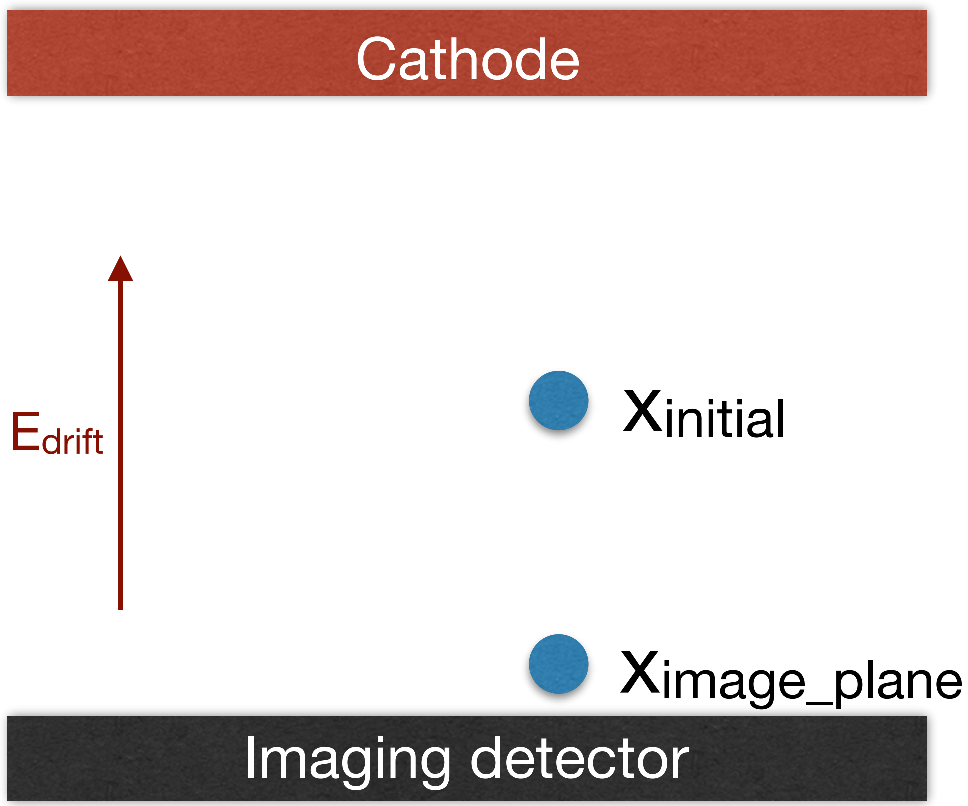
Performance limitations:

- Dead time per pixel > 475 ns,
- Output bandwidth < 5.2 Gbps (80 MEvents/s).

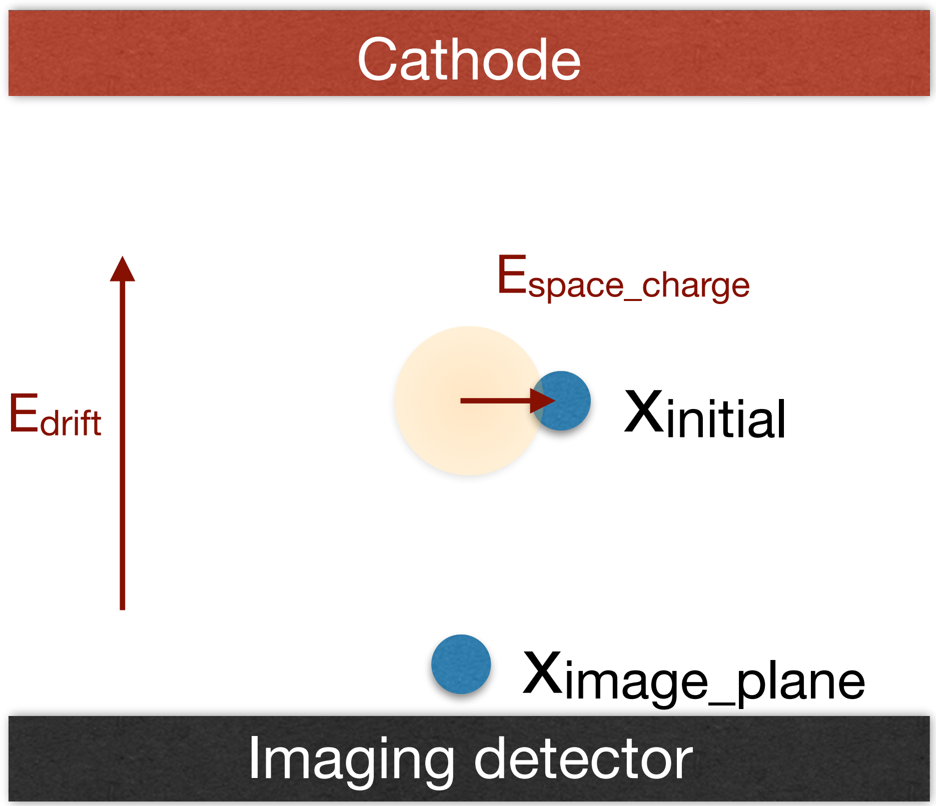
Conceptual design.



Field cage design.

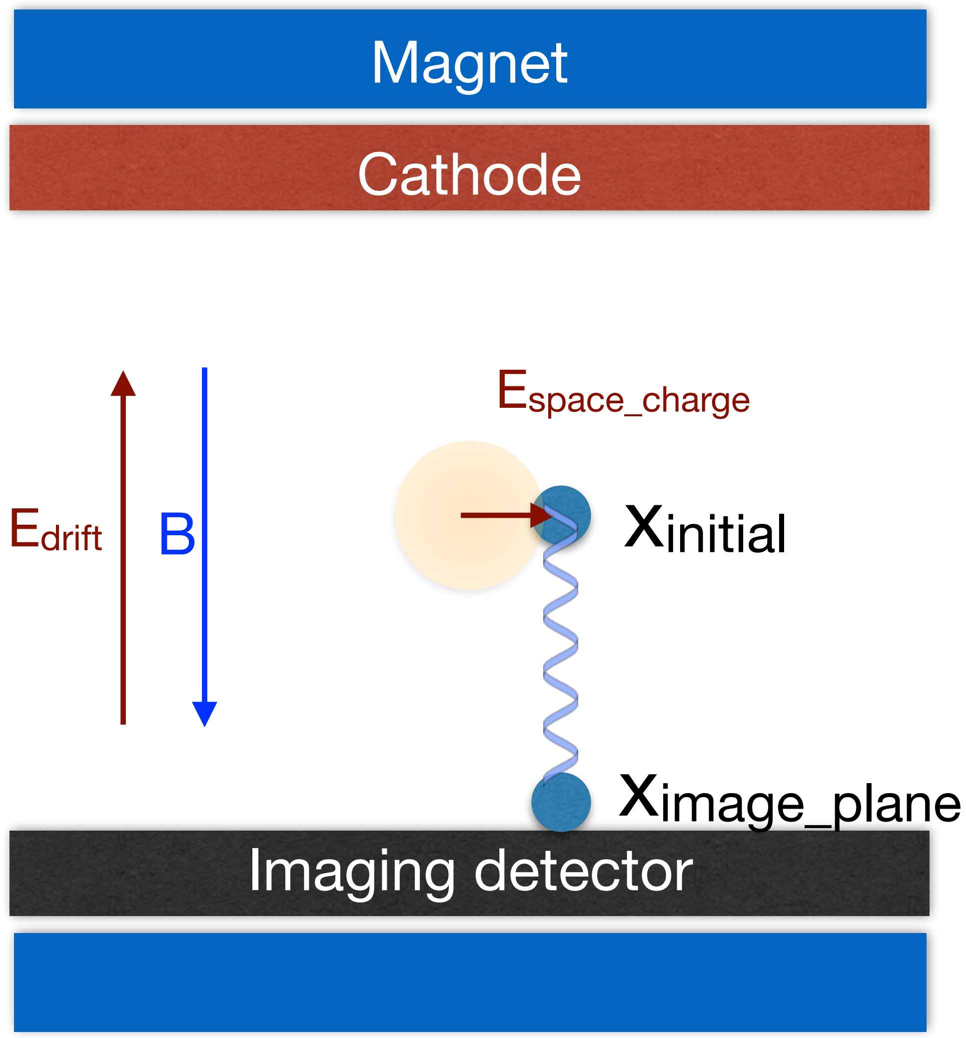


Ideal ($x_{image\_plane} = x_{initial}$)



Distortion due to beam space charge.

Field cage design.

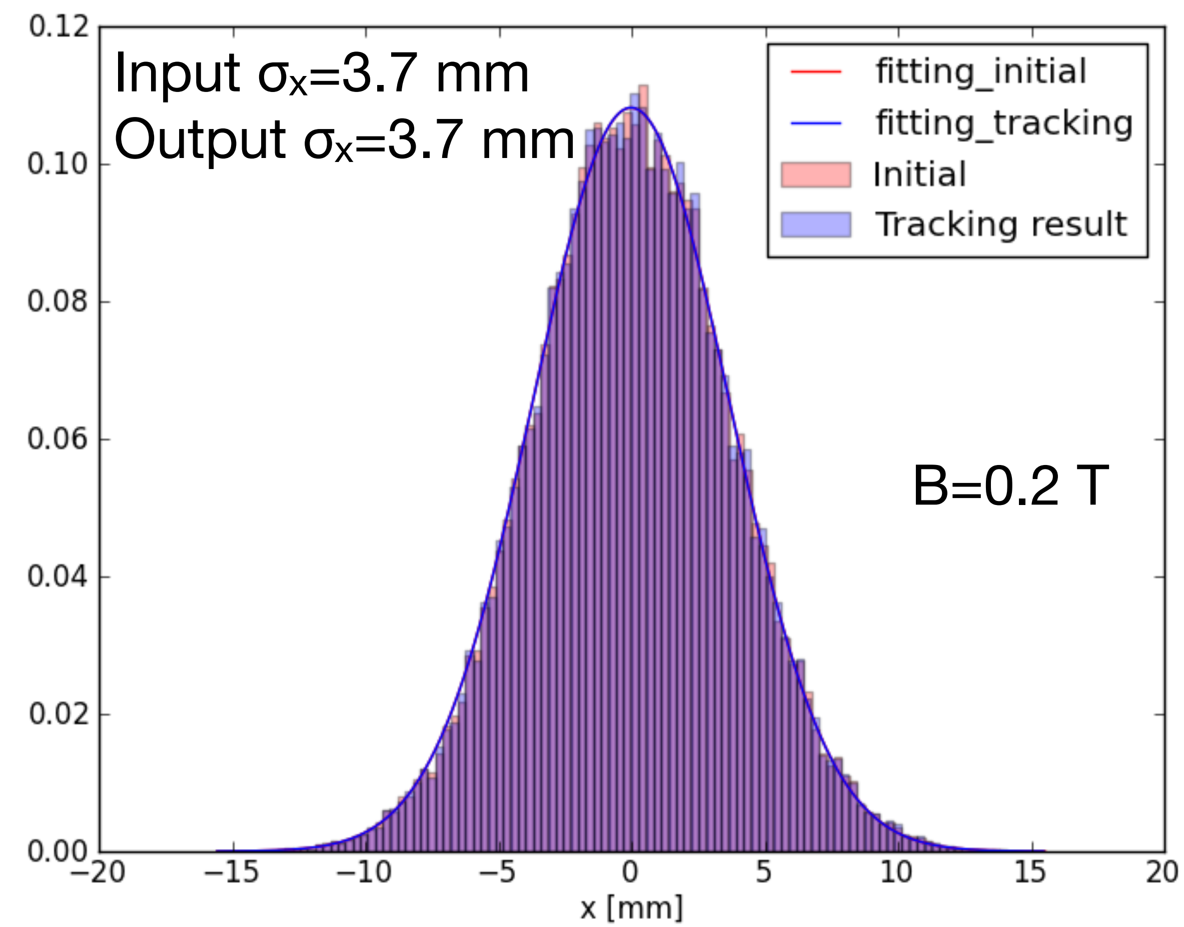


Design questions:

1) Strength of magnetic field?
2) Homogeneity of magnetic field?
3) Homogeneity of electric field?

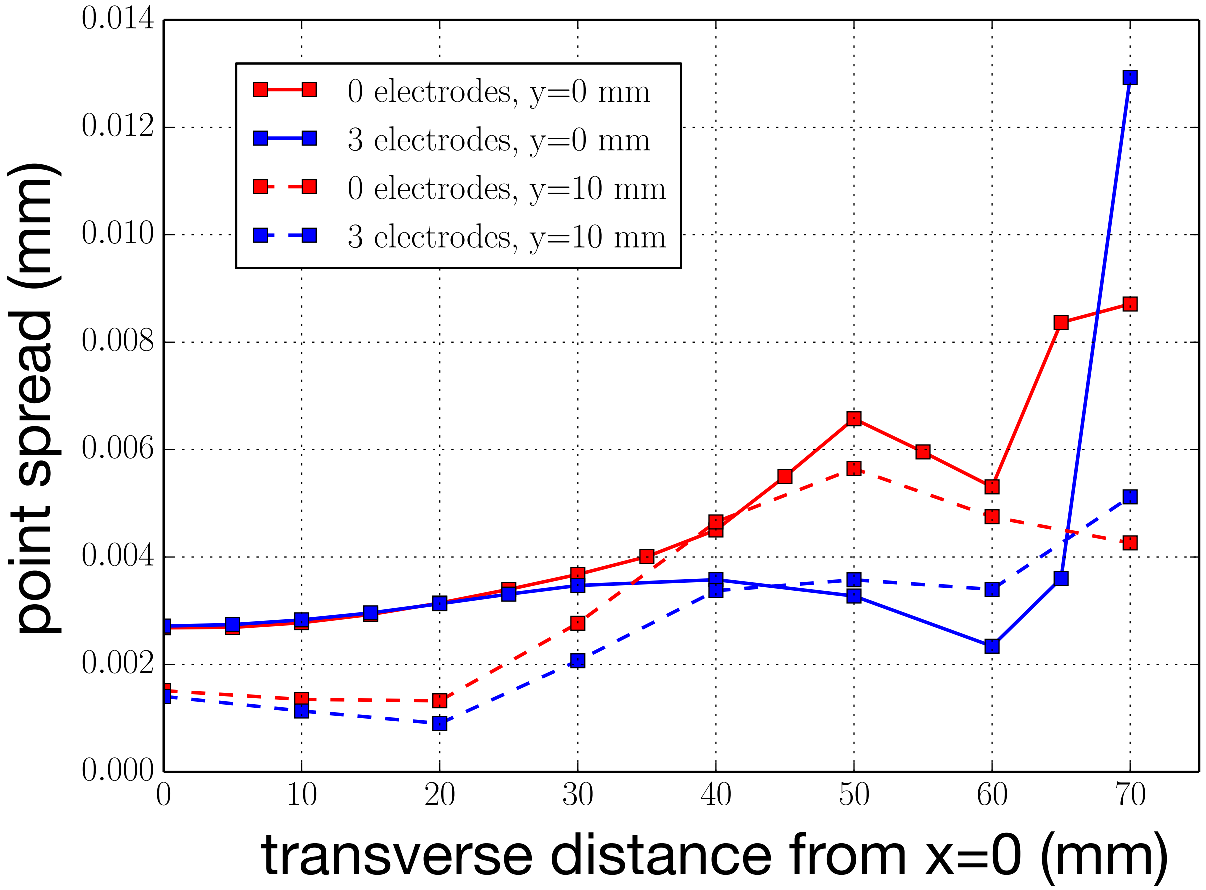
Simulation.

- Complete simulation of IPM performance by Kenichiro.
- Includes all known physical effects:
  - Initial electron velocity.
  - Space charge.
  - Drift field & magnetic field inhomogeneity.
- Validated on LHC BGI data.
- Distortion < 0.1%; even with upto a factor 10 higher beam intensity.

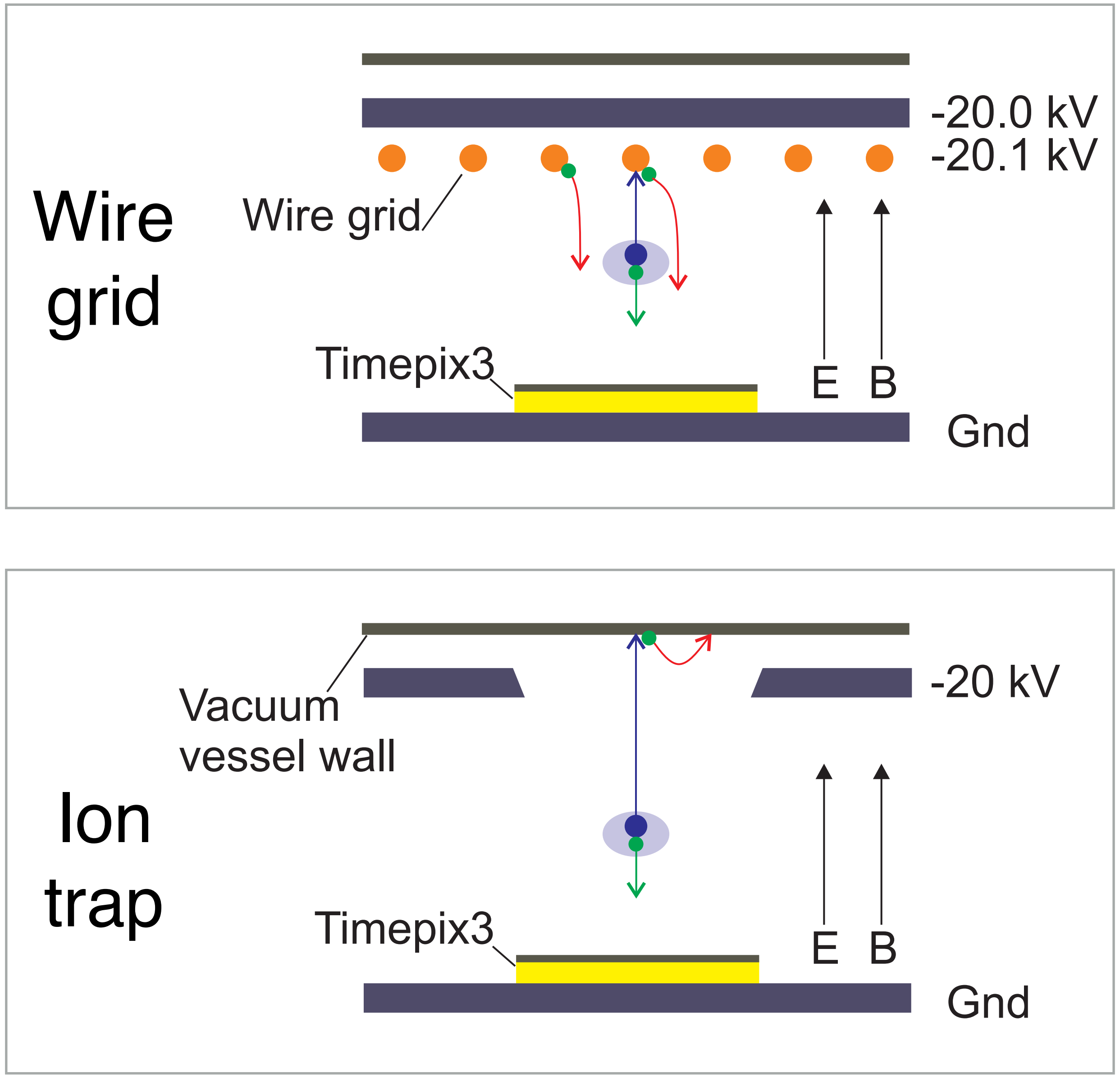


Field cage: Novel design elements.

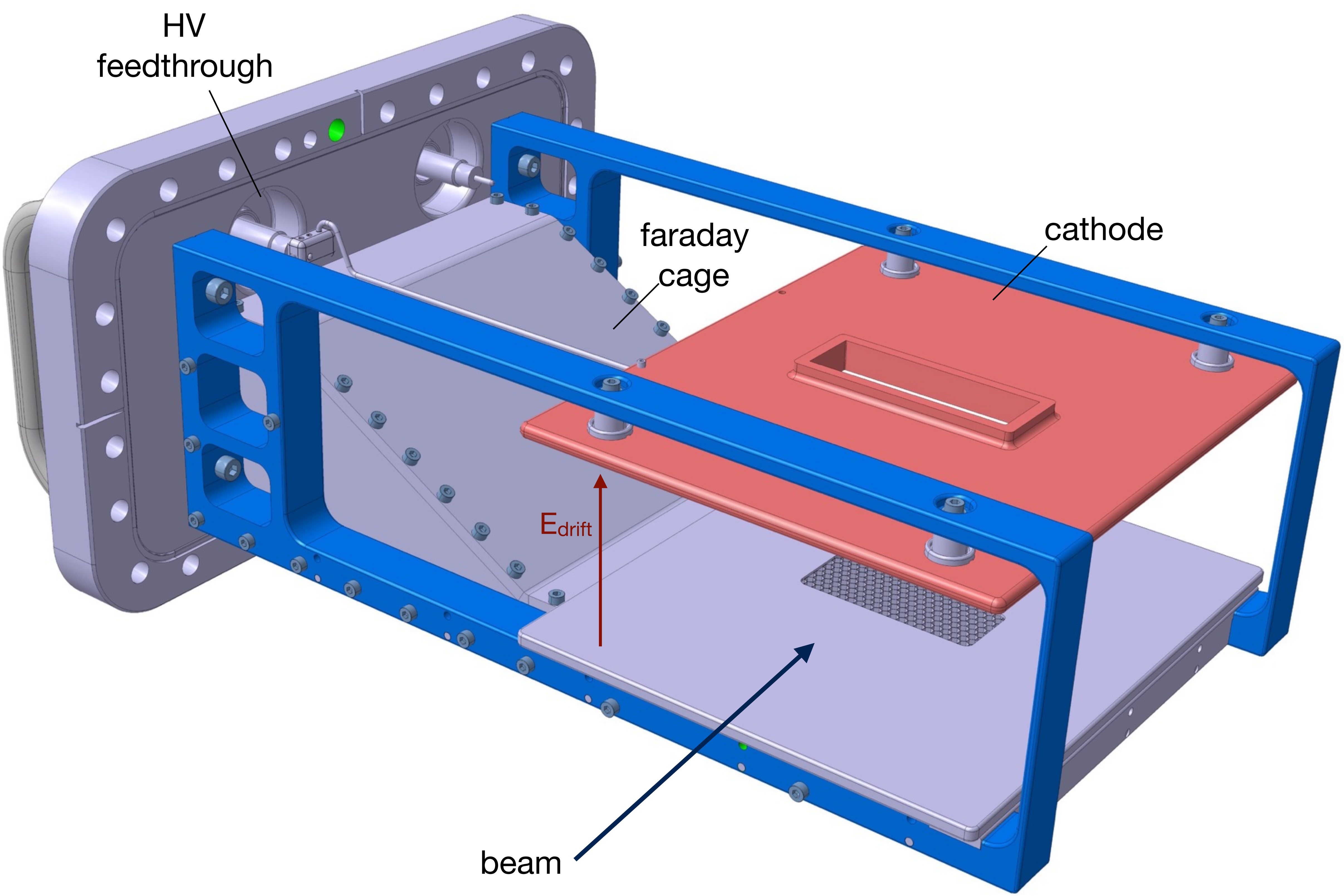
No Side-Electrodes



Ion Trap



Technical design.



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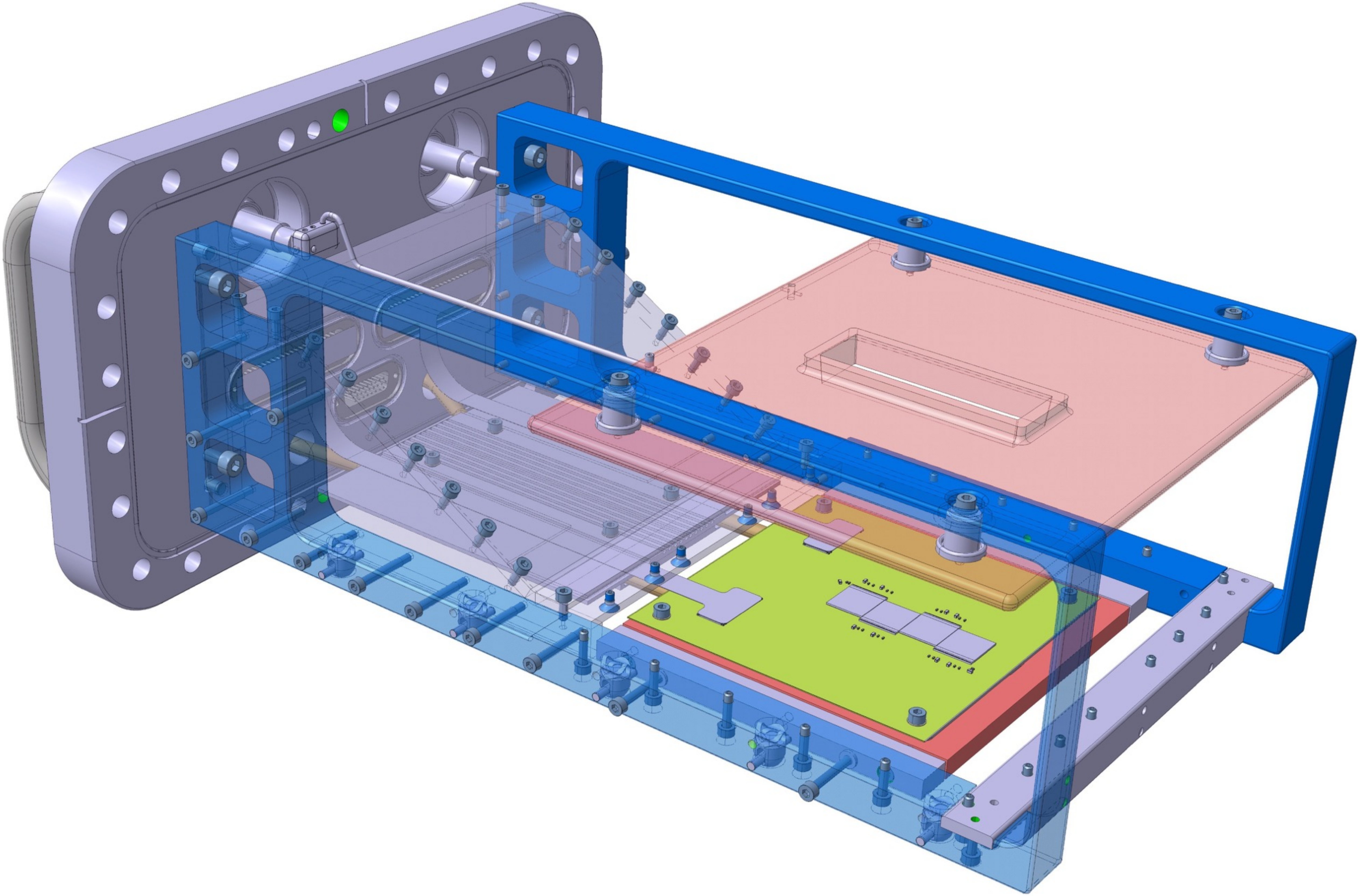

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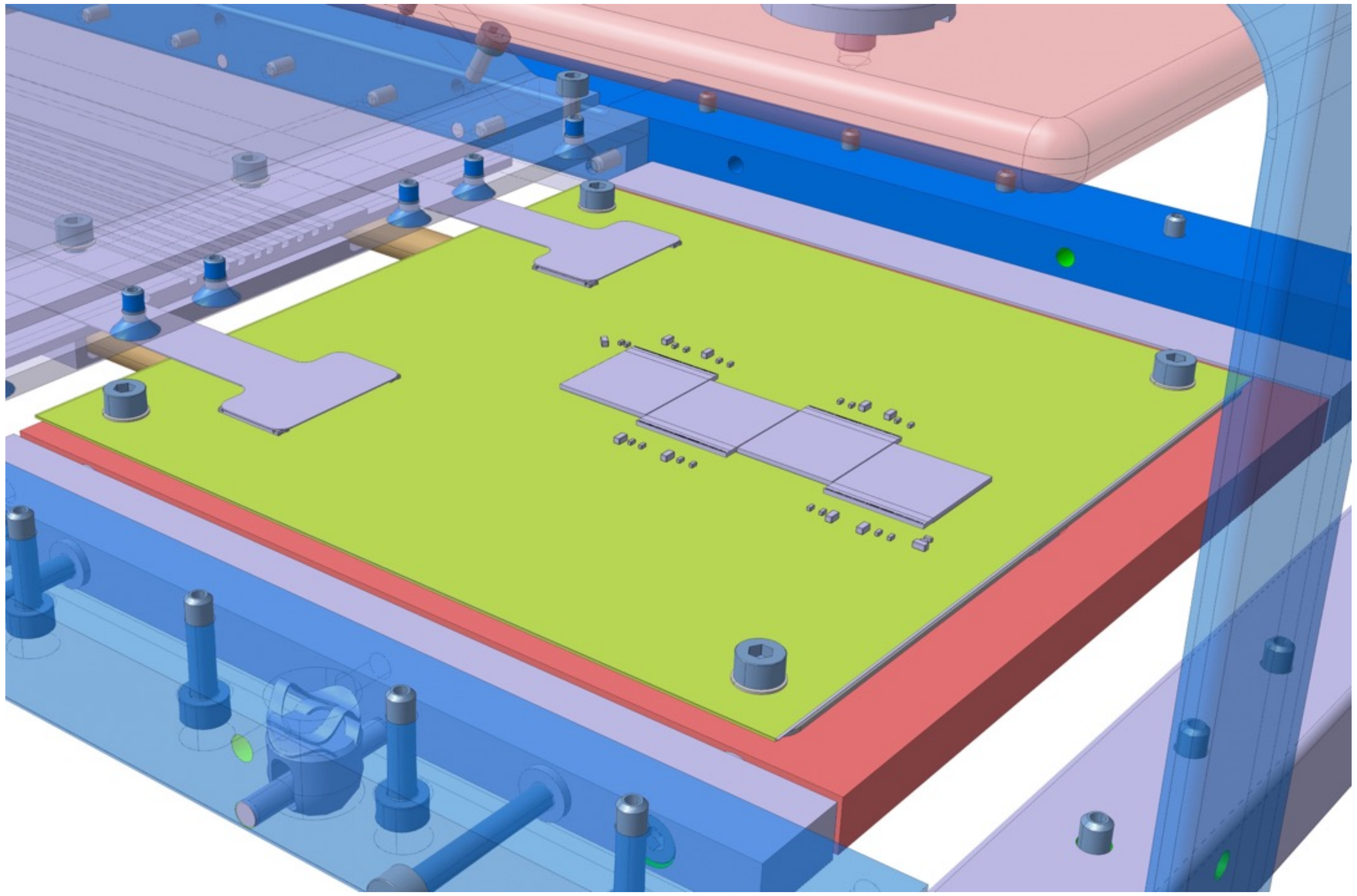
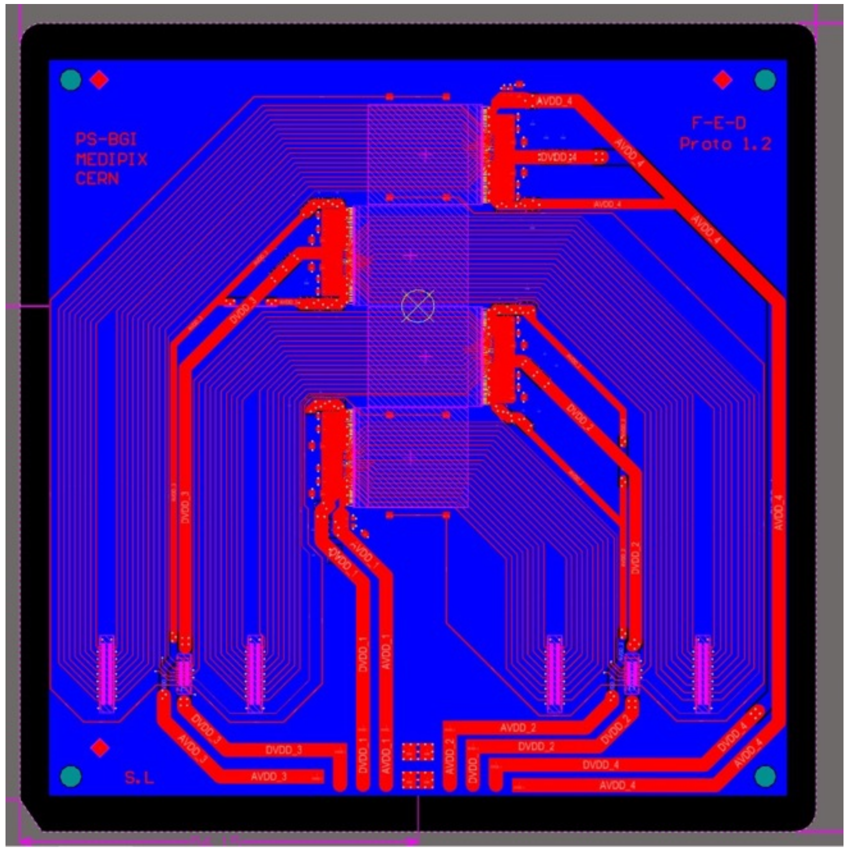
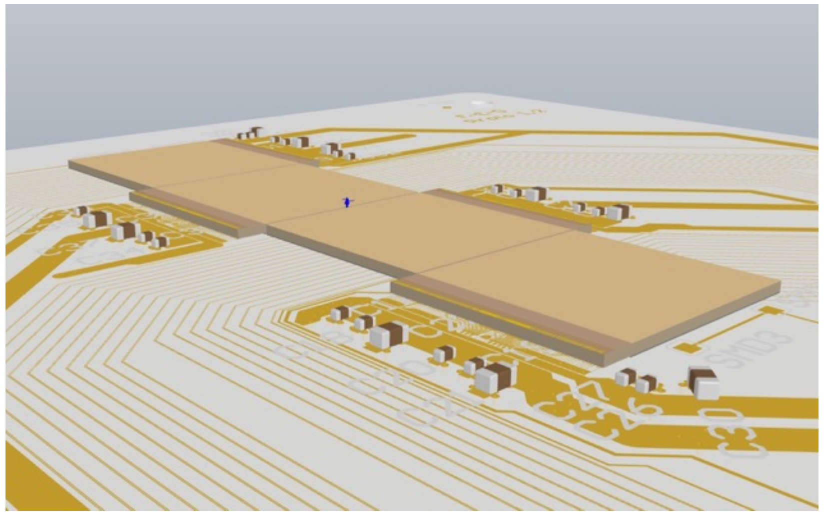
Pixel detector, front-end and back-end readout electronics.



Pixel detector: Requirements and design.

- Operation in UHV → Careful selection of materials & processes.
- High speed digital interface (20.48 Gb/s) → Control of track impedance, cable lengths & connections.
- High Radiation levels (>10 KGy/yr) → Use of radiation hard components.
- Cooling → Liquid cooling to 0 deg.



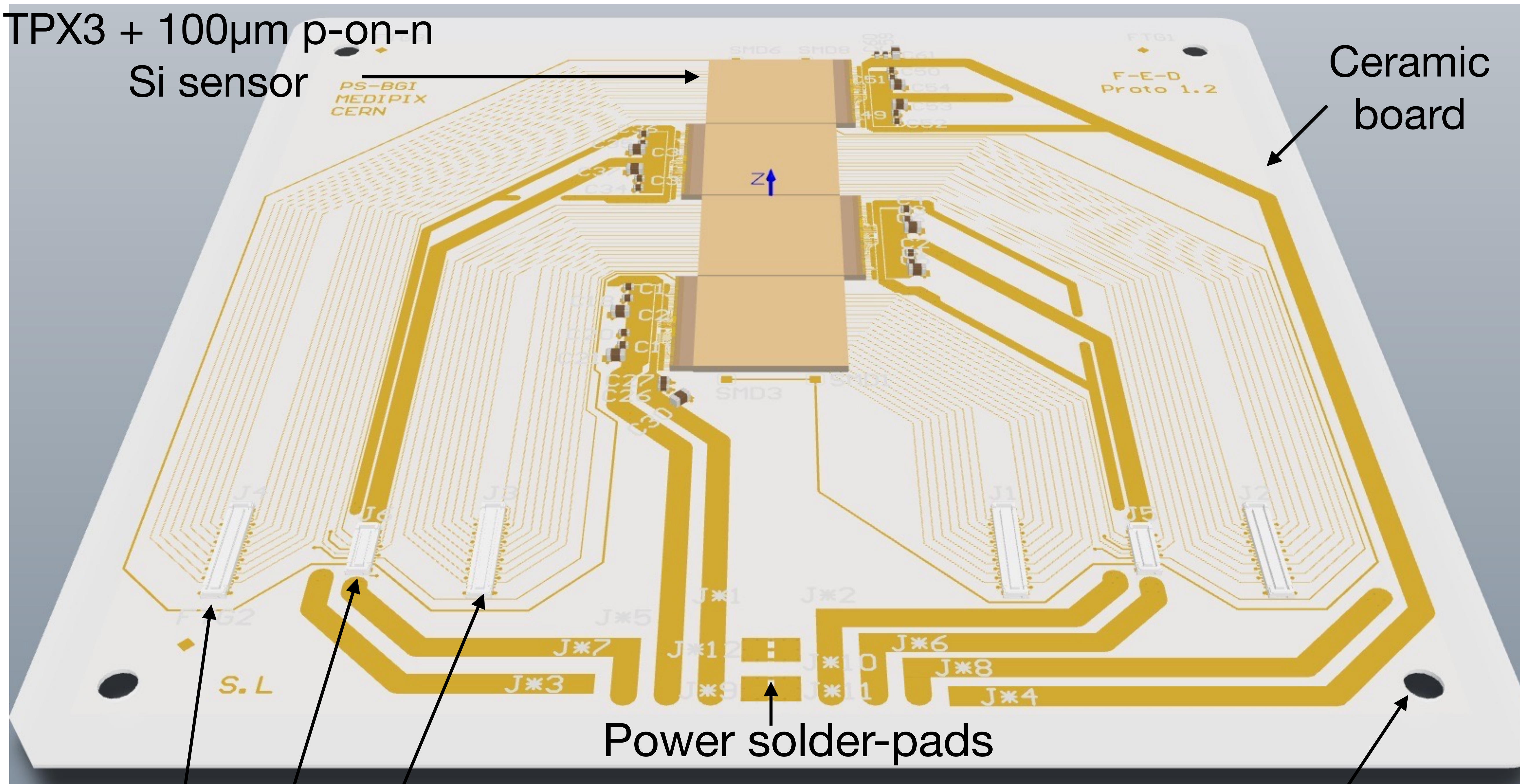


Pixel detector: Ceramic board.

beam

TPX3 + 100μm p-on-n Si sensor

Ceramic board



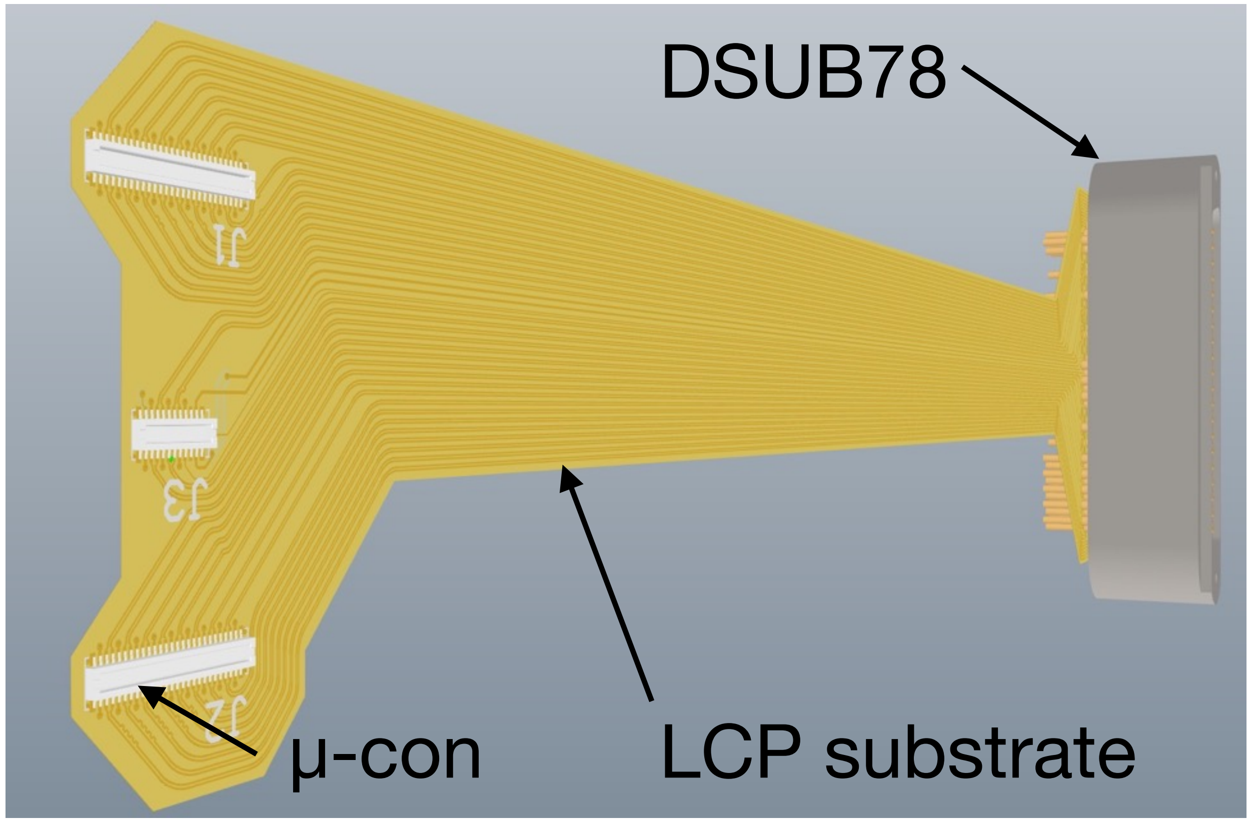
Power solder-pads

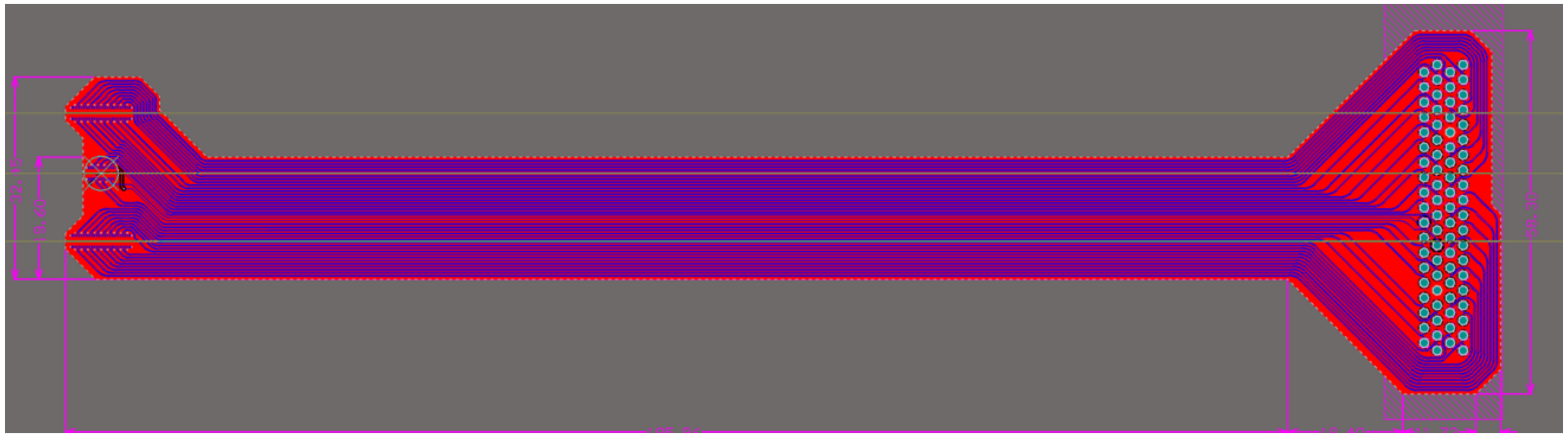
μ-connectors

Fixation holes

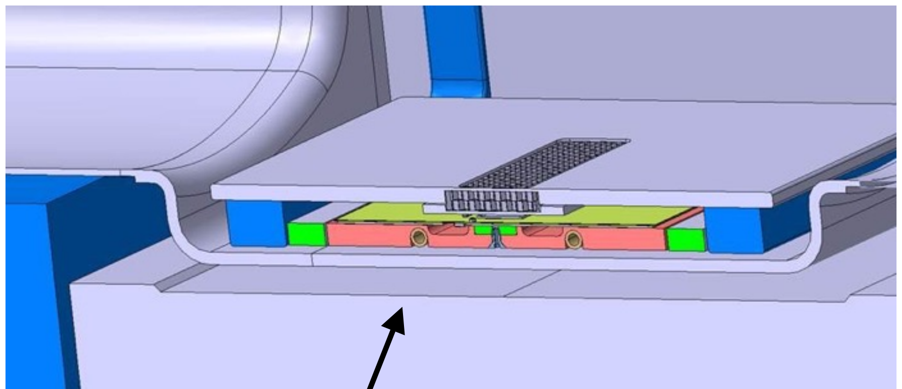
Pixel detector: Flexible cables.

- Link between the ceramic board and the electrical feedthrough.
- Impedance and differential pair skew control.
- Vacuum qualified polyamide substrate.

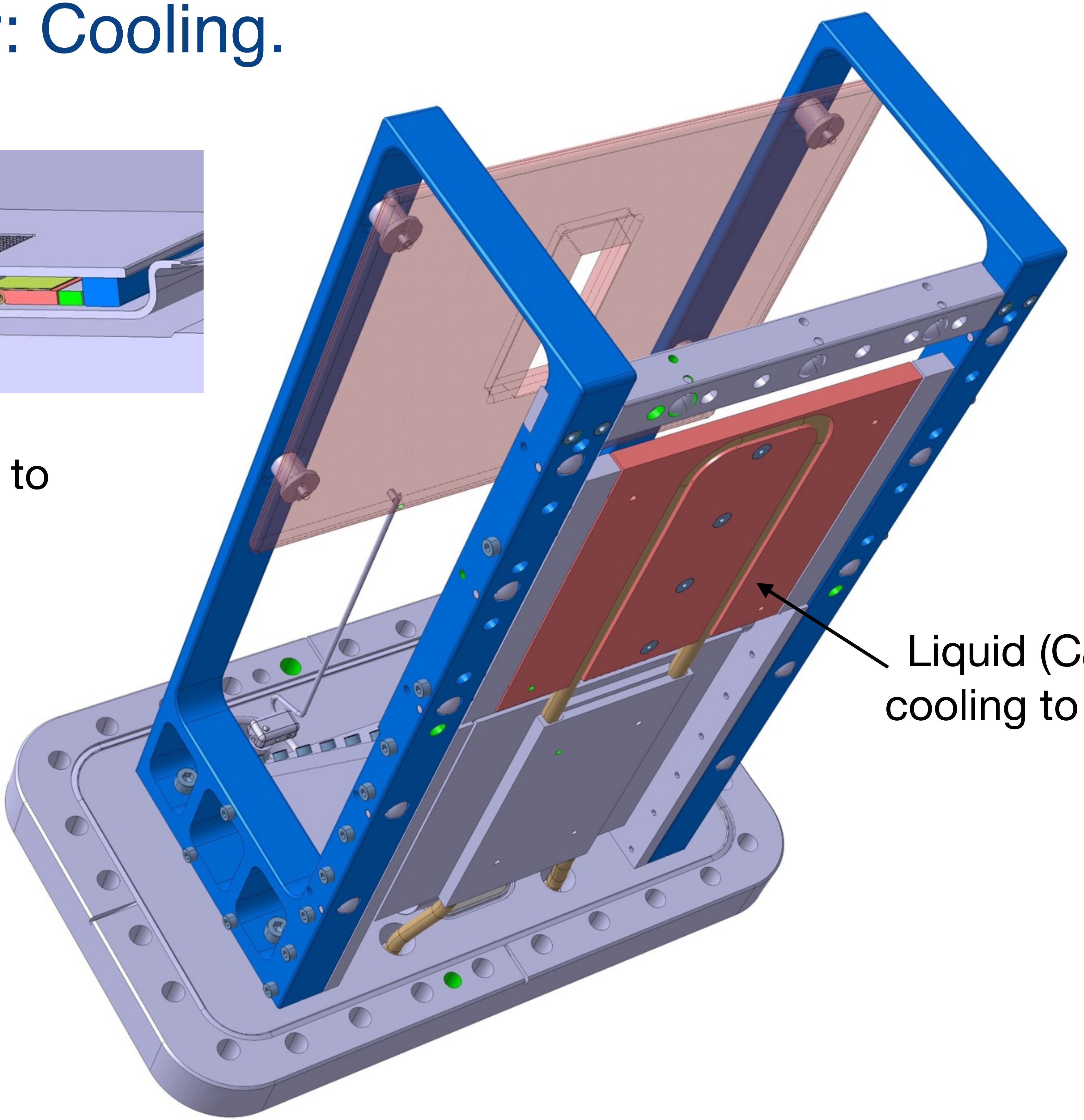




Pixel detector: Cooling.

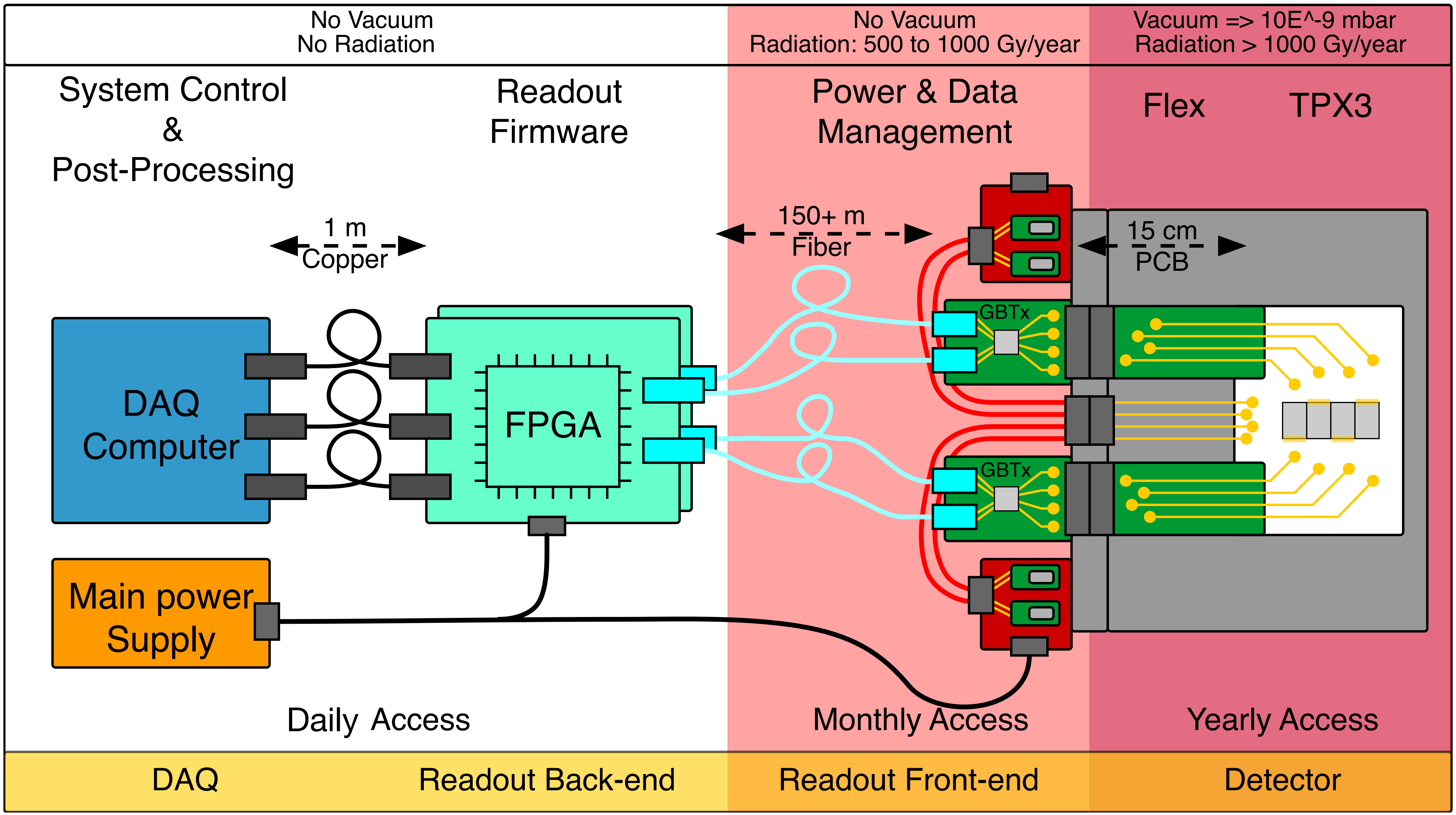


Ceramic brazed to copper.



Liquid (C_6F_{14}) cooling to 0 °C.

Readout architecture: Long term.



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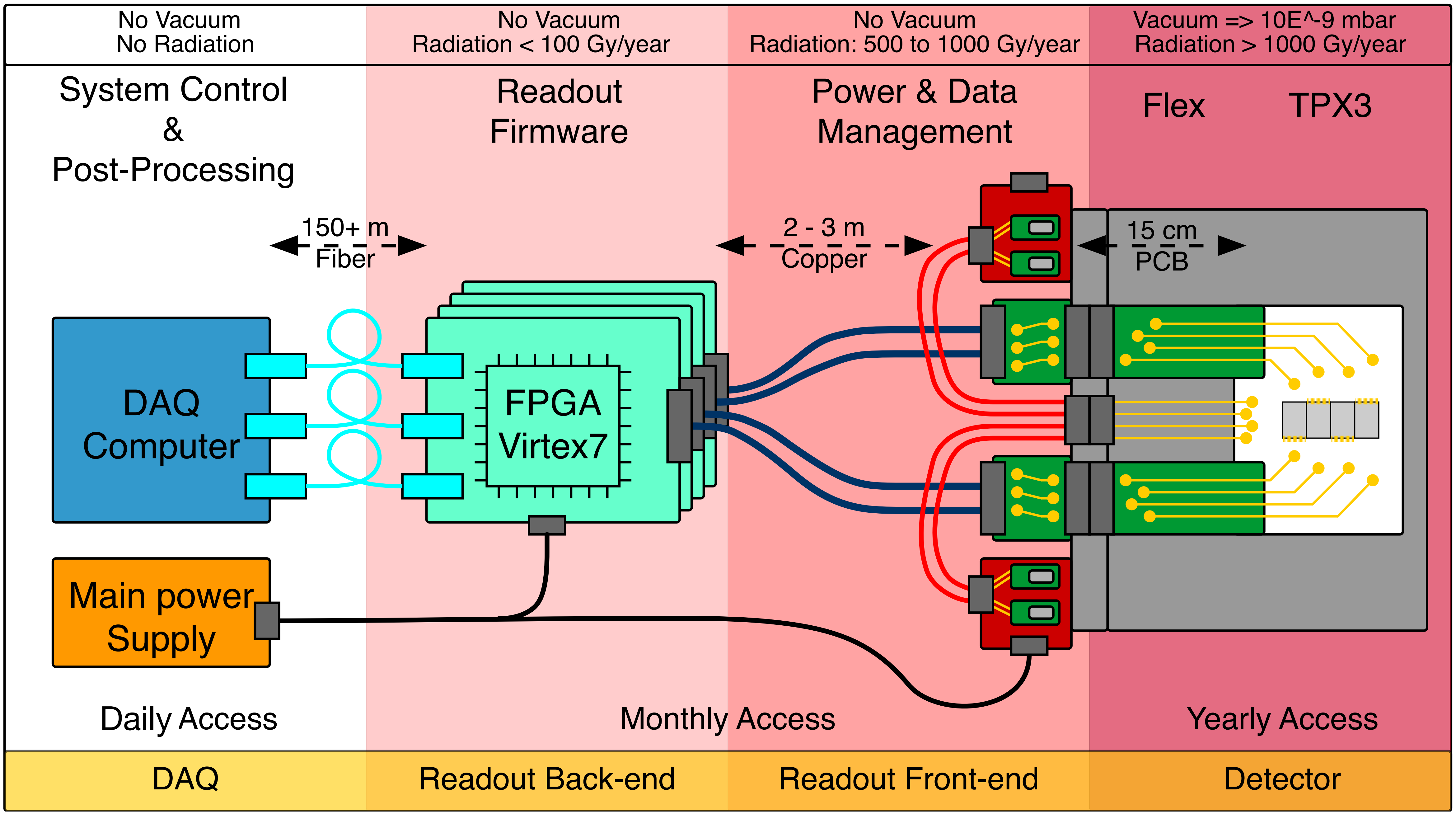
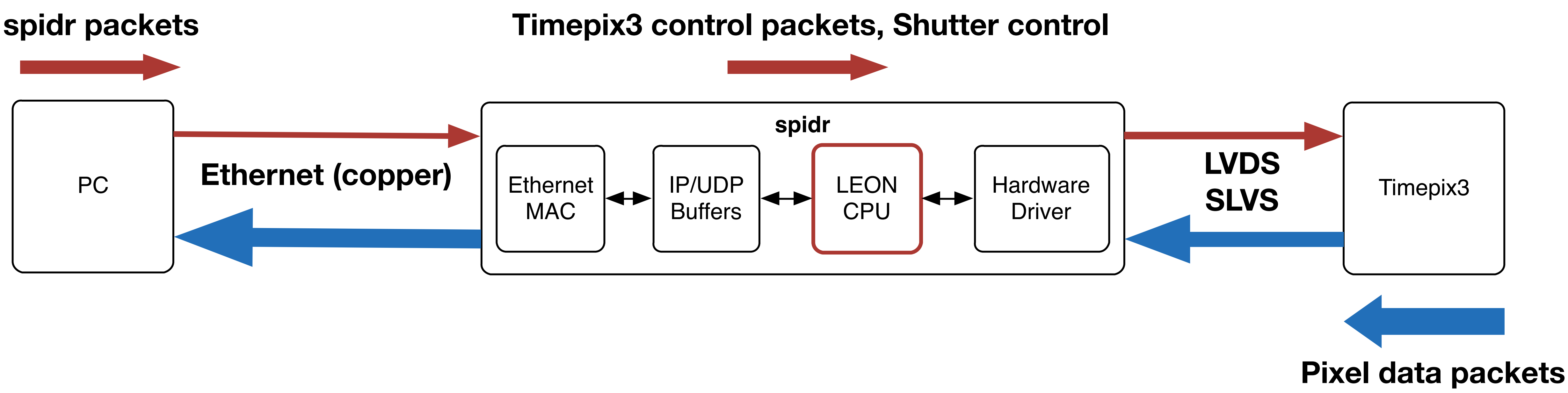
Readout architecture: For 2016 prototype tests.



Pixel detector readout firmware.

SPIDR firmware (NIKHEF):

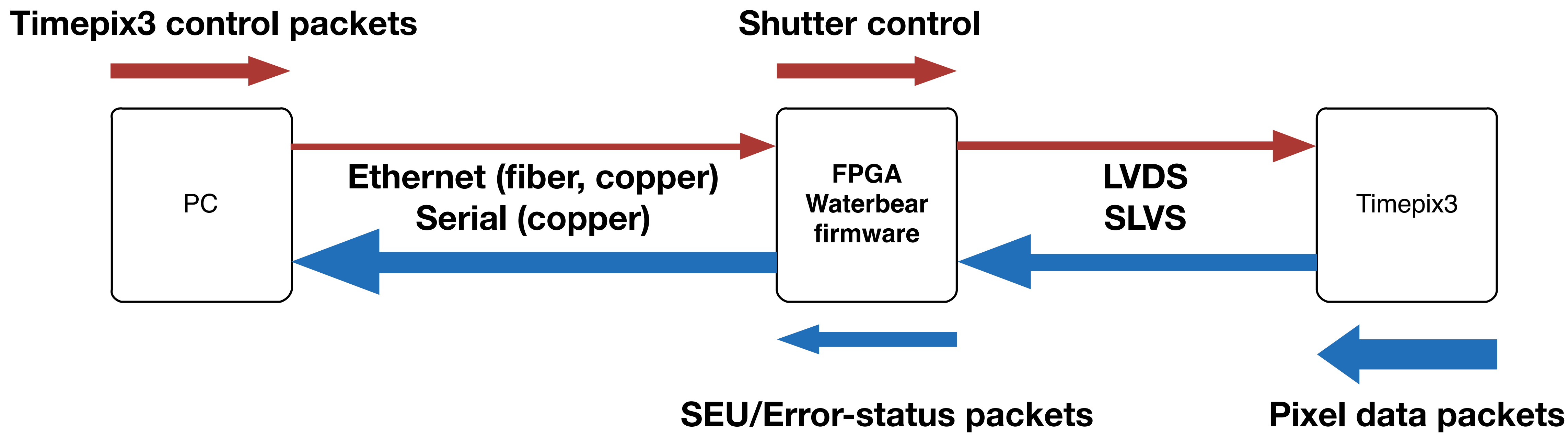
- General purpose readout system for all Medipix / Timepix chips,
- Not designed for operation in radiation environment,
- No GBTx support.



Radiation tolerant readout firmware for Timepix3.

Create Timepix3 control packets directly in the PC (not the FPGA).

FPGA firmware:
- Routes packets to the Timepix3 chips,
- Triplicates logic to mitigate SEUs.

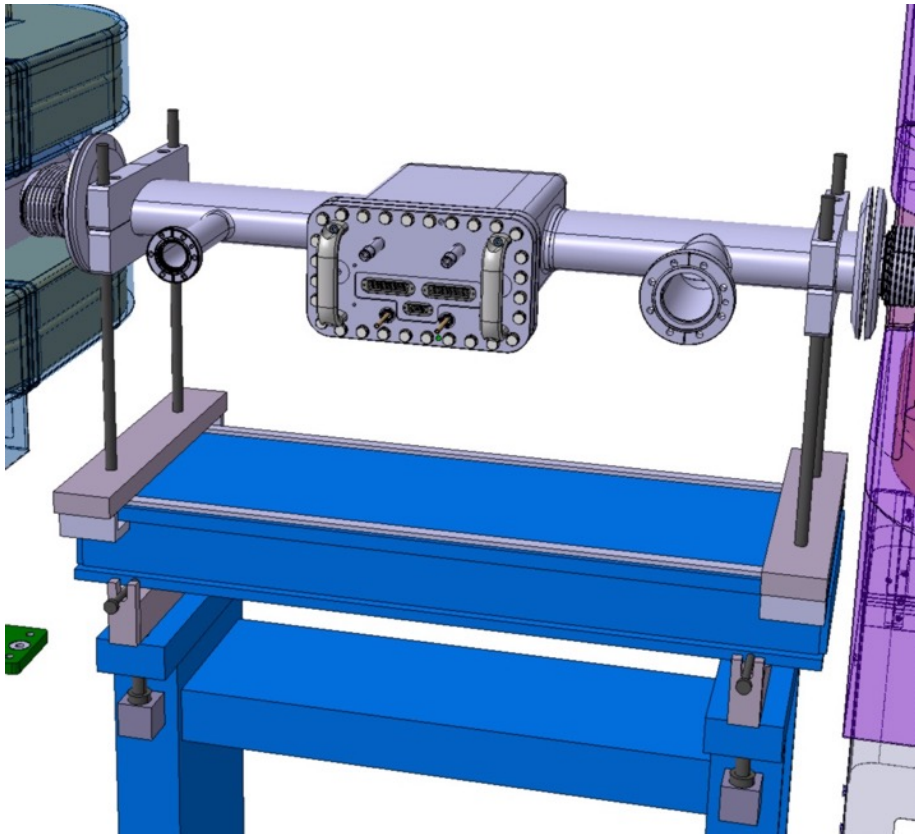


Outlook & Summary.

Pixel detector based IPM offers the potential for:
- bunch-by-bunch and turn-by-turn measurement of the beam size,
- an MCP free instrument.

Key developments:
- pixel detector readout electronics,
- complete IPM simulation.

Installation of prototype device in June 2016 technical stop.

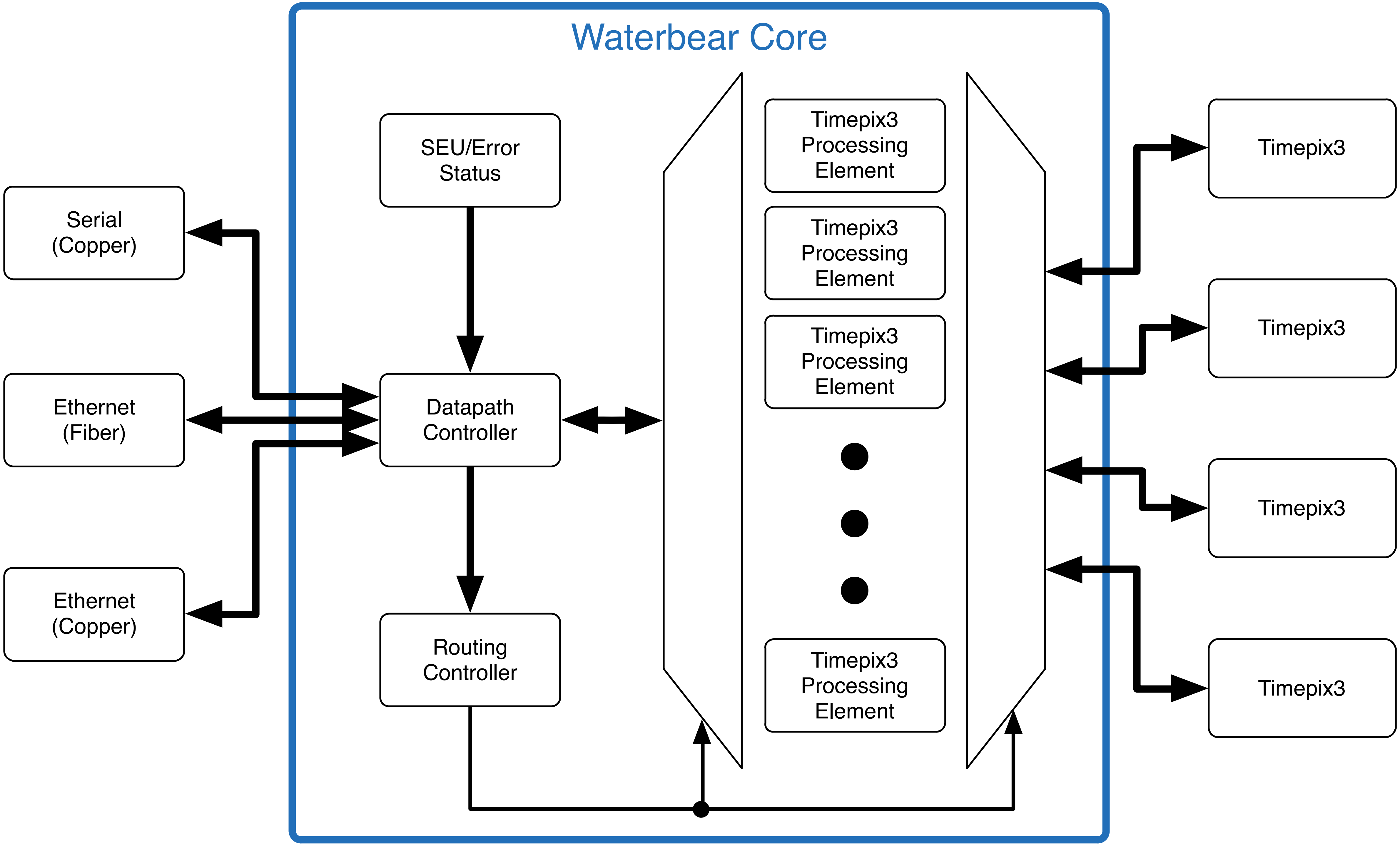


Objectives:
- Gain experience with pixel detector in beam environment.
- Quantify number of ionisation & background electrons.

Thanks!

Spare Slides.

Radiation tolerant firmware.



New triplet magnet design.