PIONEER collaboration meeting June 2024

ATAR session

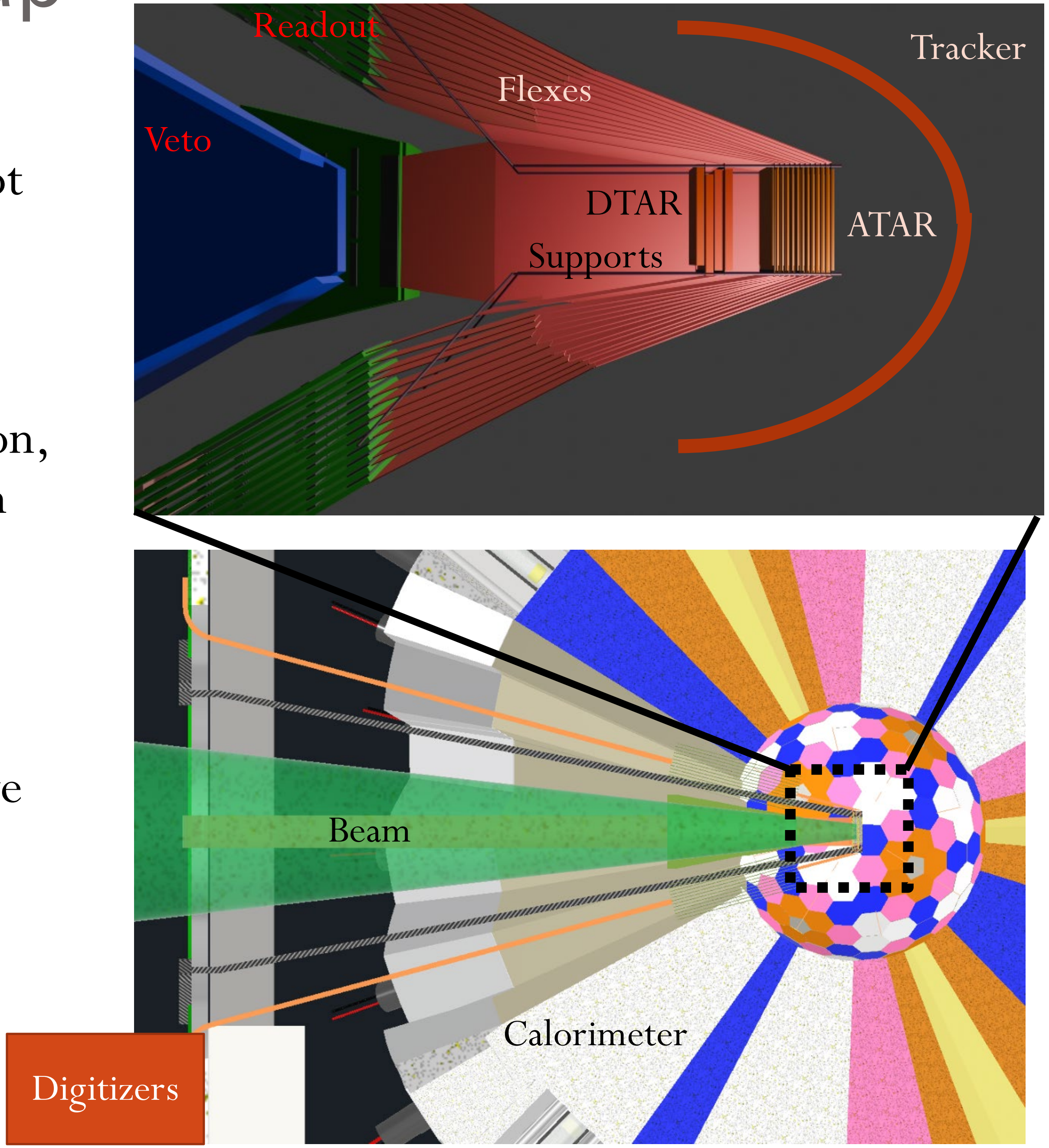
Dr. Simone M. Mazza (UCSC) for the ATAR group

CENPA, Seattle

PIONEERS's target region – a recap

- PIONEER's target region is composed by
  - **Veto** counter, negating particles going to the calorimeter not passing through the active region
  - **DTAR** (Degrader TARget), slows down Pions, made of few thick active layers
  - **ATAR** (Active TARget), high granularity and timing precision, detects pion decay mode via topology and energy deposition
  - **Tracker** to track exiting positrons into the Calorimeter

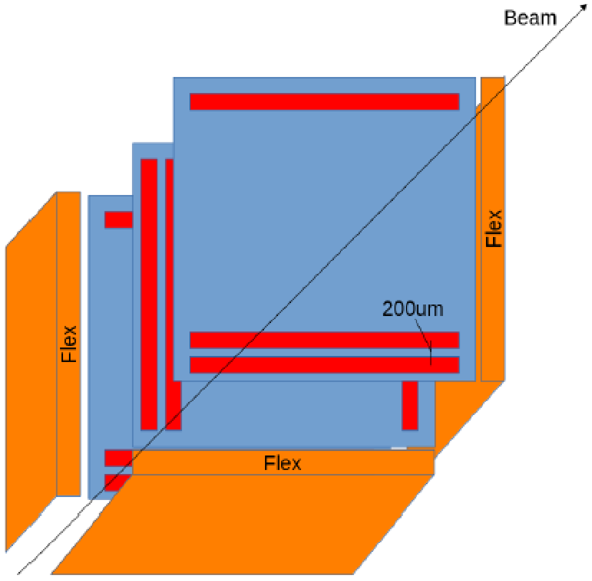
- DTAR and ATAR are supported by rods and frames
  - Read out through flexes that bring the signal out of the active region
  - Readout chip in boards outside of the active region
  - Digitizers outside of the Calorimeter region



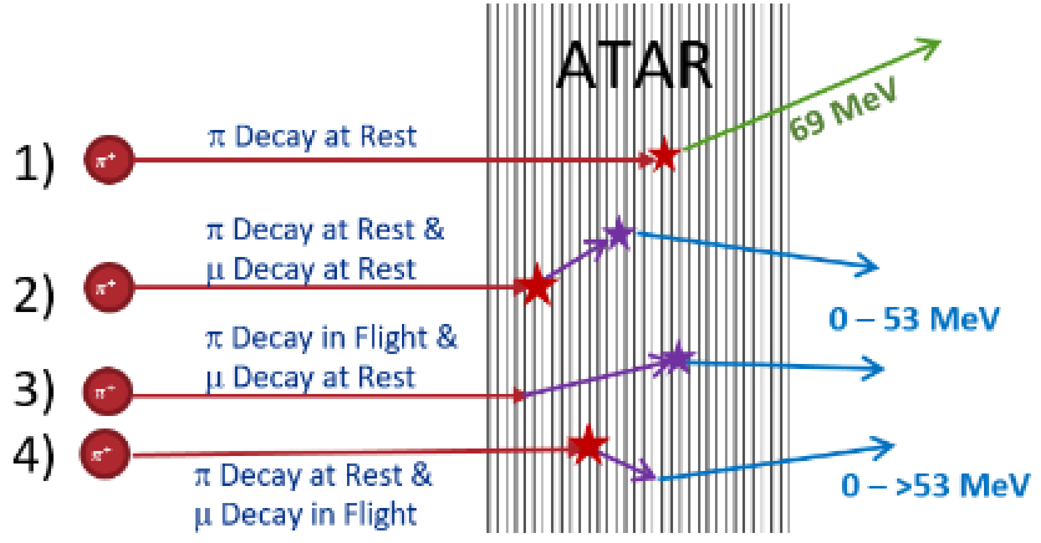
Dr. Simone M. Mazza - University of California Santa Cruz

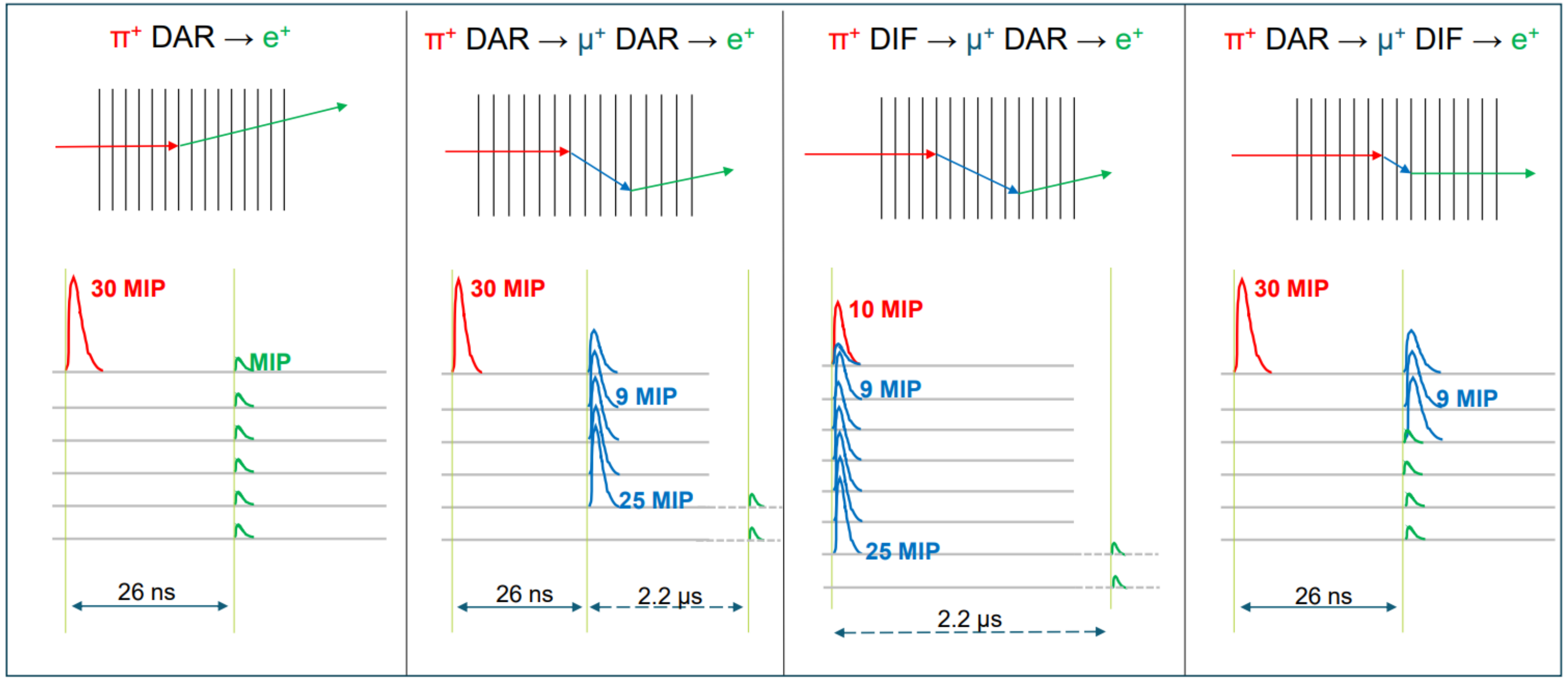
PIONEERS's ATAR current 'baseline' design

- The ATAR provides Advanced de-convolution analysis can identify pulses close in time
  - Detect and identify π→eν and π→μν→eνν and π or μ decay in flight
- The chosen device for the ATAR is an LGADs high granularity technology (AC-LGADs or TI-LGADs)
  - Baseline design: 48 layers of 120um thick 2x2 cm LGADs
  - Strip detectors with pitch of 200um with alternating strip orientation
  - Each plane has an offset to allow connection with the readout flex (connected with either wire bond or spTAB)
- Readout FAST3 chip (INFN Torino) and digitization HD-SOC (NALU scientific)



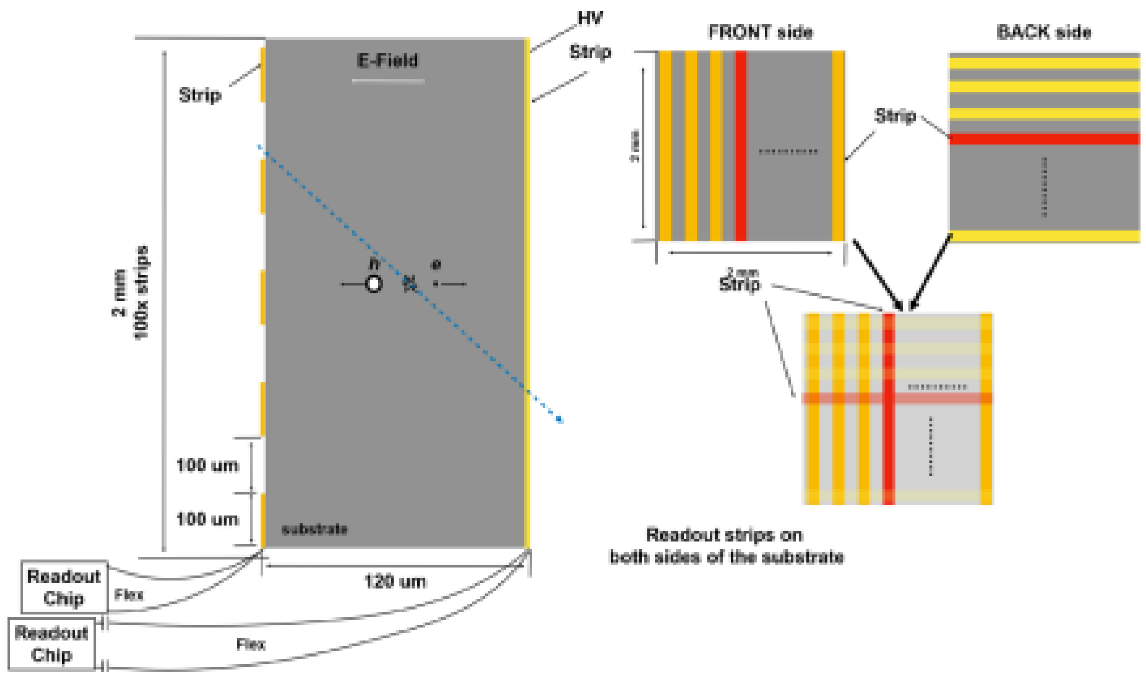
What happens ↔ **What is measured**





Alternative ATAR designs

- **Alternative sensor design**: double sided detector with AC strips on one side and DC perpendicular strips in the other
  - Better tracking (X-Y position information) and better energy reading from DC-pads
  - Channel density might be too high (need 2x channels)
- **Alternative detector design with PiN** (no gain)
  - Same geometry but based on PiN silicon sensors
- Being developed at BNL, first prototype sensors in testing



Pros

- PIN is known to be **linear** in energy response to energy deposition from 1 to 100 MIP
  - Excellent stopping π/μ separation
- With the charge collection signal, much easier to calibrate the energy response (**uniform, stable and topology independent**)

Cons

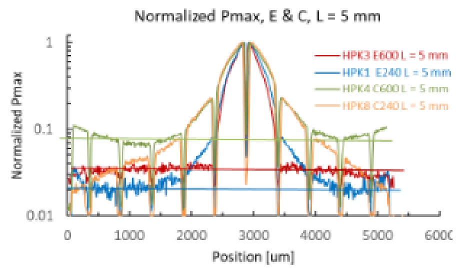
- Need a working design of **pre-amp electronics to achieve > 9:1 signal-to-noise ratio for MIP signal, which requires more power**
  - With FAST, the S/N ~ 5:1 for MIP signal
  - Also have impact in timing resolution (to be elaborated in details)

https://indico.cern.ch/event/1175216/contributions/5064174/attachments/2524418/4341713/Alternative_Design_ATAR.pdf

ATAR's ongoing R&D - Sensors

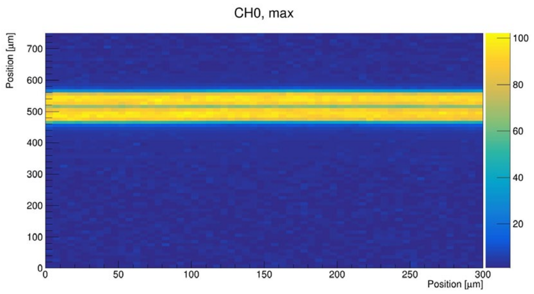
- Testing of **HPK AC-LGAD prototypes** showing a reduced charge sharing profile (https://indico.cern.ch/event/1184921/contributions/5574830/)
- Testing of **FBK TI-LGAD prototypes**
  - Waiting for some samples from AIDA run, thicker (100 um) run ongoing
- A **first prototype sensor production** of double-sided strip sensors was completed at BNL and is currently under test
- Characterization of thicker LGADs from FBK (100um, 150um)
- **LGAD gain saturation** was studied with ions at the CENPA Tandem accelerator, results show substantial gain saturation for initial prototypes (https://indico.cern.ch/event/1184921/contributions/5574780/)
- **LGAD energy resolution** measured in the SSRL X-ray beam line. It ranges from 8-15% but it is higher with AC-LGAD prototypes (up to 25%) (https://dx.doi.org/10.1088/1748-0221/18/10/P10006)
- <u>LGAD energy response (resolution/saturation) is a big challenge!</u>
  - <u>PIN option requires a different readout chip to achieve the S/N</u>

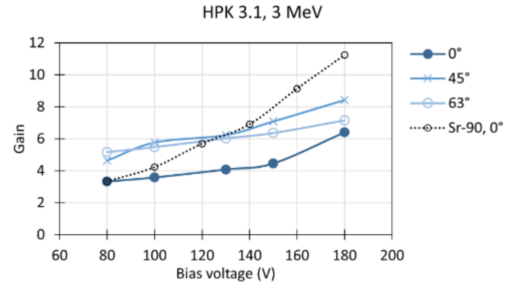
HPK AC-LGADs



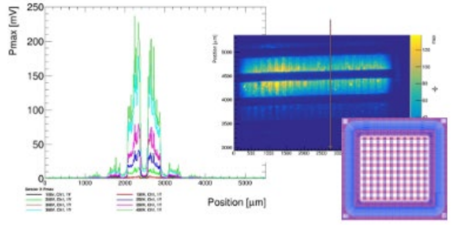
(d) Charge sharing profile for several new HPK strip AC-LGAD (thickness 50 um)

FBK TI-LGADs



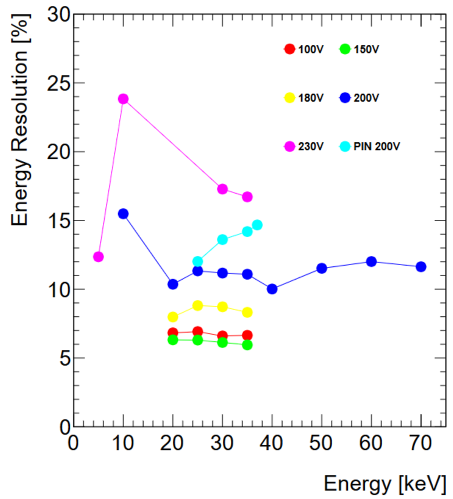


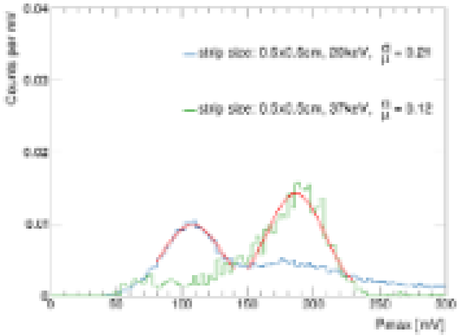
Gain suppression with 3MeV protons



(a) Laser tests done on BNL double-sided sensor production

Double-sided sensor tests

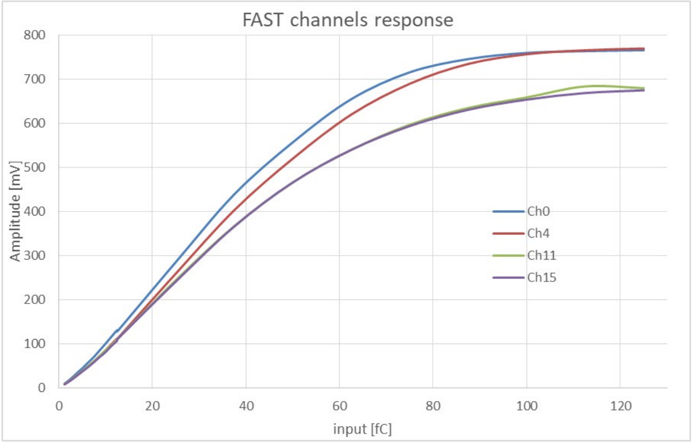


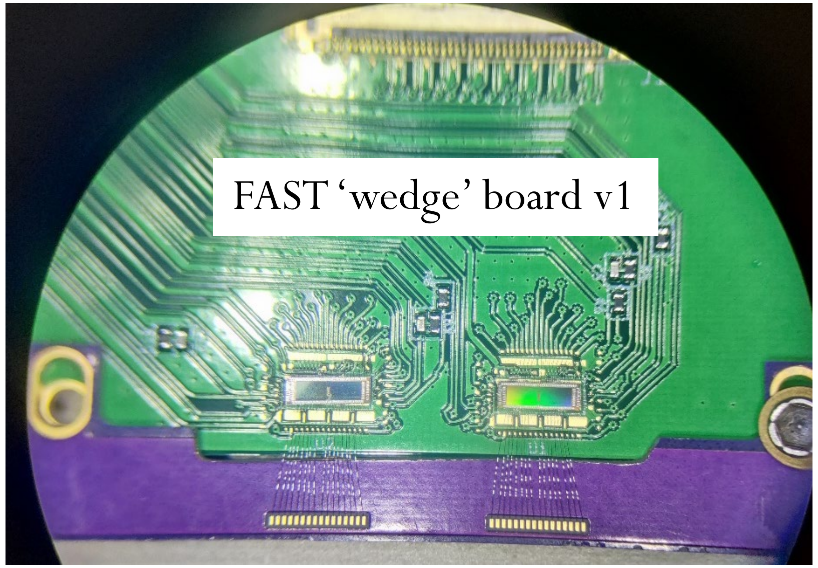


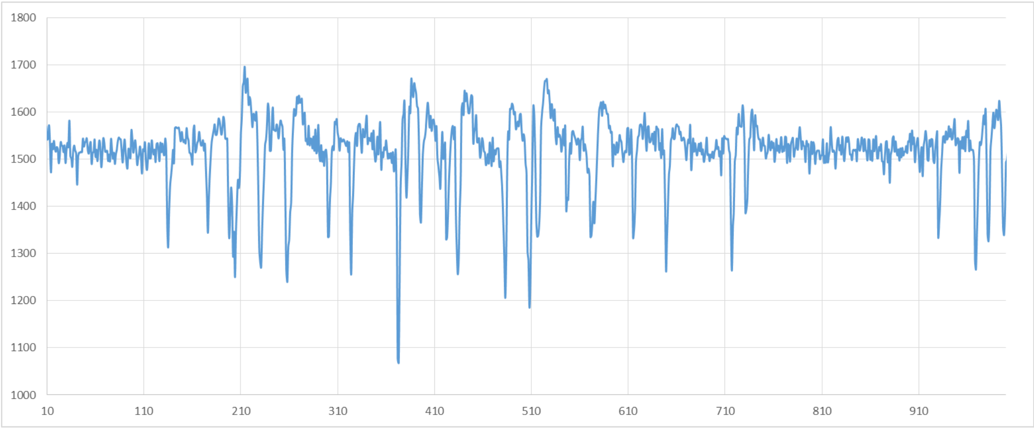
(c) Energy resolution of X-rays for strip AC-LGADs

ATAR’s ongoing R&D - Electronics

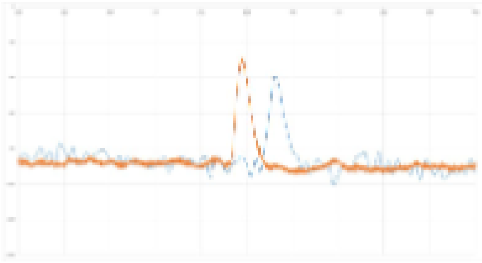
- **Characterization of FAST** chip and AS-ROC alternative chip (https://indico.cern.ch/event/1255624/contributions/5445271/)
  - FAST3 shows great dynamic range!
- Finished development of a discrete component low-noise PIN readout board for PIN alternative
- Ongoing characterization of **HD-SOC digitizer** and an alternative SAMPIC digitizer
- **Fabrication of the FAST “wedge” board** and characterization of FAST3 with LGAD prototypes.
- Fabrication and characterization of flexes for high bandwidth signal transmission
- <u>Dynamic range and cross talk is a big challenge (combination of MIP hits and up to 50-100x MIP hits)</u>
  - <u>Also ability to digitize continuously or have a smart triggering scheme for the digitizer</u>



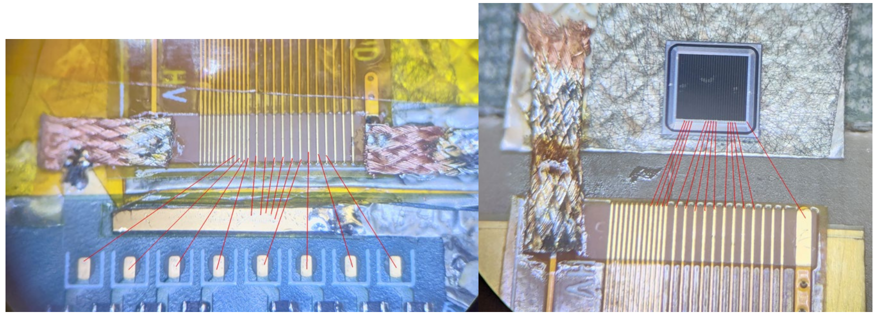




Pulse train taken at SSRL with LGAD+FAST3+HD-SOC



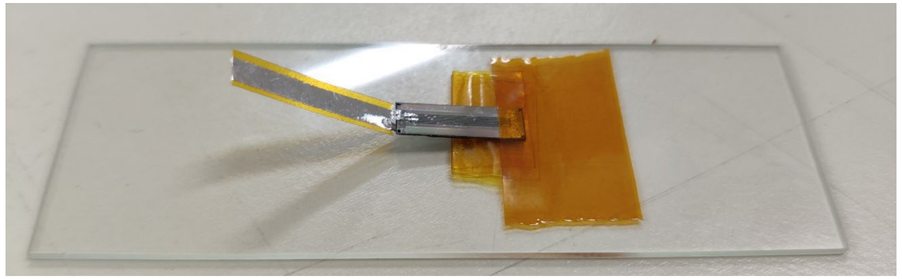
(f) FAST2 pulse with Oscilloscope (orange) and HD-SoC (blue)

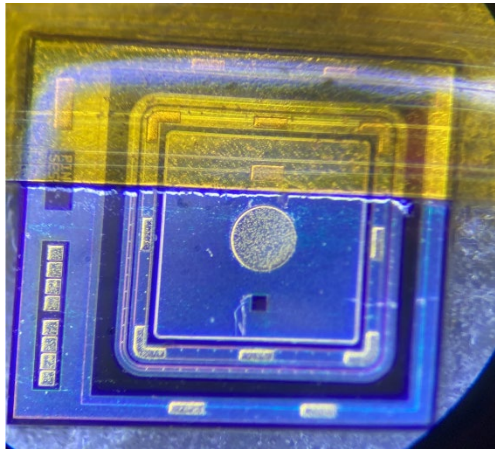


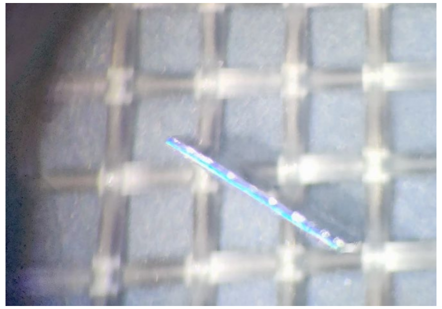
Flex characterization

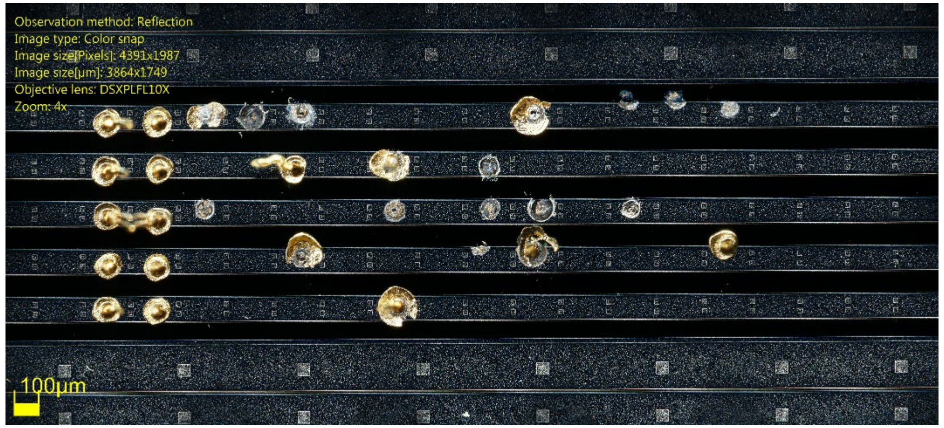
ATAR's ongoing R&D - Mechanics

- Demonstration of mechanical connection of two double-sided sensors with a few techniques (Anisotropic Conductive Paste, stud bonds)
- Parylene tests to insulate sensors areas when assembled in tight stacks
- spTAB connection trials on strip sensors
- Support wafer thinning for LGAD devices to be fully active
  - Tried thinning down support on 50um, 100um and 150um active thickness sensors. Post-processing all devices were still working
- <u>Everything is very compact; assembly procedure is still to be defined. Together with thermal payload</u>


spTAB connection to strip sensor (back and front)


LGAD with Parylene coating

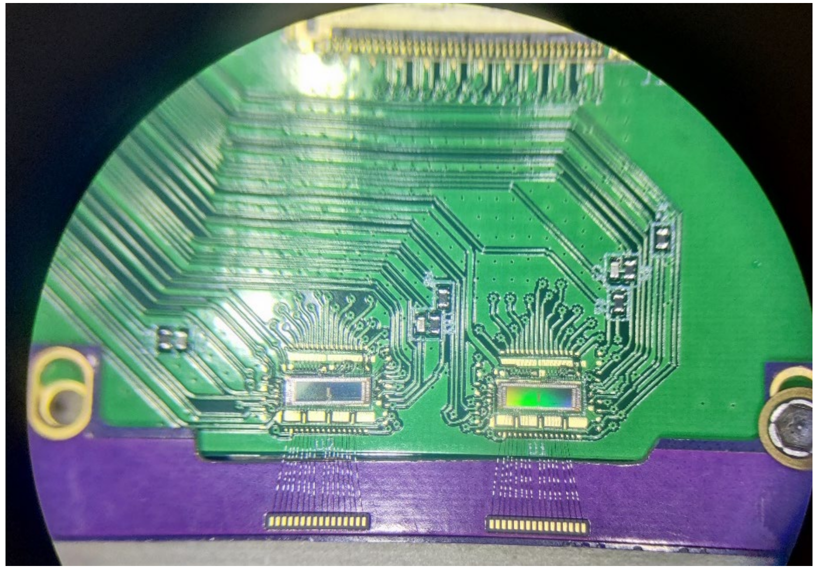

LGAD thinned down to 60-90um

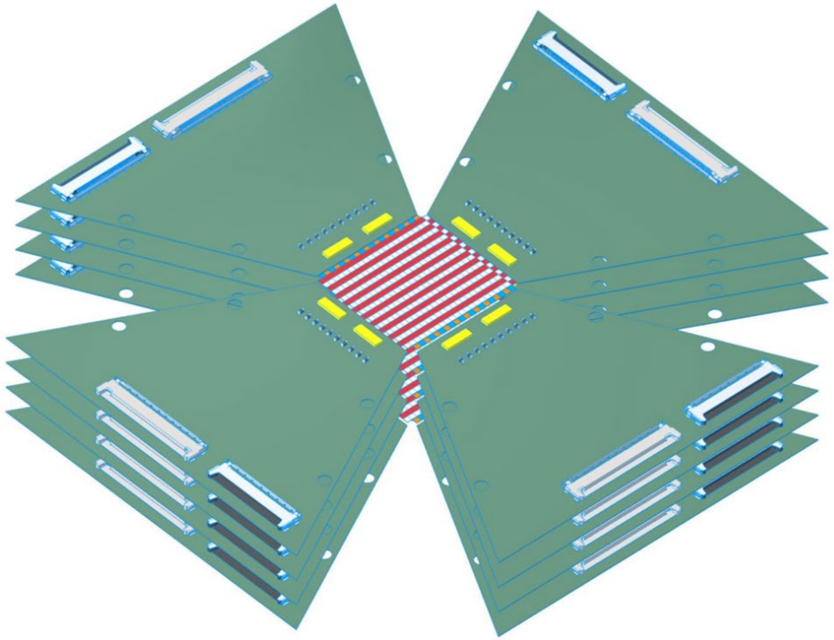


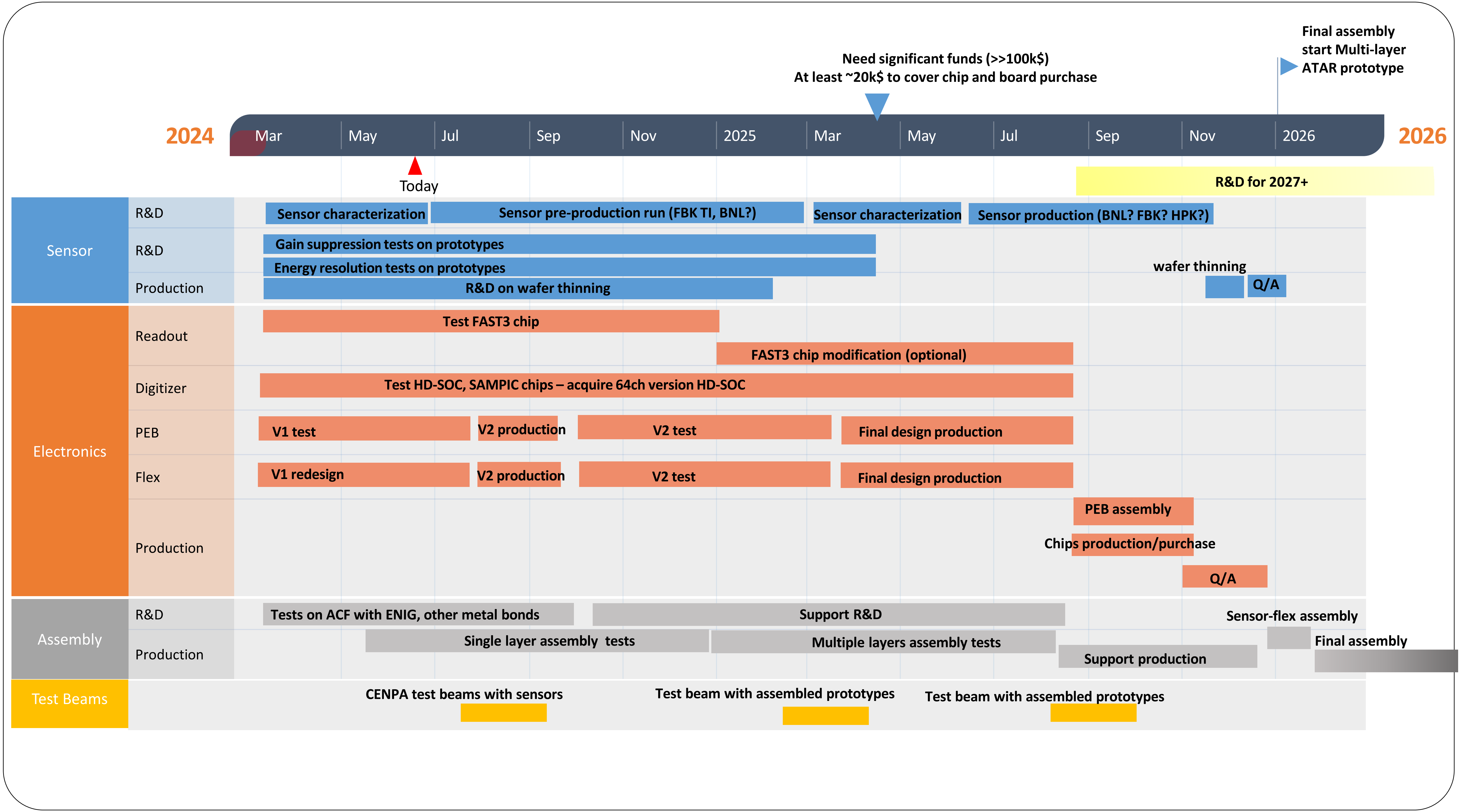
LGAD with stud bonds

ATAR's near future major milestone

- **Production of a multi-layer device with 10-12 layers before the PSI shutdown in 2026**
  - Goal: demonstrate the live decay tracking capabilities of the ATAR
- Layers are 100-150um thick single side strip devices, size is 1cmx1cm with pitch 200um
  - ~50 channels per layer, ~500 channels total (~10% of final ATAR)
  - Sensors are wafer thinned to remove support
- Readout is wedge boards with 2-3x FAST 3 chips per board
- Sensors are 'stacked' in layers of 4, each serviced by 4 wedge boards
  - Sensors directly connected to PEB (or with short flex) with spTAB or wire-bond
  - Sensors protected by Parylene at the edge
- ~10x HD-SOC (64ch version) for digitization
  - Mini-coax connection between boards and HD-SOC
- <u>We have a clear path to achieve this, need to decide on a sensor technology and start a sensor production and chip procurement in ~1 year</u>
  - If no (or limited) funding is available, we have to survive with sample prototype sensors that we can recuperate from other productions
  - (e.g. ongoing thicker TI-LGAD production at FBK)






Final assembly
start Multi-layer
ATAR prototype
Need significant funds (>>100k$)
At least ~20k$ to cover chip and board purchase
2024
Mar
May
Jul
Sep
Nov
2025
Mar
May
Jul
Sep
Nov
2026
2026
Today
R&D for 2027+
Sensor
R&D
Sensor characterization
Sensor pre-production run (FBK TI, BNL?)
Sensor characterization
Sensor production (BNL? FBK? HPK?)
R&D
Gain suppression tests on prototypes
Energy resolution tests on prototypes
wafer thinning
Production
R&D on wafer thinning
Q/A
Electronics
Readout
Test FAST3 chip
FAST3 chip modification (optional)
Digitizer
Test HD-SOC, SAMPIC chips – acquire 64ch version HD-SOC
PEB
V1 test
V2 production
V2 test
Final design production
Flex
V1 redesign
V2 production
V2 test
Final design production
Production
PEB assembly
Chips production/purchase
Q/A
Assembly
R&D
Tests on ACF with ENIG, other metal bonds
Support R&D
Sensor-flex assembly
Production
Single layer assembly tests
Multiple layers assembly tests
Final assembly
Support production
Test Beams
CENPA test beams with sensors
Test beam with assembled prototypes
Test beam with assembled prototypes

ATAR's opportunities for interested groups

- **Development of sensor technology for the ATAR**
  - Be involved in sensor characterization preparation at test beams (readout, support, cables, etc) and lab (energy resolution, repetition rate, angled tracks effect, gain saturation)
  - Continue development of PIN and double-sided option (sensors, readout) e.g. continue discussion with Micron for a double-sided sensor production
  - Possible new technology options for phase II? CMOS, 3D?
  - Contact and work with another LGAD vendor (HPK?)

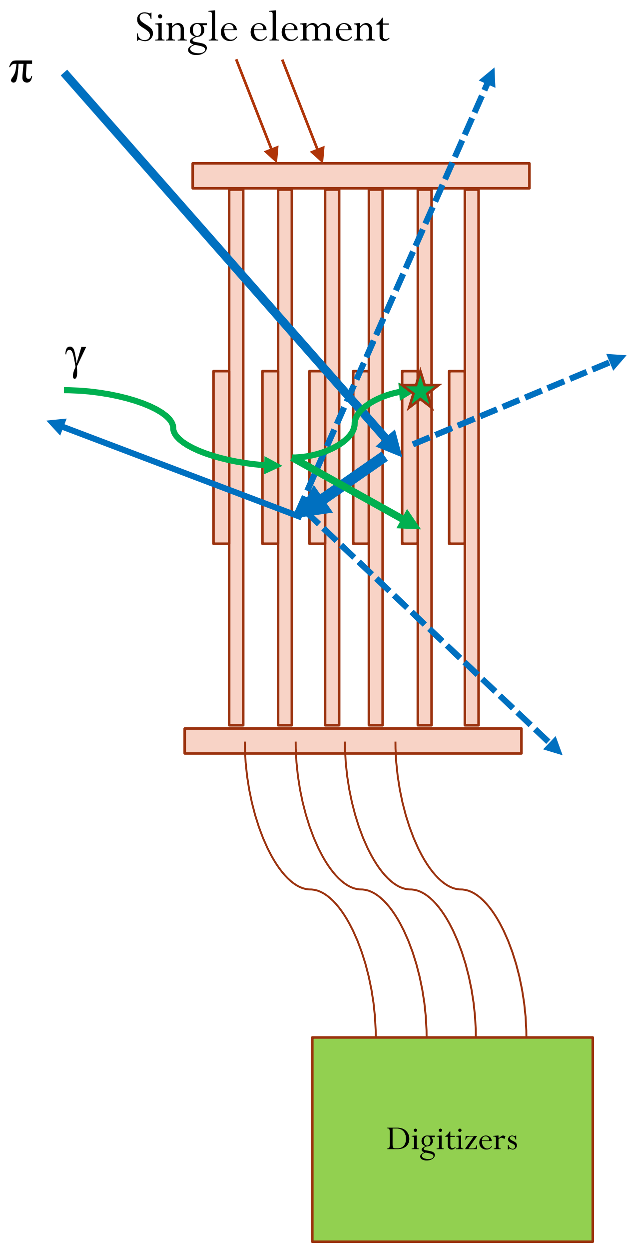
- **Development of readout technology for the ATAR**
  - Identification/test of another readout chip option
  - Identification/test of another digitizer option
  - Development of IC PIN readout option
  - Development of cables between IC board and digitizer

- **Development of mechanics support and sustainable assembly procedure**
  - Assembly procedure
  - Mechanical support and materials
  - Glue for assembly and how it affects electrical component
  - Thermal calculation and simulation
  - Sensor-to-board connection alternative
  - ATAR thermal mockup
  - Sensor stack assembly alternative
  - Double-sided design assembly
  - PEB support and cooling
  - Digitizer crate and positioning

- **DTAR/VETO**
  - Overall DTAR/VETO design
  - DTAR/VETO sensors
  - DTAR/VETO readout
  - DTAR/VETO support and assembly

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 (TOF PET)



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
- 'Baseline' LGAD single-sided design with alternatives
- In the past year we had quite some development for sensors, mechanics and readout
- Current plan: production of a multi-layer device with 10-12 layers before the PSI shutdown in 2026
  - Without funding it will be harder!