# The ATAR baseline design
# what we have, what's missing

## PIONEER Collaboration meeting

### University of Washington, Oct. 16-18, 2023

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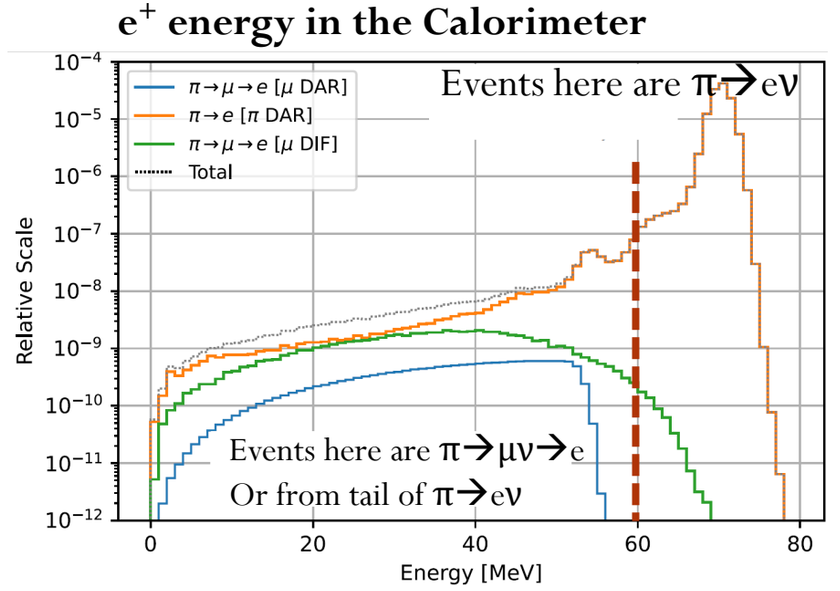
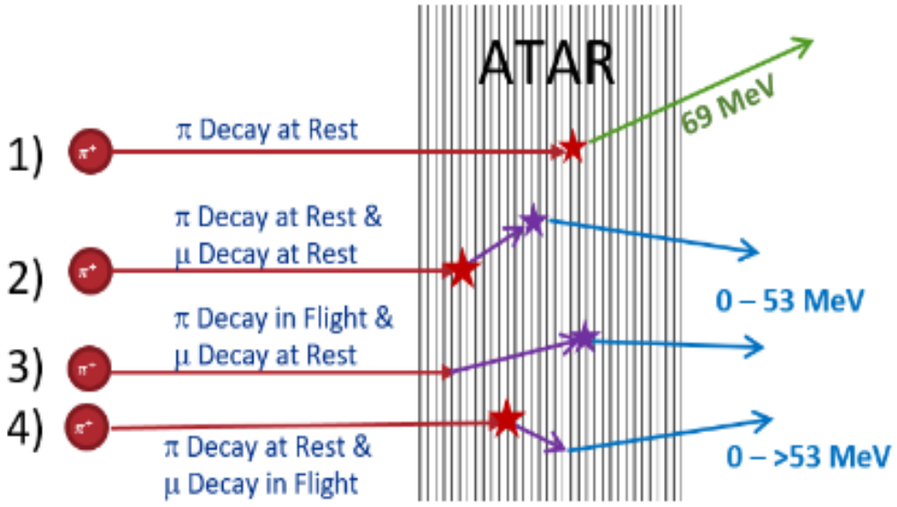
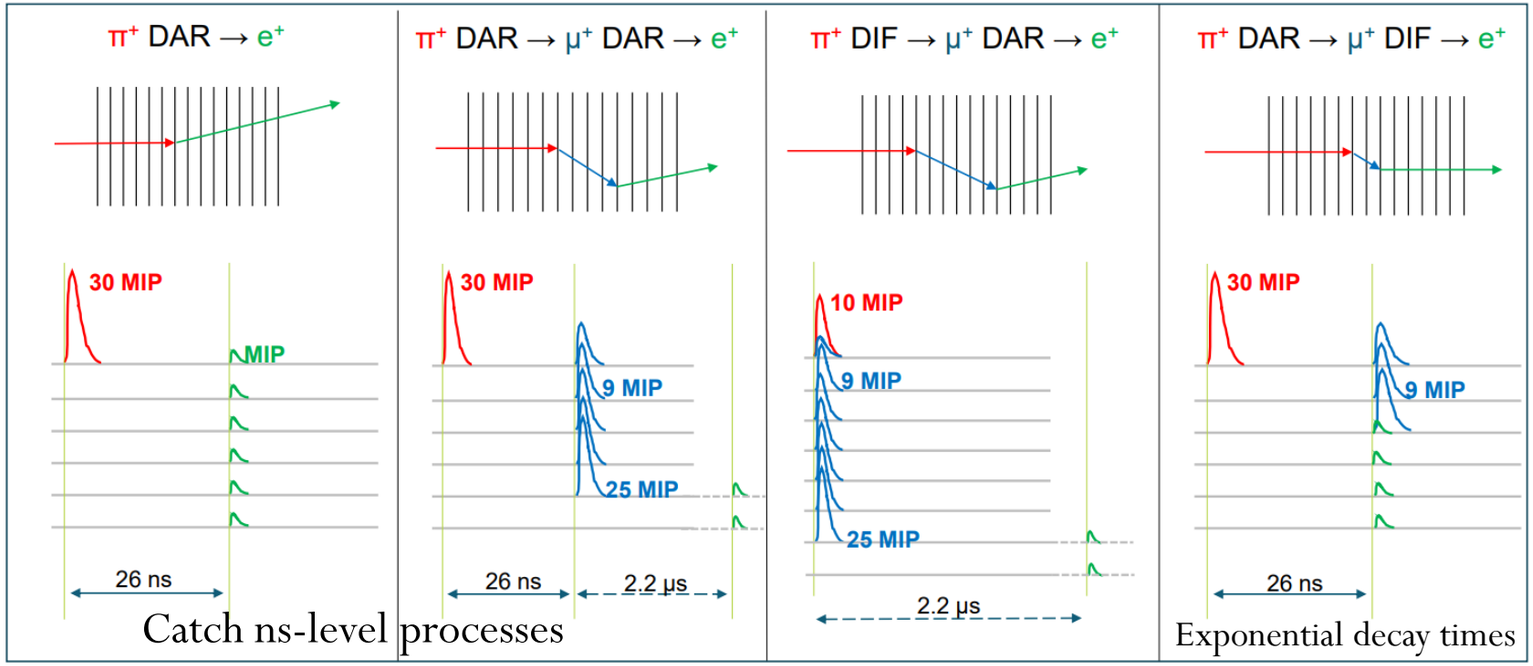
# What do we need the ATAR for

- **Goal: measure spectra of π→eν and π→μν→eννν**
  - Tail (0 → 70MeV) fraction measurement
  - Determine acceptance between π→eν and π→μν→eννν
- Readout is with fast electronics and fully digitized:
  - Highly granular hit position, time and energy
  - Advanced recognition of pions/muons/electrons
- **Need complex event reconstruction**





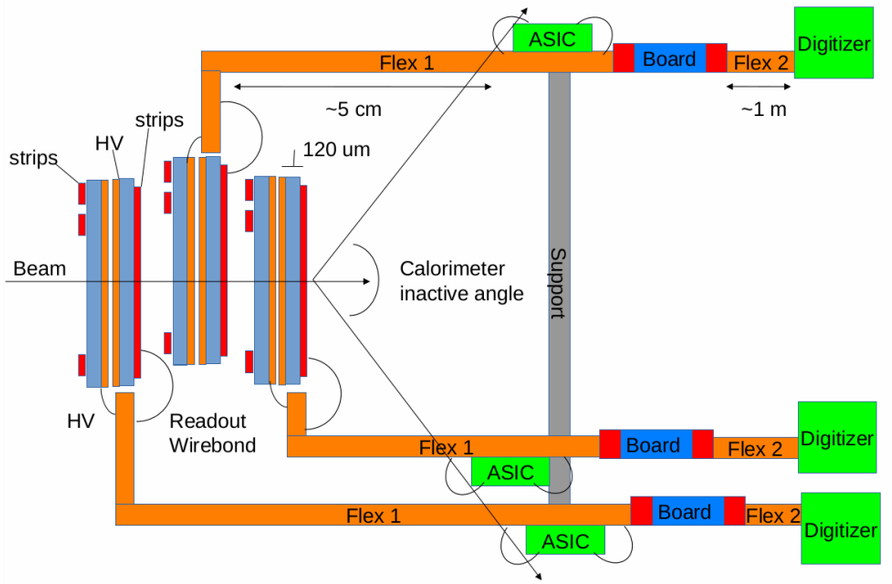

https://indico.cern.ch/event/1175216/contributions/5064176/ https://indico.cern.ch/event/1175216/contributions/5064175/

# Current ATAR design

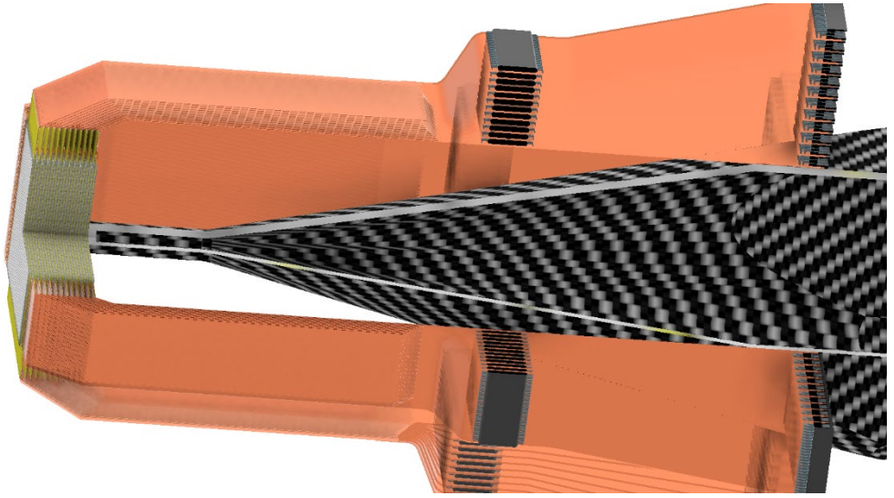
- ATAR is a full silicon active target: 2x2 cm area 5.76 mm thick
  - Very dense detector with high granularity
- Sensor: single sided high-granularity LGAD strips
  - AC-LGADs or TI-LGADs
  - Alternatives: silicon PiN sensor and/or double-sided readout sensors (see next talk!)

- **ATAR initial design**
  - **48 layers of 120um thick LGADs**
  - 100 strips, 2 cm length, with 200 um pitch (2x2 cm area)
  - Gap between layers crucial for muon ID, as low as possible
- Readout flexes on the four sides bringing signal to a fast amplifier
  - Depending on the final structure sensors can be directly mounted on a board
- The **ATAR signals will be fully digitizer** in a region of interest (ROI, temporal or spatial) for each event

ATAR concept



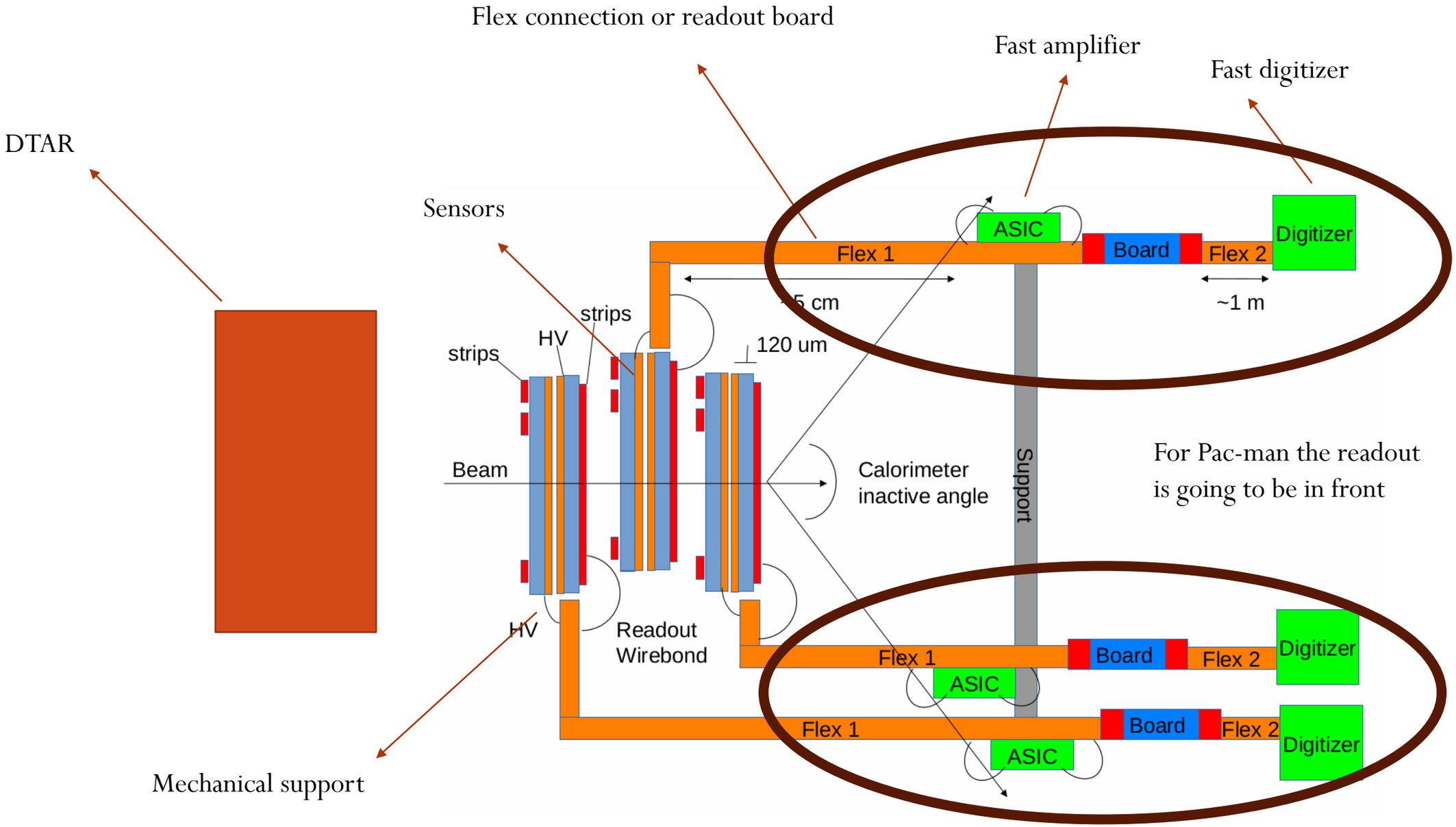

ATAR mechanical drawing



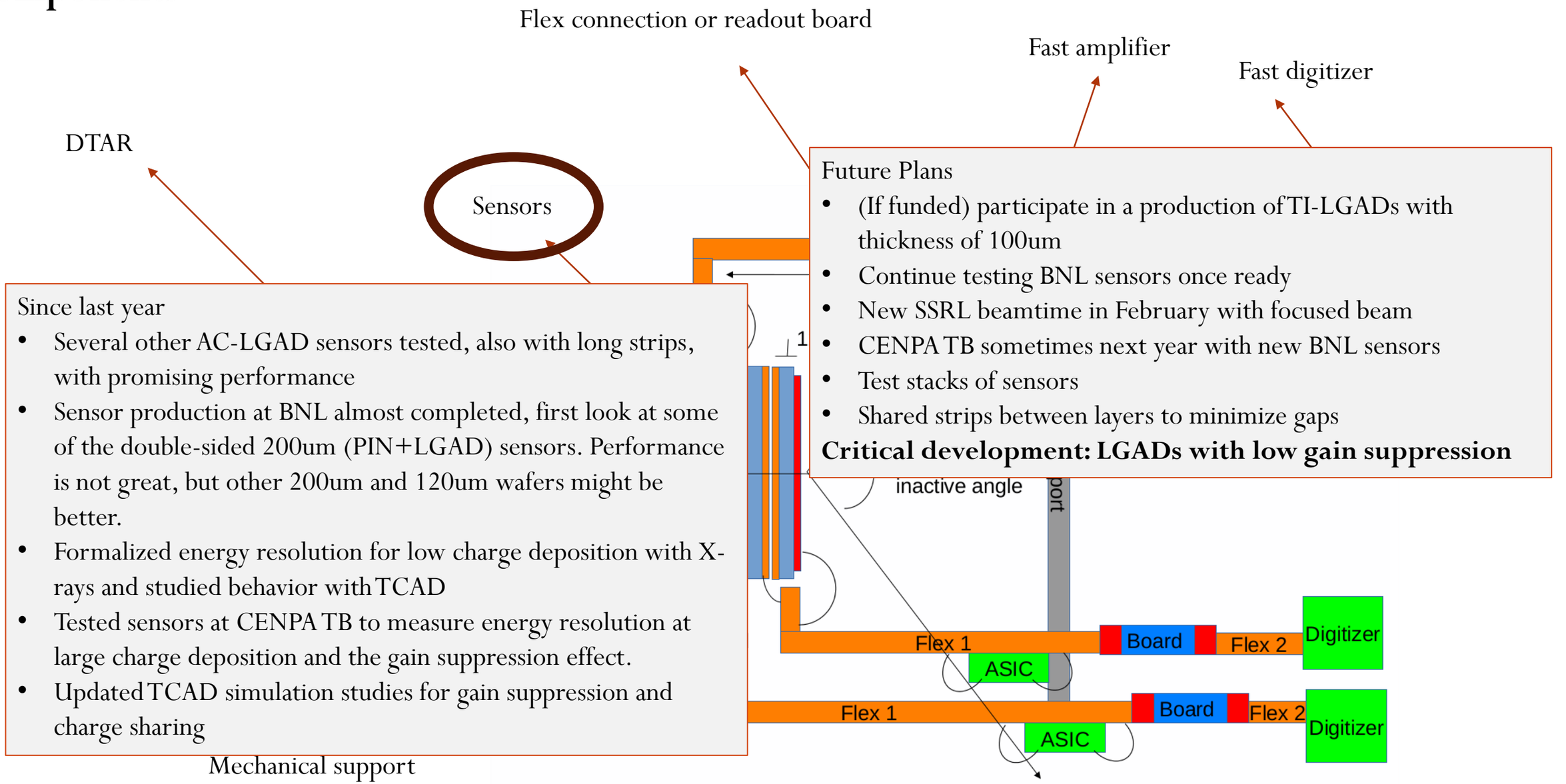
# ATAR performance requirements

- **Recognize hits that are few ns apart** with very different deposited energy
  - To detect pion/muon DIF events
- **High spatial granularity in X/Y/Z**
  - To detect muon track and event topology
- **Full digitization: good energy resolution and linearity on the hits**
  - Able to recognize pions/muons deposits and measure the energy lost by positrons in the ATAR
- **Low material around ATAR**
  - To reduce impact on positron energy
- **Amplifier and digitizer with large dynamic range**
  - Measure MiP and non-MiP events → reduce cross talk to avoid non-MiP events covering MiP events
- **Minimize blind regions and dead regions** in between layers
  - To avoid missing muon detector
- **Complex trigger scheme** to be interfaced with global trigger
  - To take good data with a reasonable frequency

# Components


Flex connection or readout board
Fast amplifier
Fast digitizer
DTAR
Sensors
ASIC
Board
Flex 1
Flex 2
Digitizer
~1 m
strips
HV
strips
120 um
Beam
Calorimeter
inactive angle
Support
For Pac-man the readout
is going to be in front
HV
Readout
Wirebond
Flex 1
Board
Flex 2
Digitizer
ASIC
Flex 1
Board
Flex 2
Digitizer
ASIC
Mechanical support

# Components




Since last year

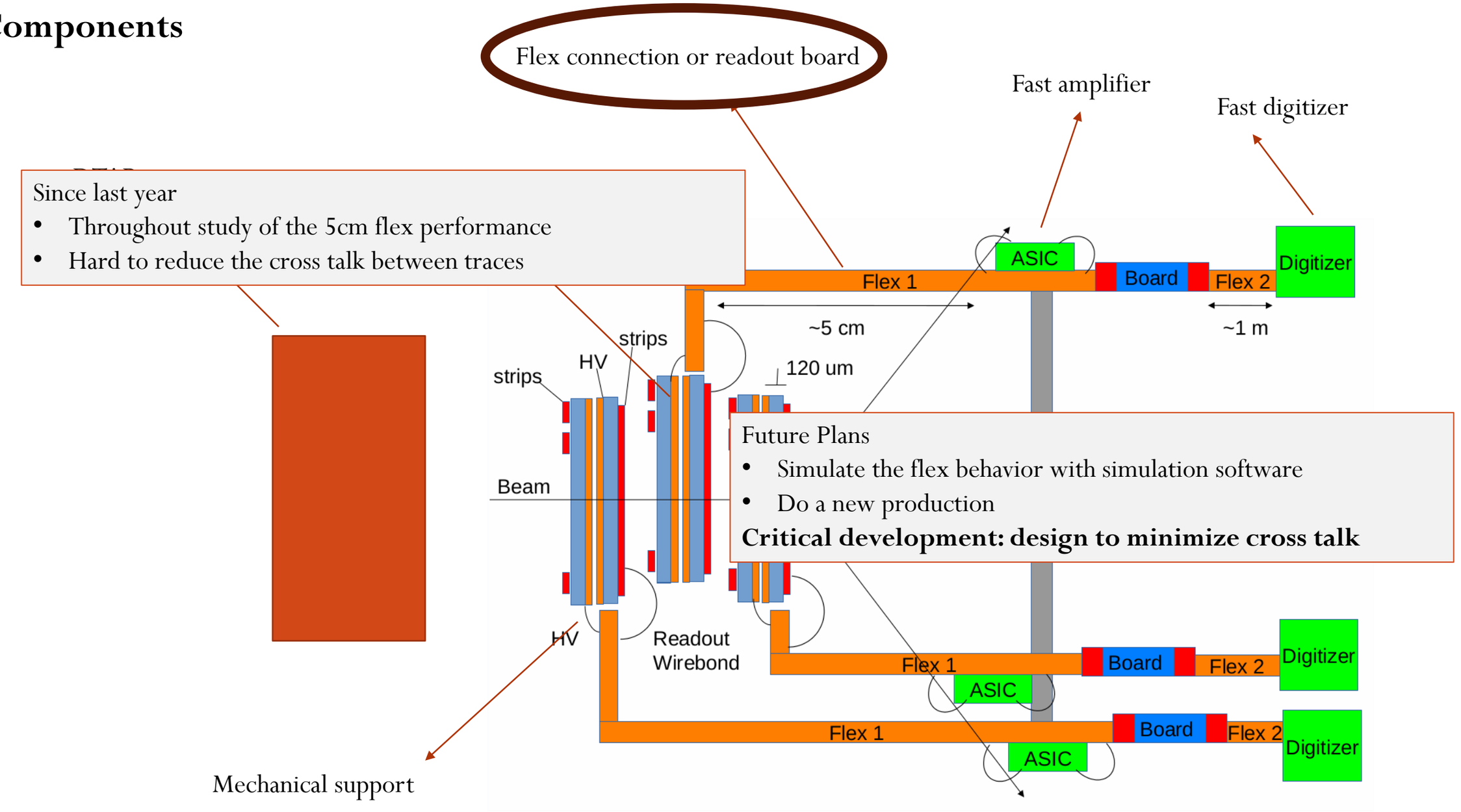
- Several other AC-LGAD sensors tested, also with long strips, with promising performance
- Sensor production at BNL almost completed, first look at some of the double-sided 200um (PIN+LGAD) sensors. Performance is not great, but other 200um and 120um wafers might be better.
- Formalized energy resolution for low charge deposition with X-rays and studied behavior with TCAD
- Tested sensors at CENPA TB to measure energy resolution at large charge deposition and the gain suppression effect.
- Updated TCAD simulation studies for gain suppression and charge sharing

Future Plans

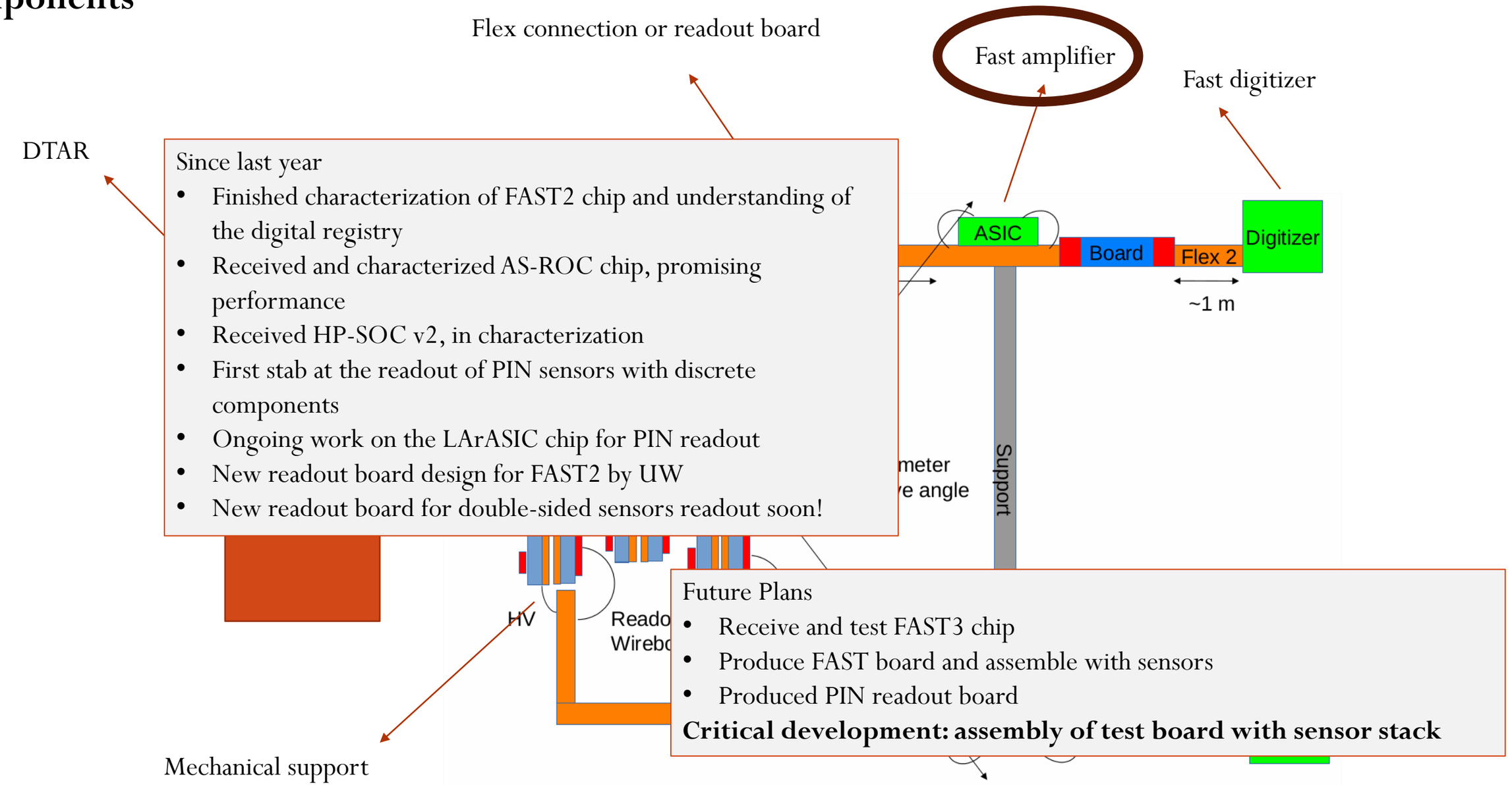
- (If funded) participate in a production of TI-LGADs with thickness of 100um
- Continue testing BNL sensors once ready
- New SSRL beamtime in February with focused beam
- CENPA TB sometimes next year with new BNL sensors
- Test stacks of sensors
- Shared strips between layers to minimize gaps

**Critical development: LGADs with low gain suppression**

# Components


Flex connection or readout board
Fast amplifier
Fast digitizer
Since last year
• Throughout study of the 5cm flex performance
• Hard to reduce the cross talk between traces
ASIC
Board
Flex 1
Flex 2
Digitizer
~5 cm
~1 m
strips
HV
strips
120 um
Beam
Future Plans
• Simulate the flex behavior with simulation software
• Do a new production
Critical development: design to minimize cross talk
HV
Readout
Wirebond
Flex 1
Board
Flex 2
Digitizer
ASIC
Flex 1
Board
Flex 2
Digitizer
ASIC
Mechanical support

# Components




Since last year

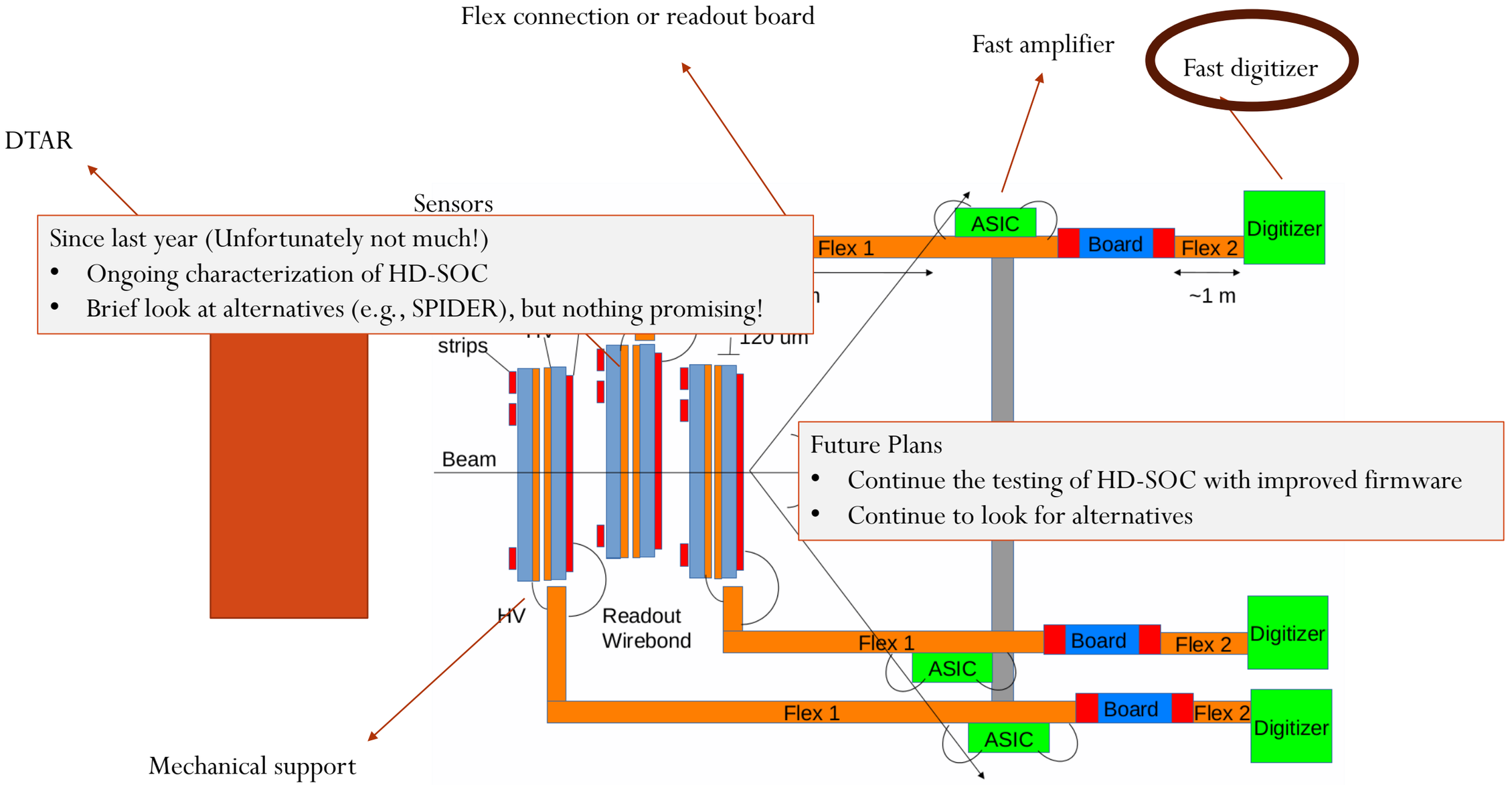
- Finished characterization of FAST2 chip and understanding of the digital registry
- Received and characterized AS-ROC chip, promising performance
- Received HP-SOC v2, in characterization
- First stab at the readout of PIN sensors with discrete components
- Ongoing work on the LArASIC chip for PIN readout
- New readout board design for FAST2 by UW
- New readout board for double-sided sensors readout soon!

Future Plans

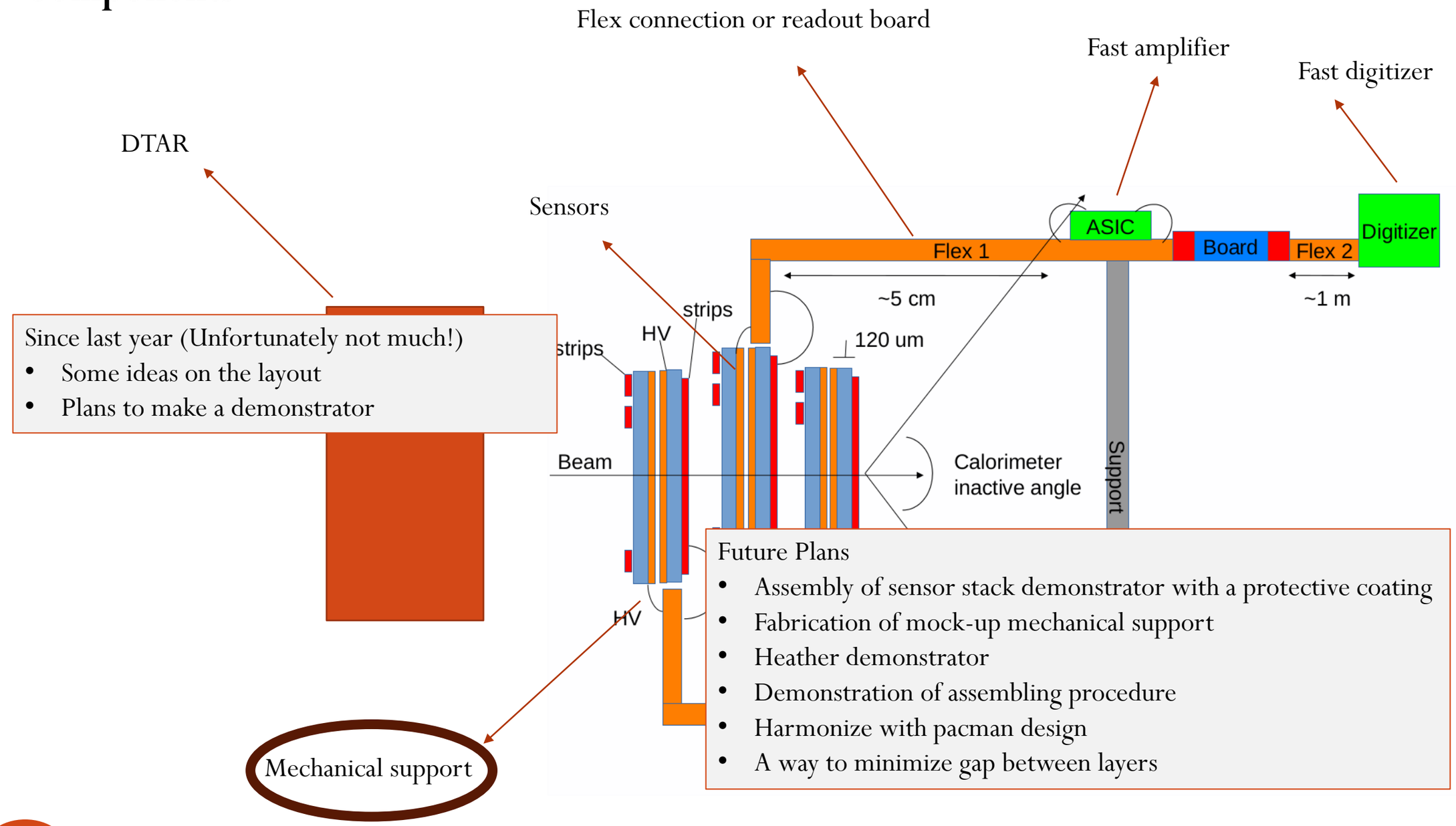
- Receive and test FAST3 chip
- Produce FAST board and assemble with sensors
- Produced PIN readout board

**Critical development: assembly of test board with sensor stack**

# Components


Flex connection or readout board
Fast amplifier
Fast digitizer
DTAR
Sensors
Since last year (Unfortunately not much!)
• Ongoing characterization of HD-SOC
• Brief look at alternatives (e.g., SPIDER), but nothing promising!
ASIC
Board
Flex 1
Flex 2
Digitizer
~1 m
strips
120 um
Beam
Future Plans
• Continue the testing of HD-SOC with improved firmware
• Continue to look for alternatives
HV
Readout
Wirebond
Mechanical support

# Components



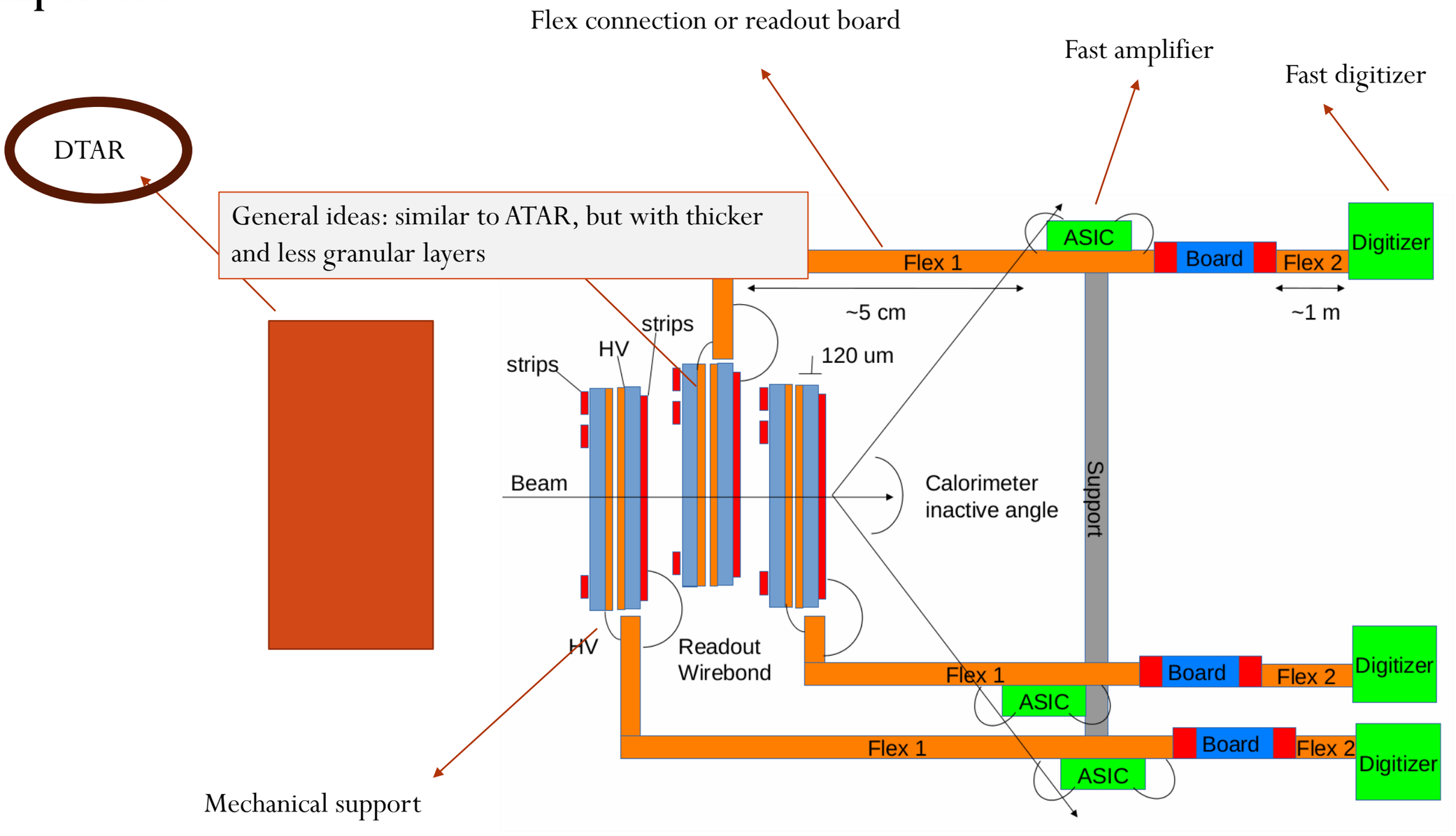

Since last year (Unfortunately not much!)

- Some ideas on the layout
- Plans to make a demonstrator

Future Plans

- Assembly of sensor stack demonstrator with a protective coating
- Fabrication of mock-up mechanical support
- Heather demonstrator
- Demonstration of assembling procedure
- Harmonize with pacman design
- A way to minimize gap between layers

# Components

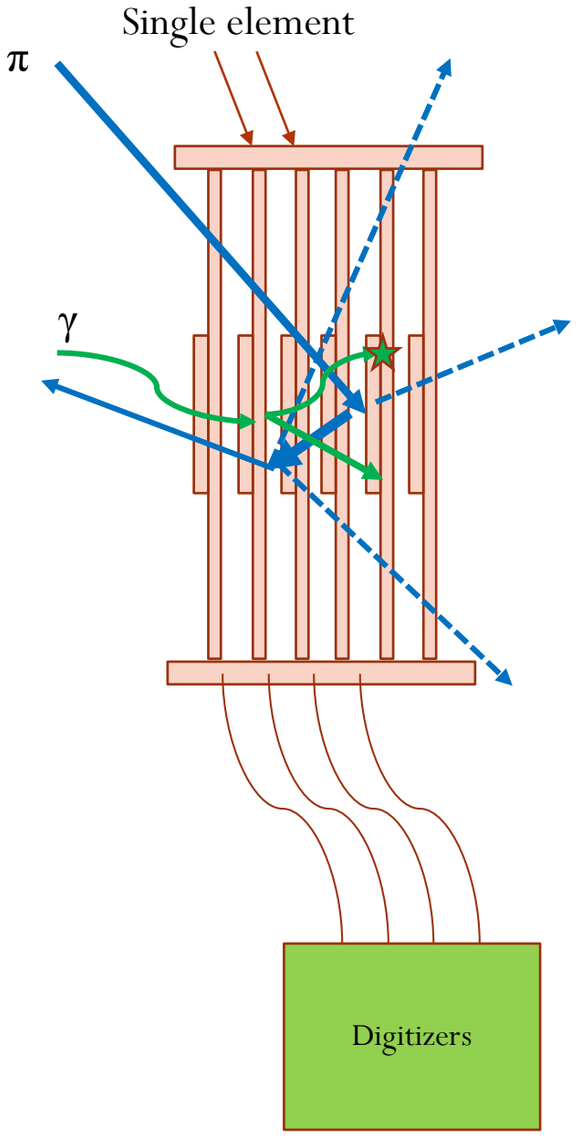

Flex connection or readout board
Fast amplifier
Fast digitizer
DTAR
General ideas: similar to ATAR, but with thicker and less granular layers
ASIC
Board
Flex 2
Digitizer
Flex 1
~5 cm
~1 m
strips
HV
strips
120 um
Beam
Calorimeter inactive angle
Support
HV
Readout Wirebond
Flex 1
Board
Flex 2
Digitizer
ASIC
Flex 1
Board
Flex 2
Digitizer
ASIC
Mechanical support

# A full 5D active target!

- PIONEER is a small experiment, to developed the needed technology we can think about **synergetic applications**

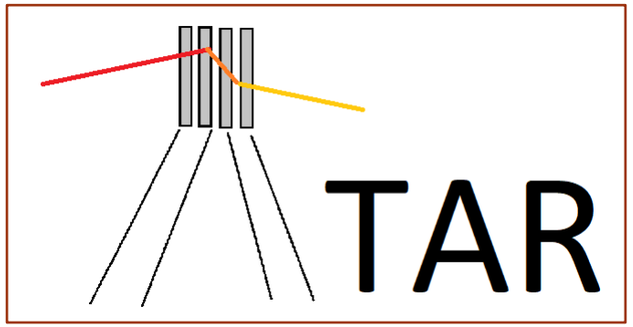
- The ATAR is being designed for PIONEER but **the single elements can be modules of a general scalable 5D active target**
  - Active elements combined to be very close together
  - Recognize hits that are few ns apart with high spatial and time resolution (4D tracking)
  - Good energy resolution on the hits (+ Energy = 5D) and large dynamic range (~1000)
  - Compact design and with minimized blind regions
- Others are producing a similar device (SMX) but our device is much more sophisticated!

- **Applications of a 5D tracking modular system** would be immediate
  - **Straightforward upgrade of dozens of test-beam facilities around the world**, also useful in laboratory applications
  - **Photon science** (X-ray diffraction and imaging, Compton scattering), fast repetition rate and enough absorption
  - **Live decay detection** in nuclear physics experiments
  - **Pair telescopes**, like the NASA Fermi telescope, to replace cross-strip Si detectors
  - **Medical science** applications

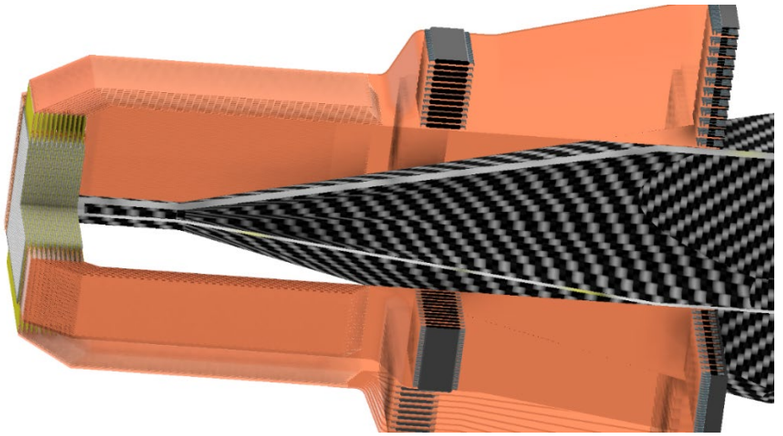


# Conclusions

- PIONEER's active target (ATAR) **is a very ambitious detector**
  - High granularity, high density and good timing capabilities
  - Need large dynamic range and good energy resolution
- **Many challenges still need to be solved**
- 2-3 current design
  - All have pros and cons and are not straightforward




- Short range plan is to have a working **ATAR prototype in a couple years** to study pion/muon decays at PSI



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# Thank you