Test Platform for Automated Scan of Multiple Sensors

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on behalf of the CMS Collaboration

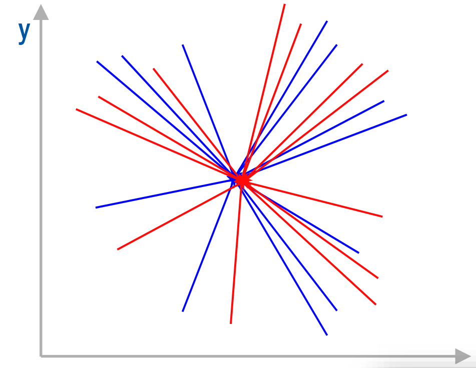
Test Platform for Automated Scan of Multiple Sensors

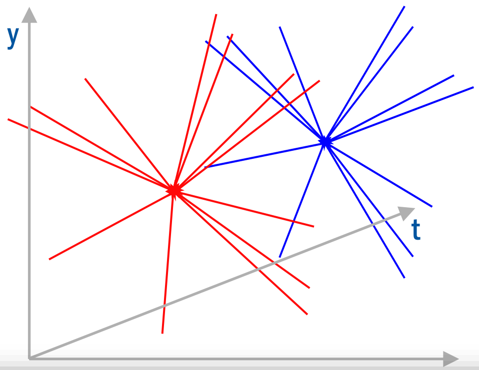
- The CMS MTD: MIP Timing Detector for HL-LHC
- UFSDs for the MTD End Caps
- Characterization of a Timing Detector
- Development of an automated scanning platform:
  - Magnetic spectrometer for Sr^{90}
  - Trigger and time reference
  - Hardware: designed using easily available and accessible components
  - Software: custom control and measurement software/firmware

Generic problem!

CMS MIP Timing Detector

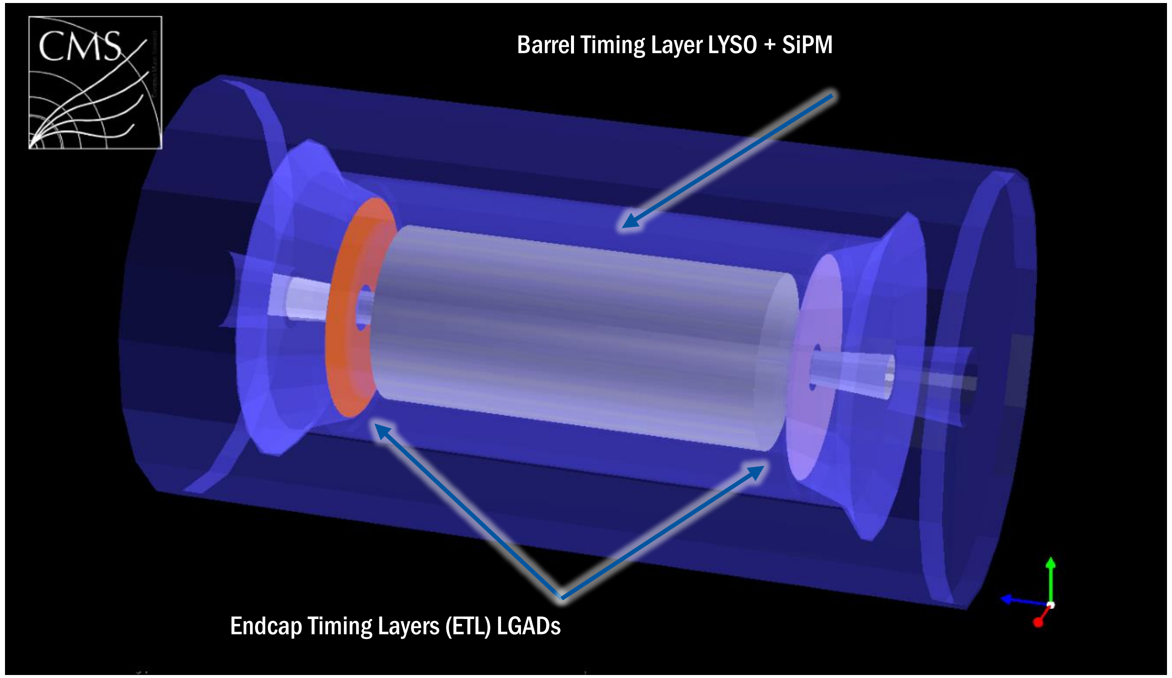
A precise timing detector can be used for Particle Identification or for pile-up suppression



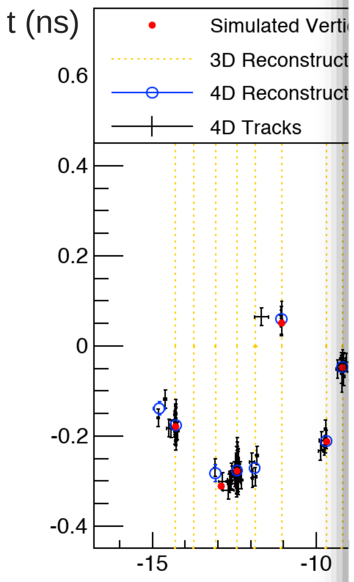


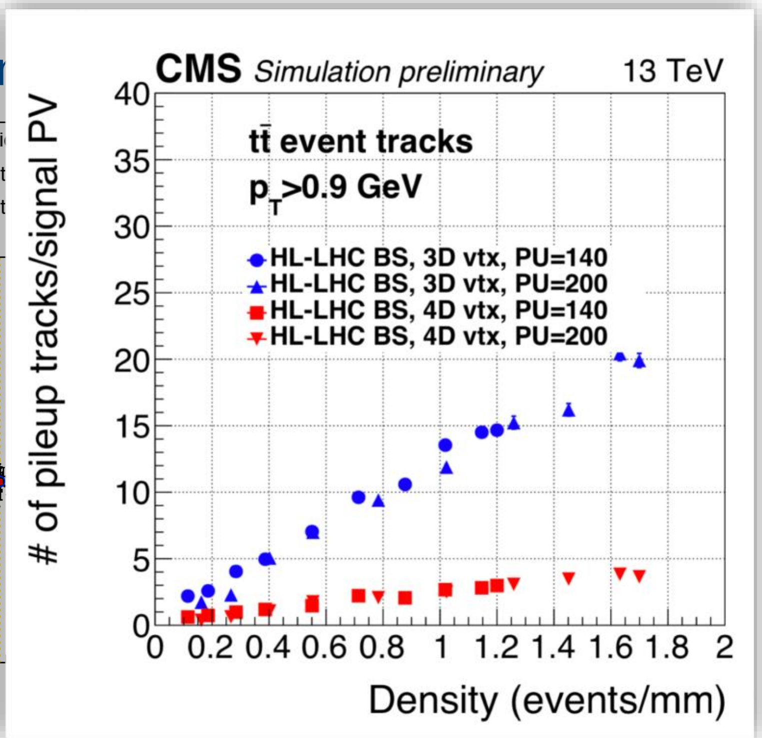
CMS MIP Timing Detector:

30-40 ps timestamp for every track



200 pileup i

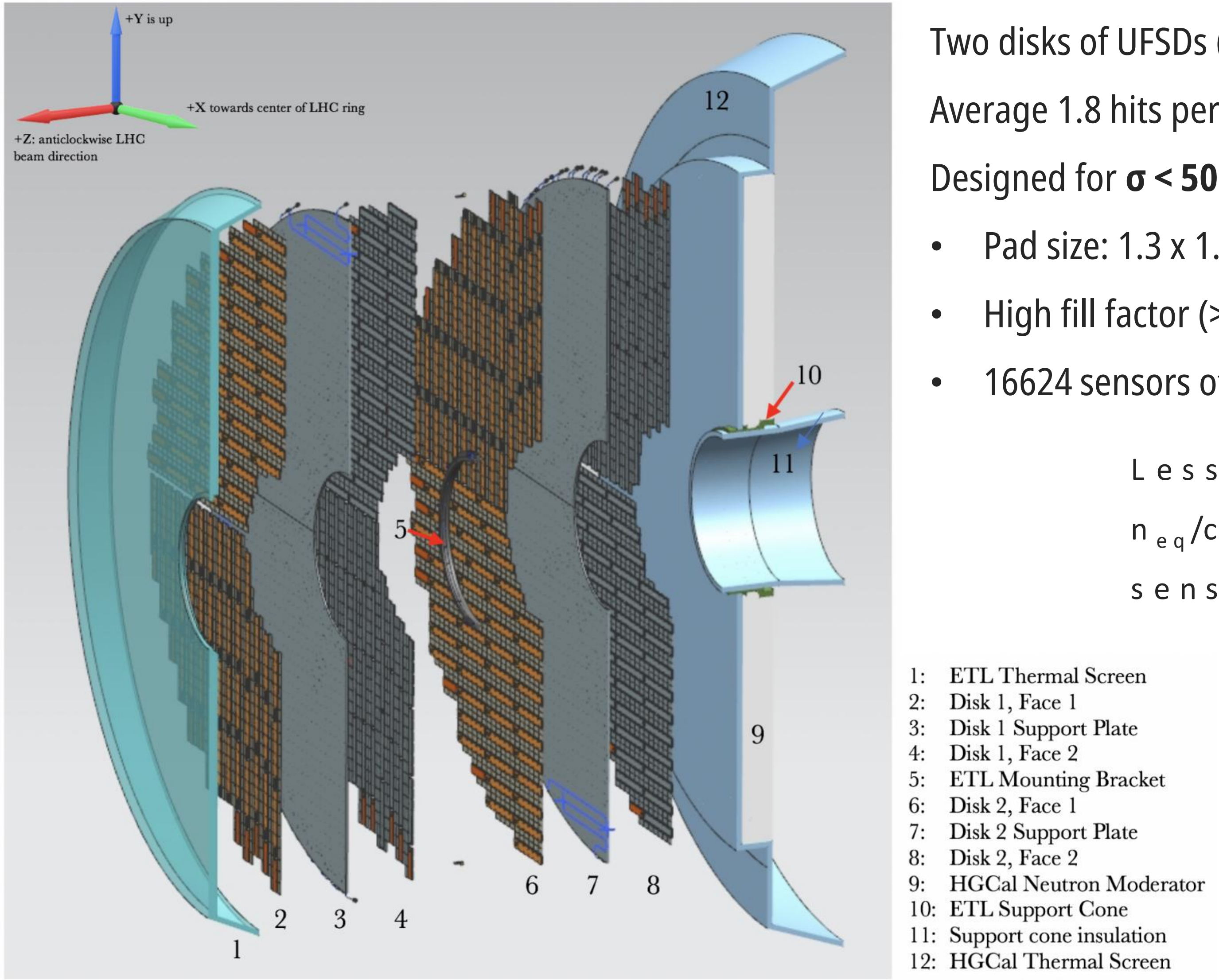




Spurious track-to-PV association suppressed by factor of ~3

U F S D s for the M T D End Caps

Using UFSDs for a "CMS size" detector poses many challenging

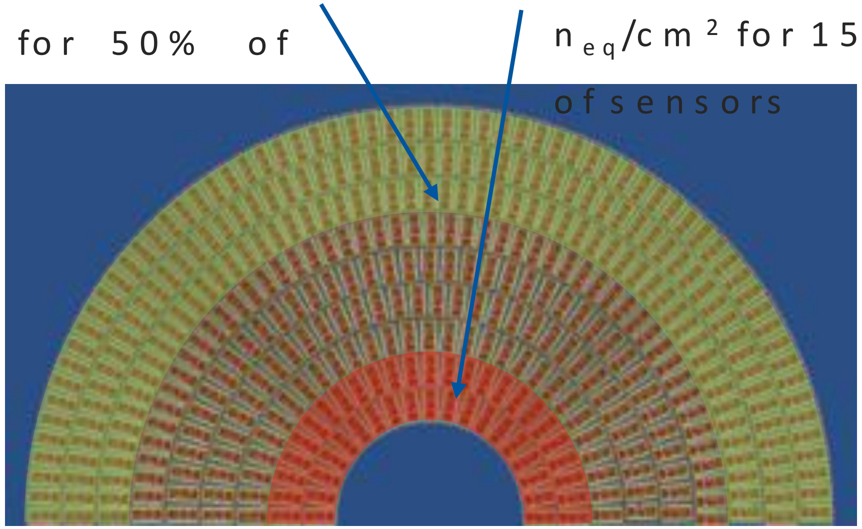


Two disks of UFSDs (per side) $1.6 < |\eta| < 3.0$:

Average 1.8 hits per track

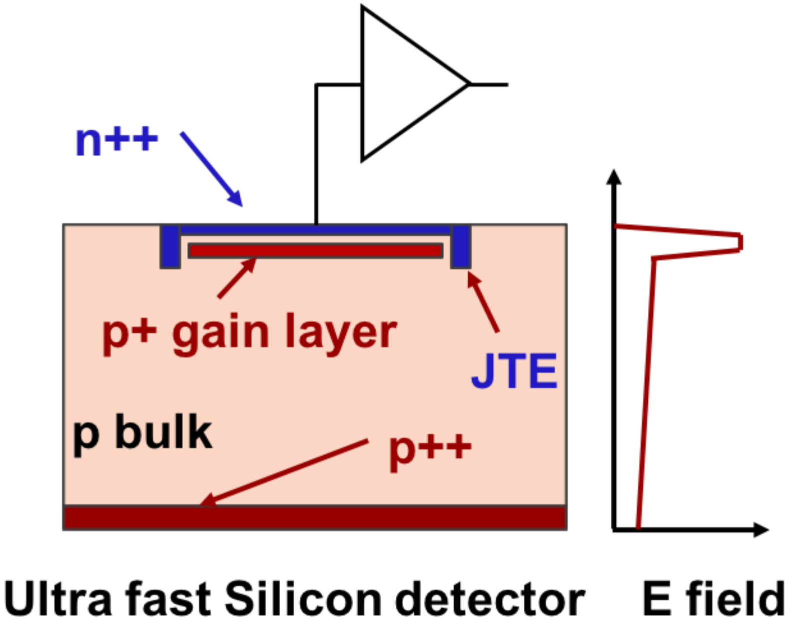
Designed for **σ < 50 ps** per hit

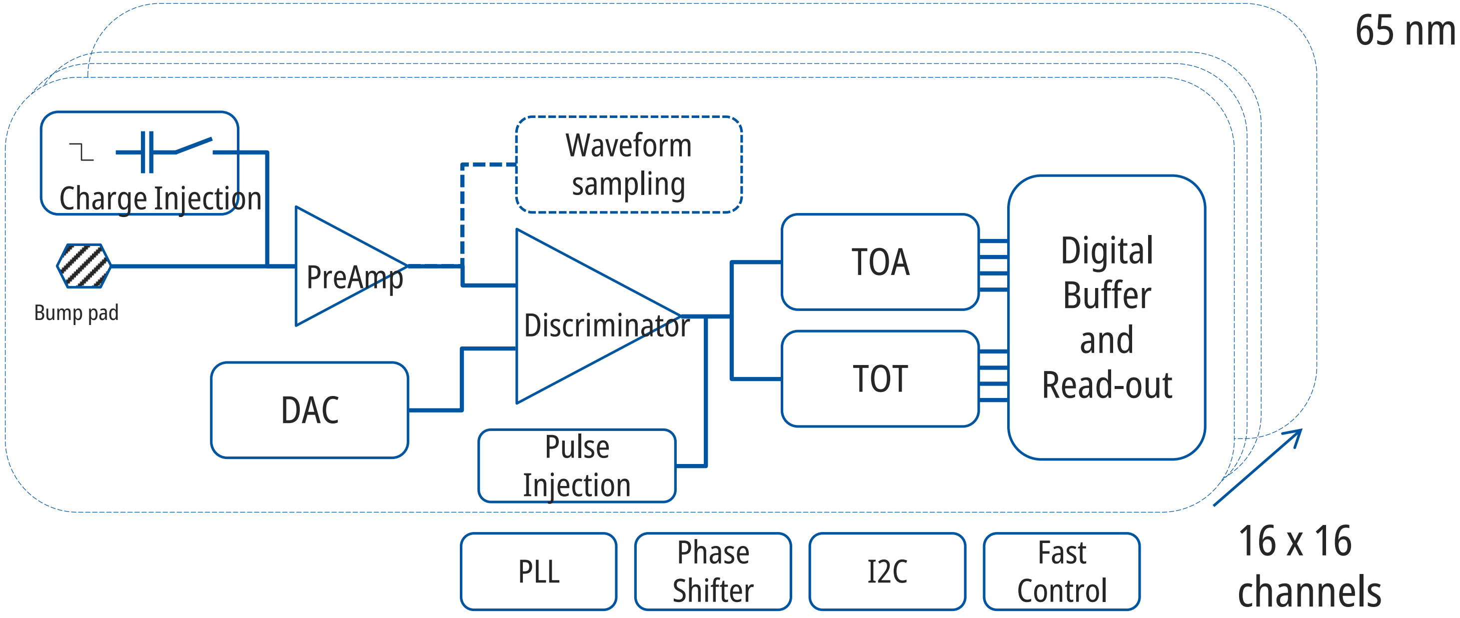
- Pad size: 1.3 x 1.3 mm^2
- High fill factor (>85% per layer)
- 16624 sensors of 2x4 cm^2



L G A D read out by the E T R O C

Ultra Fast Silicon Detectors (UFSDs) are Low Gain Avalanche Diodes (LGADs) optimized for timing measurements employing a thin multiplication layer to increase the output signal at the passage of a particle of a factor ~20





The low-gain mechanism, obtained with a moderately doped p-implant, is the defining feature of the design.

The low gain allows segmenting and keeping the shot noise below the electronic noise, since the leakage current is low.

Time precision: **25~30 ps**

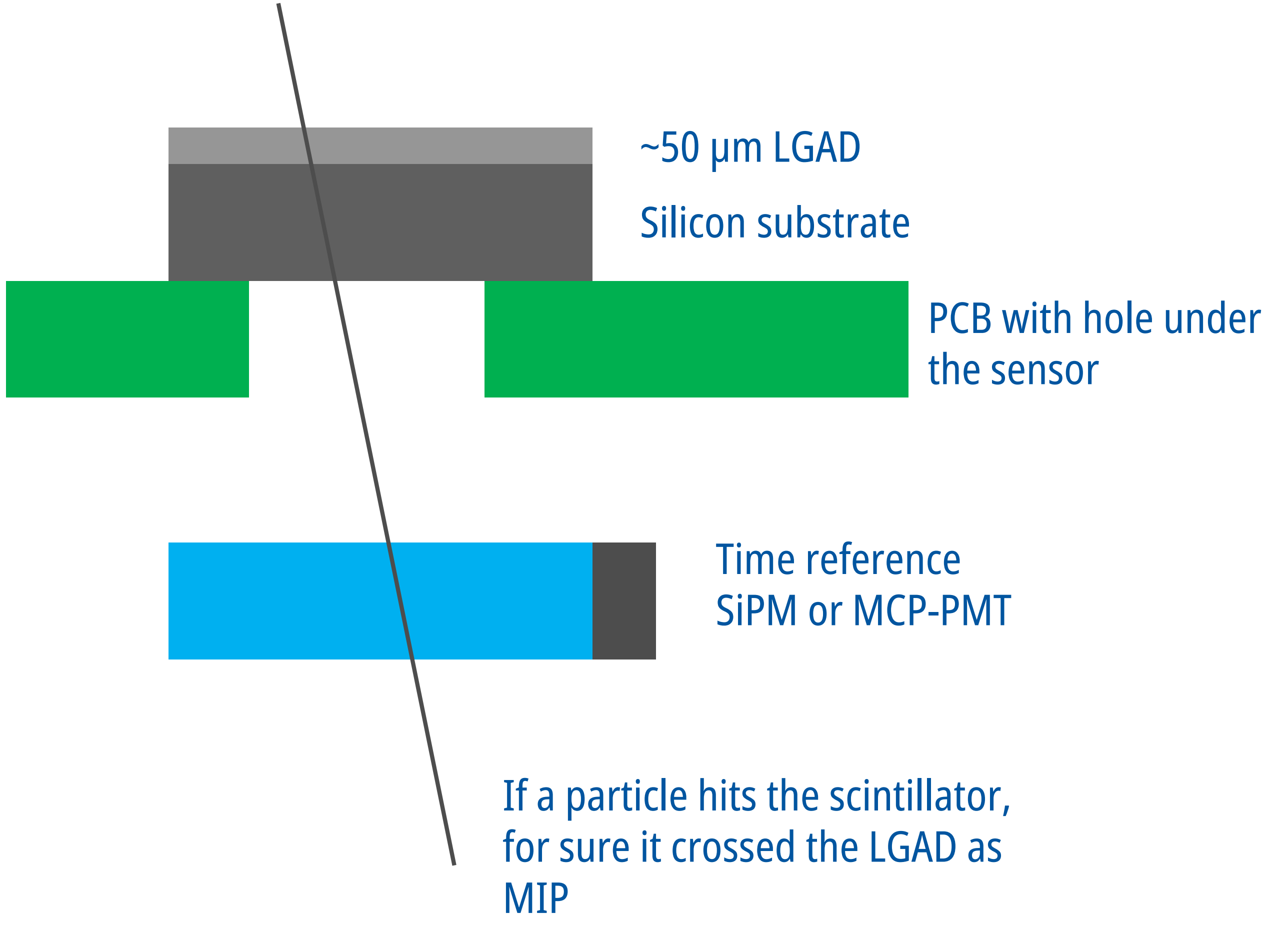
Main requirements:

- ASIC contribution to time precision <40 ps
- Power consumption: <4 mW/ch (80 kW total)
- Trigger rate: Up to 1 MHz

Characterization of a Timing Detector

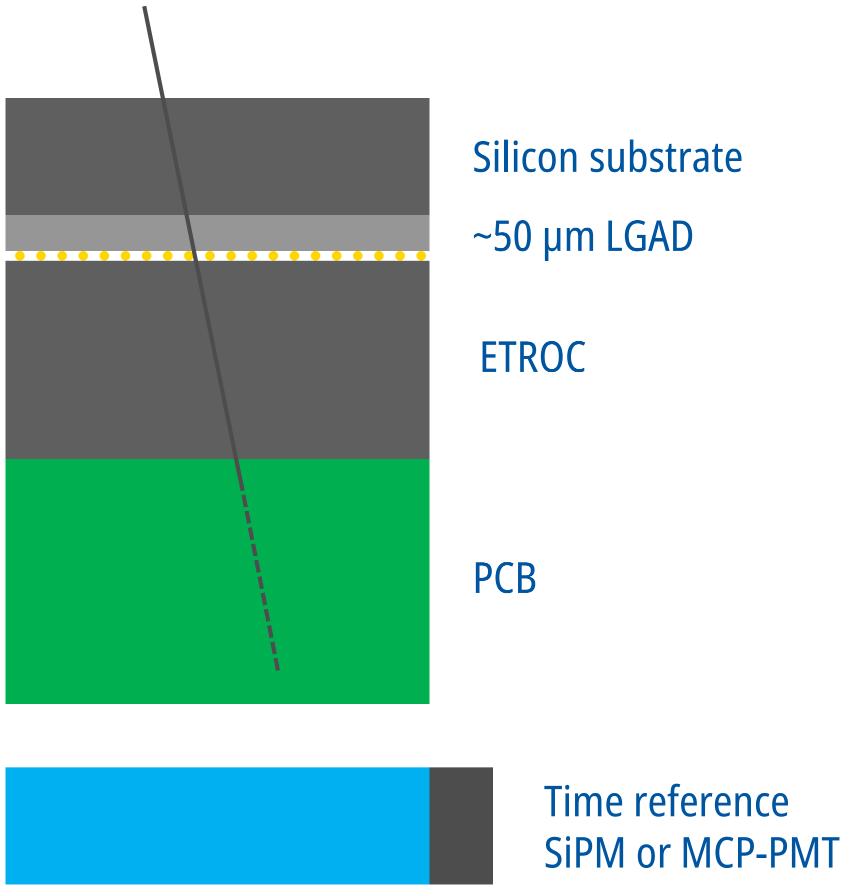
To characterize a timing detector it is mandatory to have a precise time reference

Common approach (with radioactive source):



Not Extensible! Not Flexible!

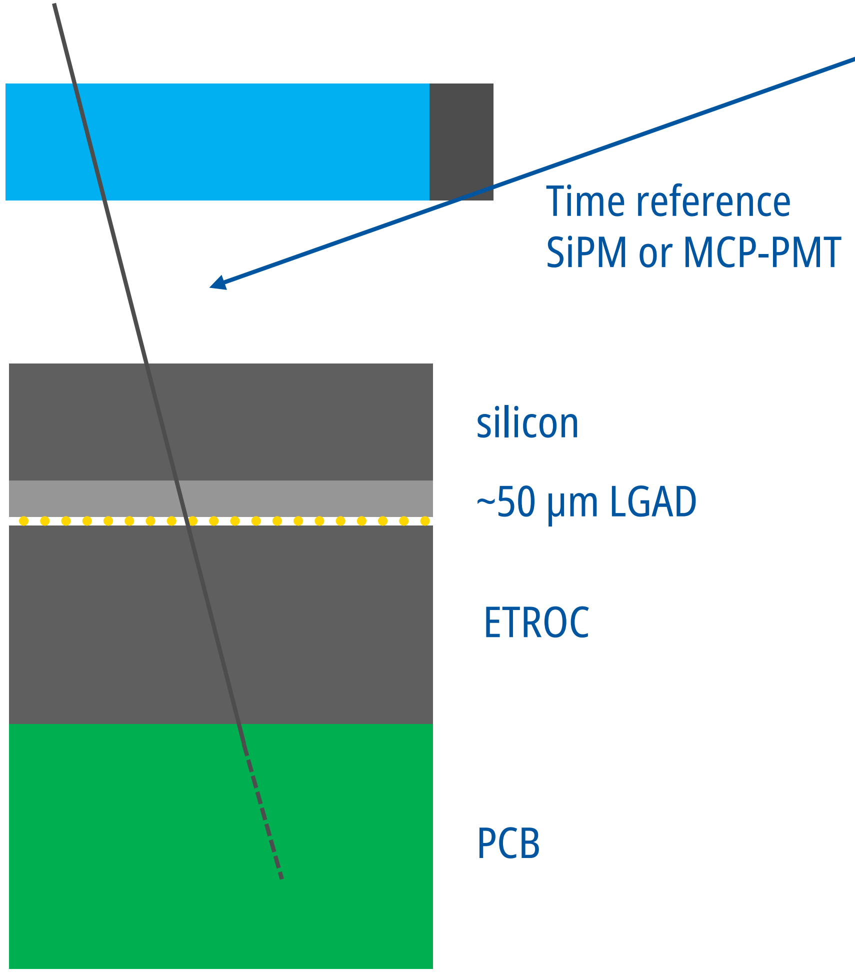
i.e., complete modules, with cooling plates...



Characterization of a Timing Detector

To characterize a timing detector it is mandatory to have a precise time reference

it should still be MIP after passing through the time reference



Precise timing and low material budget (no MCP-PMT...)

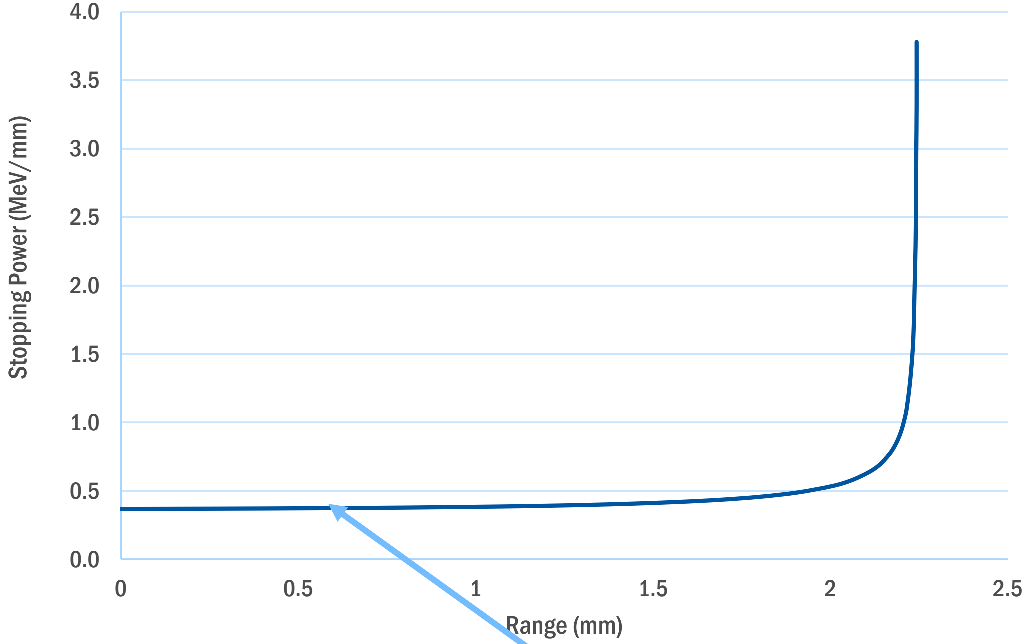
Possibilities:

- Thin plastic scintillator
- Thin plastic Cherenkov radiator
- Ultrathin silicon sensor

M IP portable source

The design goal is to have a compact source with a trigger and a time reference **before** the sensors

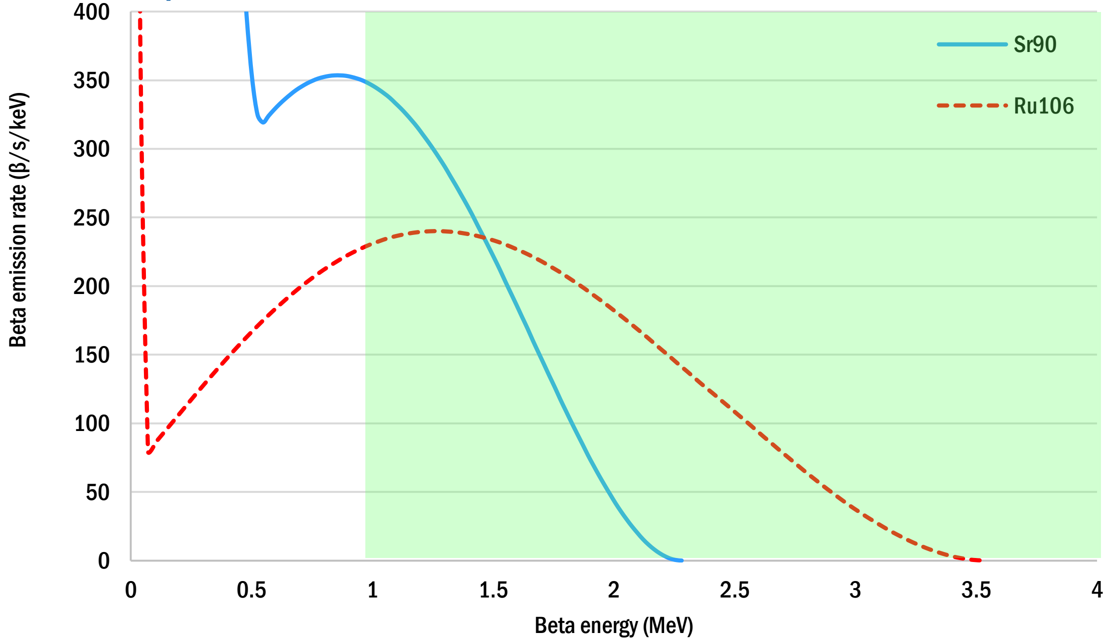
1 MeV electron in Silicon



~0.5 MeV/mm

Selecting electrons with >1 MeV, after 1 mm of Si, they'll still be MIPs

Spectrum of Sr^{90} and Ru^{106}



Both radioactive sources emit >20% (25% for Sr90) of the electrons with >0.9 MeV

Ruthenium-106 Half-Life ~ 370 days
Strontium-90 Half-Life ~ 29 years

https://nucleonica.com/

S o u r c e s p e c t r o m e t e r

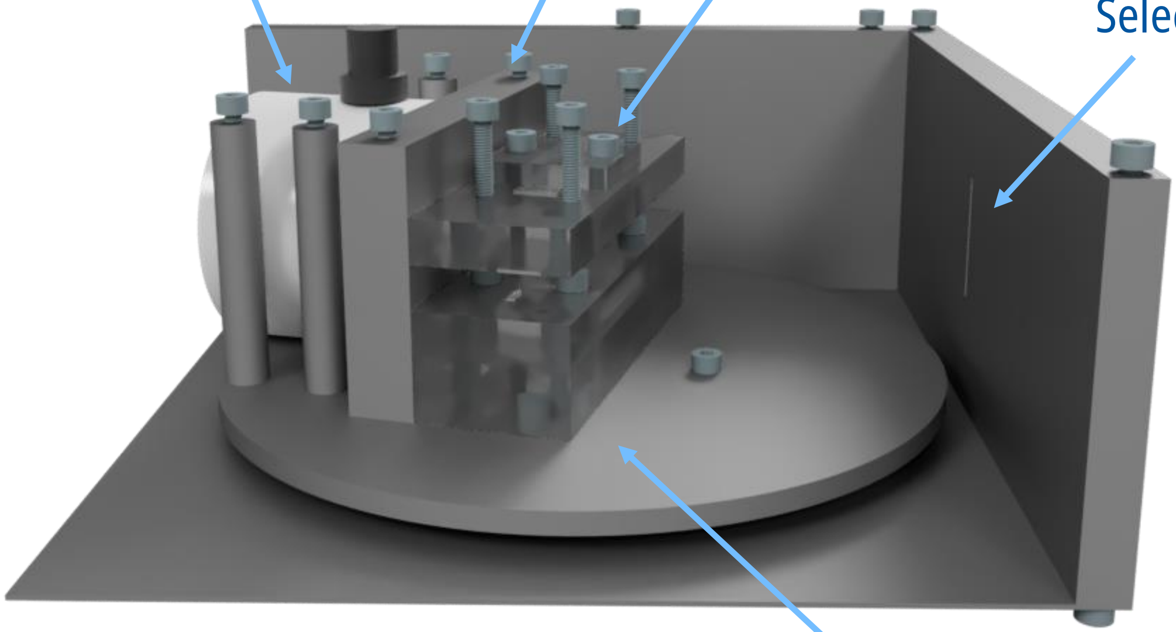
The design goal is to have a compact source with a trigger and a time reference **before** the sensors

Source: Sr^{90}

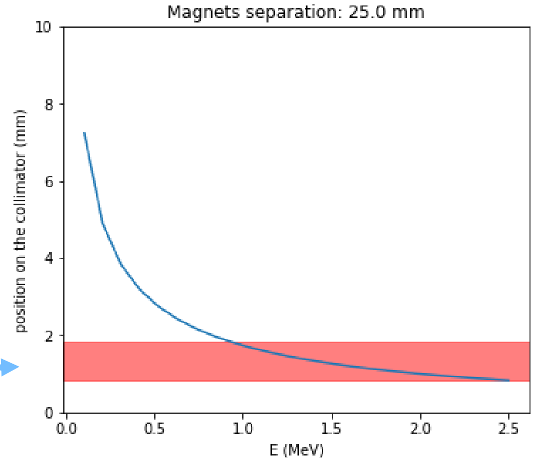
Collimator

Magnets with fine tunable support

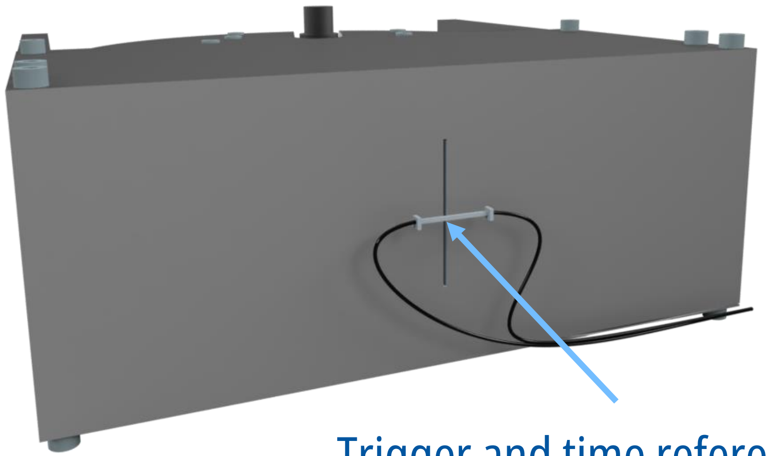
Selection Slot



Rotating support



Simulations show that it is possible to select >1MeV using small permanent magnets



Trigger and time reference

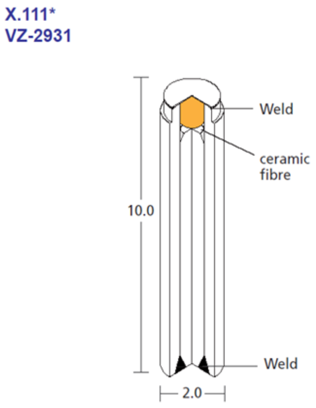
Radioactive Source Spectrometer

First prototype built and tested; a second prototype is in production.

Permanent magnet spectrometer

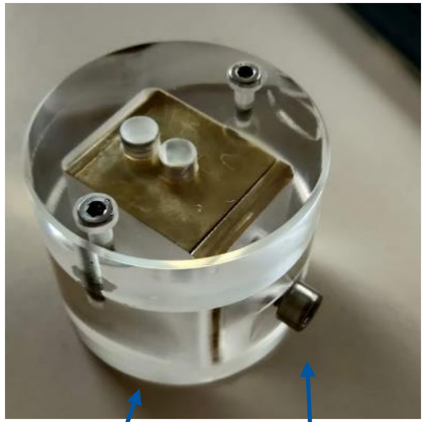
Remotely controlled shutter

Commercially available Sr^{90}



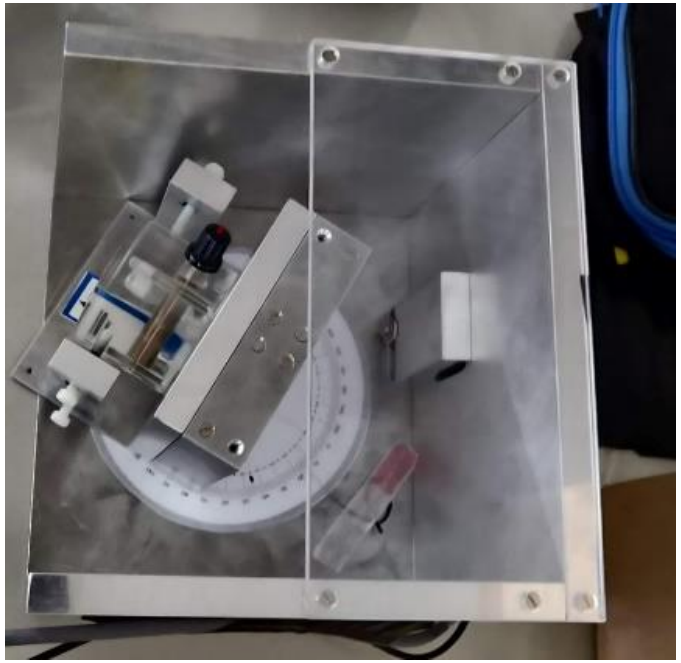
37 MBq (1 mCi)

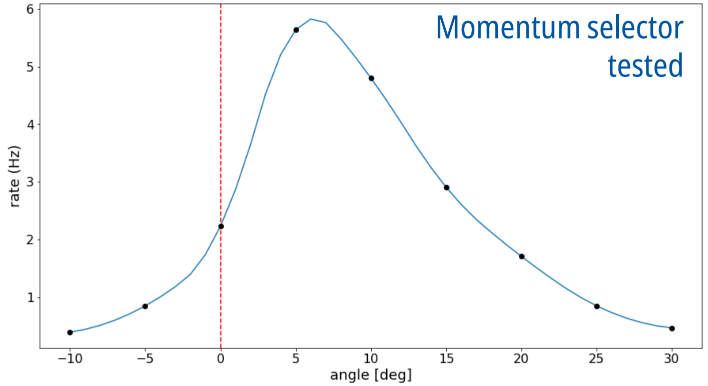
Holder with collimator



~2 mm opening

Open/close



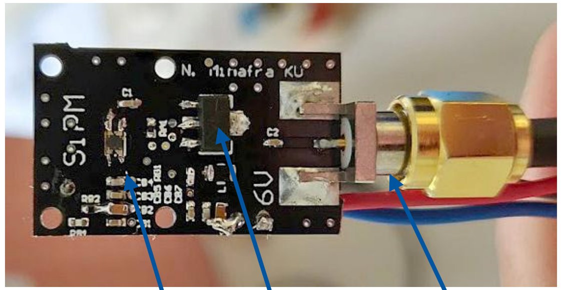


Momentum selector tested

Trigger System: thin plastic scintillator

Trigger generated by plastic scintillators read out by SiPM

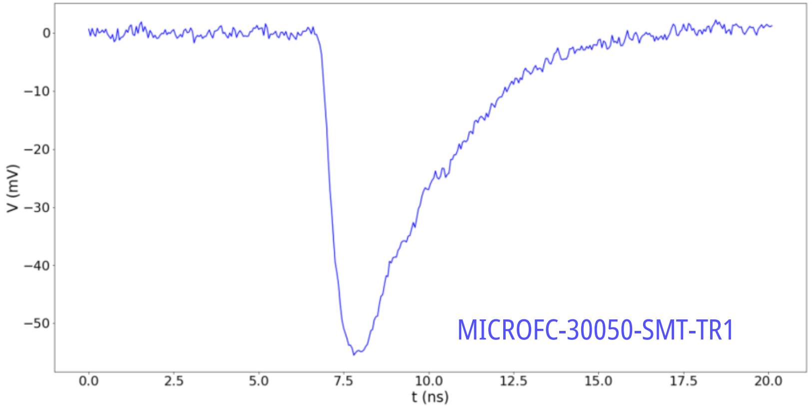
Small "all-in-one" boards with SiPM and amplifier, available for 1x1 mm2 and 3x3 mm2 (compatible with different brands of SiPM)

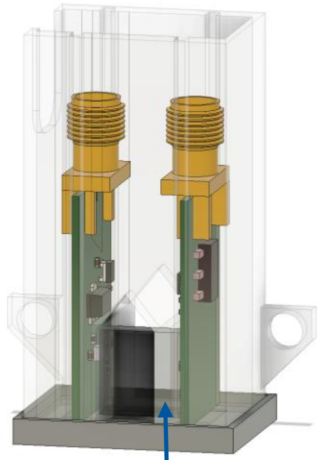


SMA output

Amplifier

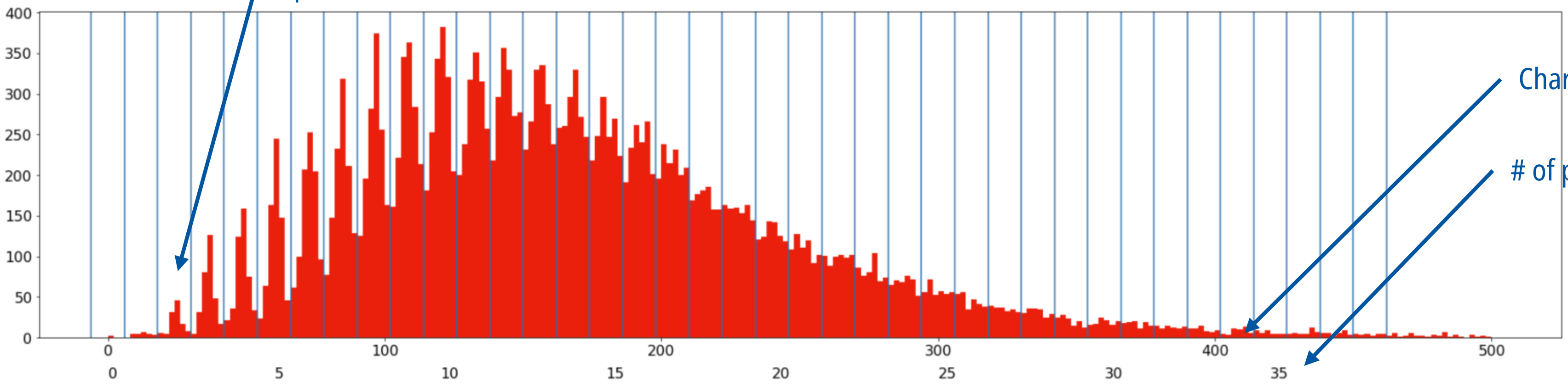
SiPM 3x3 mm^2 or 1x1 mm^2





Plastic scintillator read out on both sides (for coincidences)

2 photoelectrons

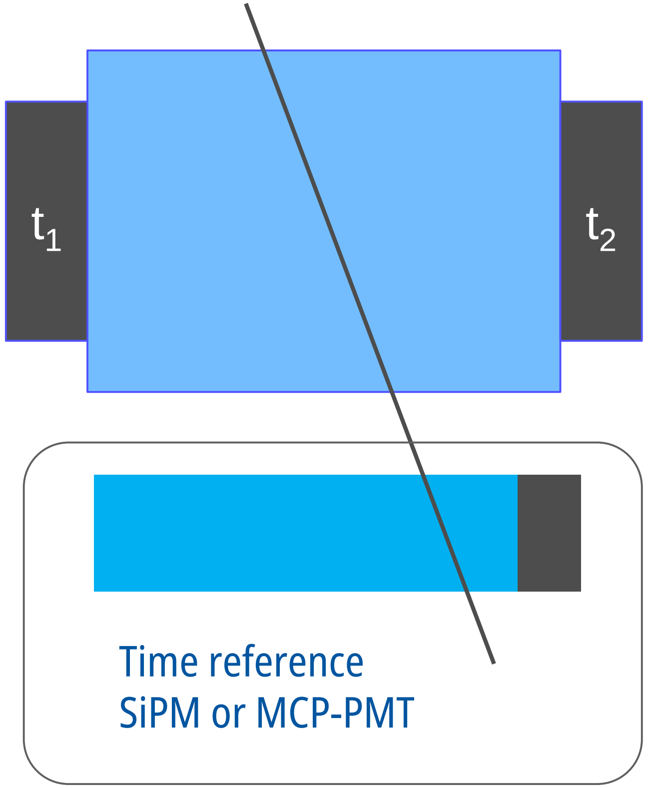


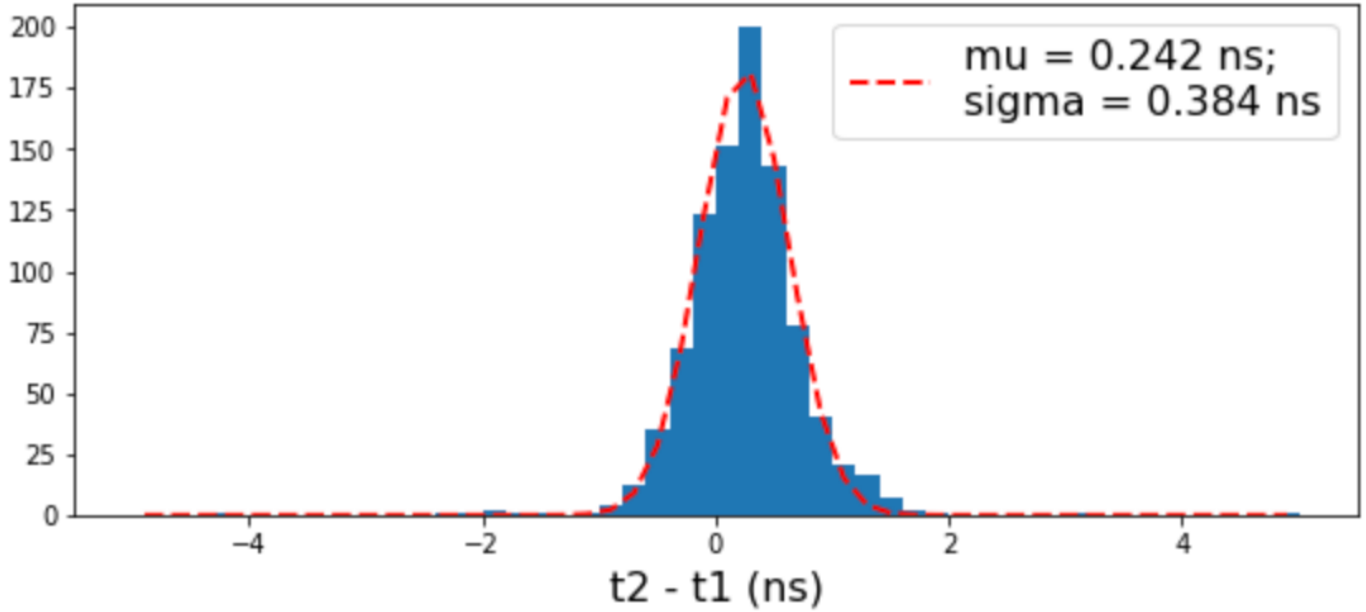
Charge (A.U.)

# of photoelectrons

Trigger System: thin plastic scintillator

Trigger generated by plastic scintillators read out by SiPM





Time precision of single measurement:

$$\sigma_1 \sim \sigma_2 \sim \frac{\sigma_{2-1}}{\sqrt{2}} \sim 270\ ps$$

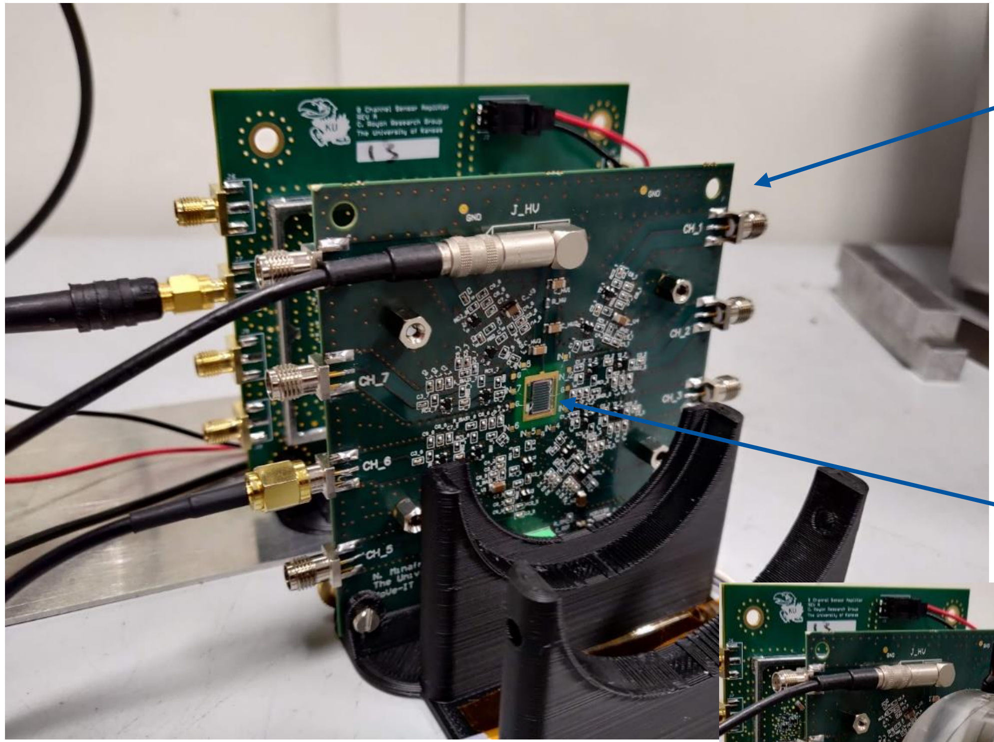
Time precision of combined measurement:

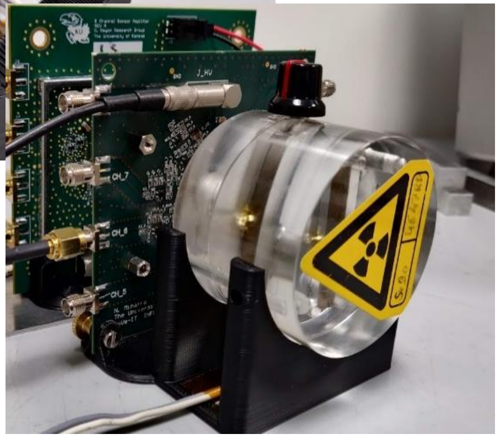
$$\sigma_{(1+2)/2} \sim \frac{\sigma_1}{\sqrt{2}} \sim \mathbf{190\ ps}$$

Still work to do...

Time reference system: “ultra-thin” L G A D

Trigger generated using an ultra-thin silicon sensor that can provide also a time reference





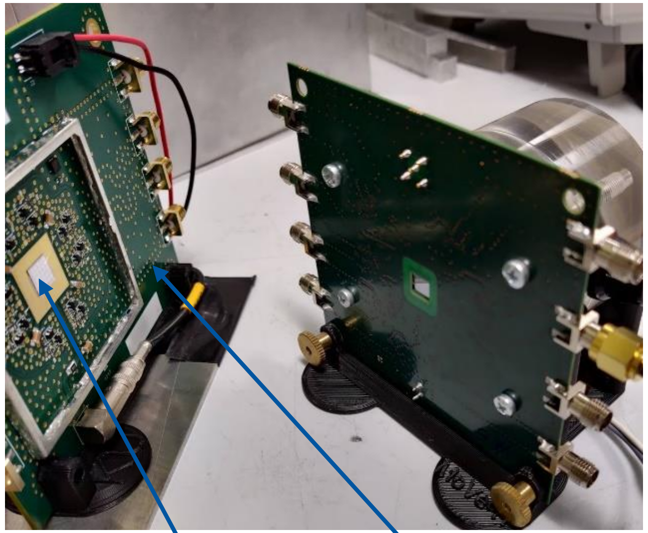
KU MoVe-IT 8ch board

8 ch board designed for linearity up to 10 MIPs and for very high rates (>200 MHz)
Not optimized for MIP time measurements

MoVe-IT LGAD sensor

Prototype of thin LGAD designed for Hadrotherapy
Thickness ~150 um

The first prototypes were affected by “pop-corn noise”, therefore the sensor was not operated in ideal conditions



ETL 5x5 LGAD

KU 8ch board

To measure the time precision of the thin LGAD, a reference sensor (CMS MTD) was installed on a KU board designed for precise timing with MIP.

The expected time precision of this setup is <30 ps

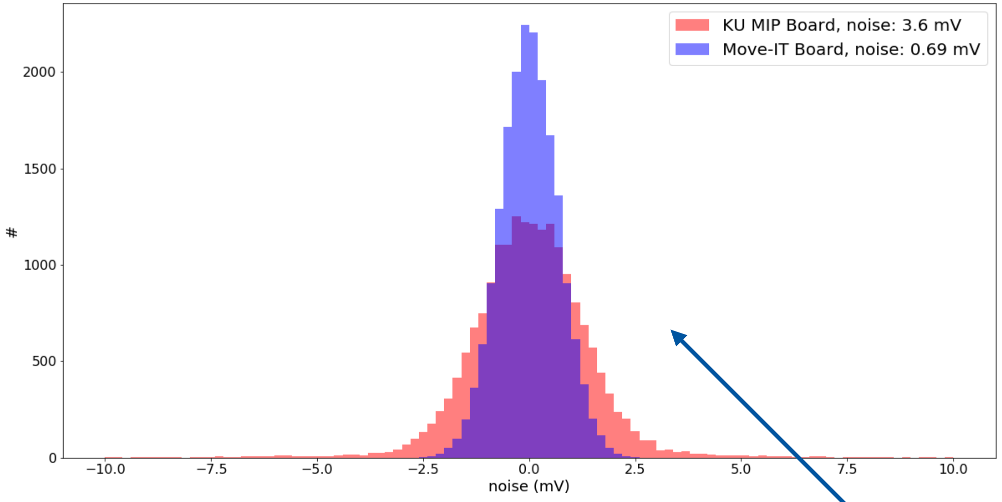
Thanks to
R. Sacchi, S. Giordanengo, V. Monaco, et al.
(INFN Torino)

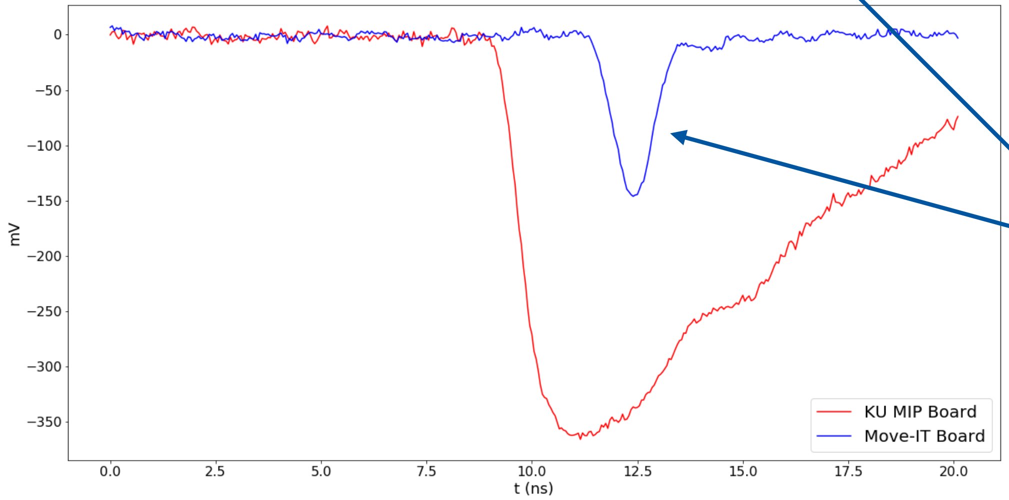
www.tifpa.infn.it/projects/move-it/
MoVe-IT - Modeling and Verification for Ion beam Treatment

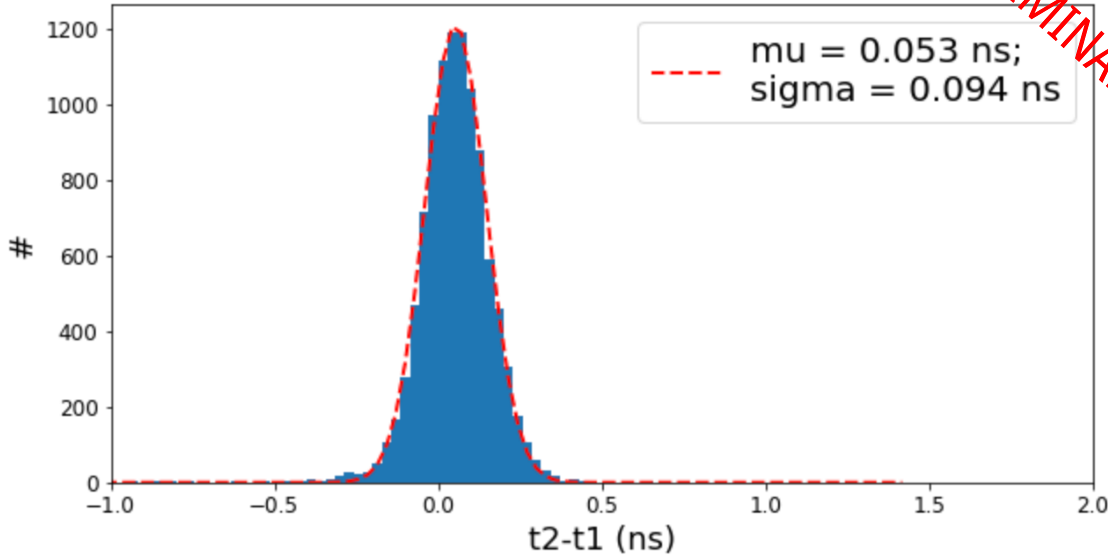
Time reference system: “ultra-thin” L G A D

Trigger generated using an ultra-thin silicon sensor that can provide also a time reference

PRELIMINARY







KU MoVe-IT board is designed with a lower gain (hence lower noise) to avoid saturation with ~10 MIPs charge deposit.

The output signal is quite smaller and faster wrt the board optimized for MIP detection

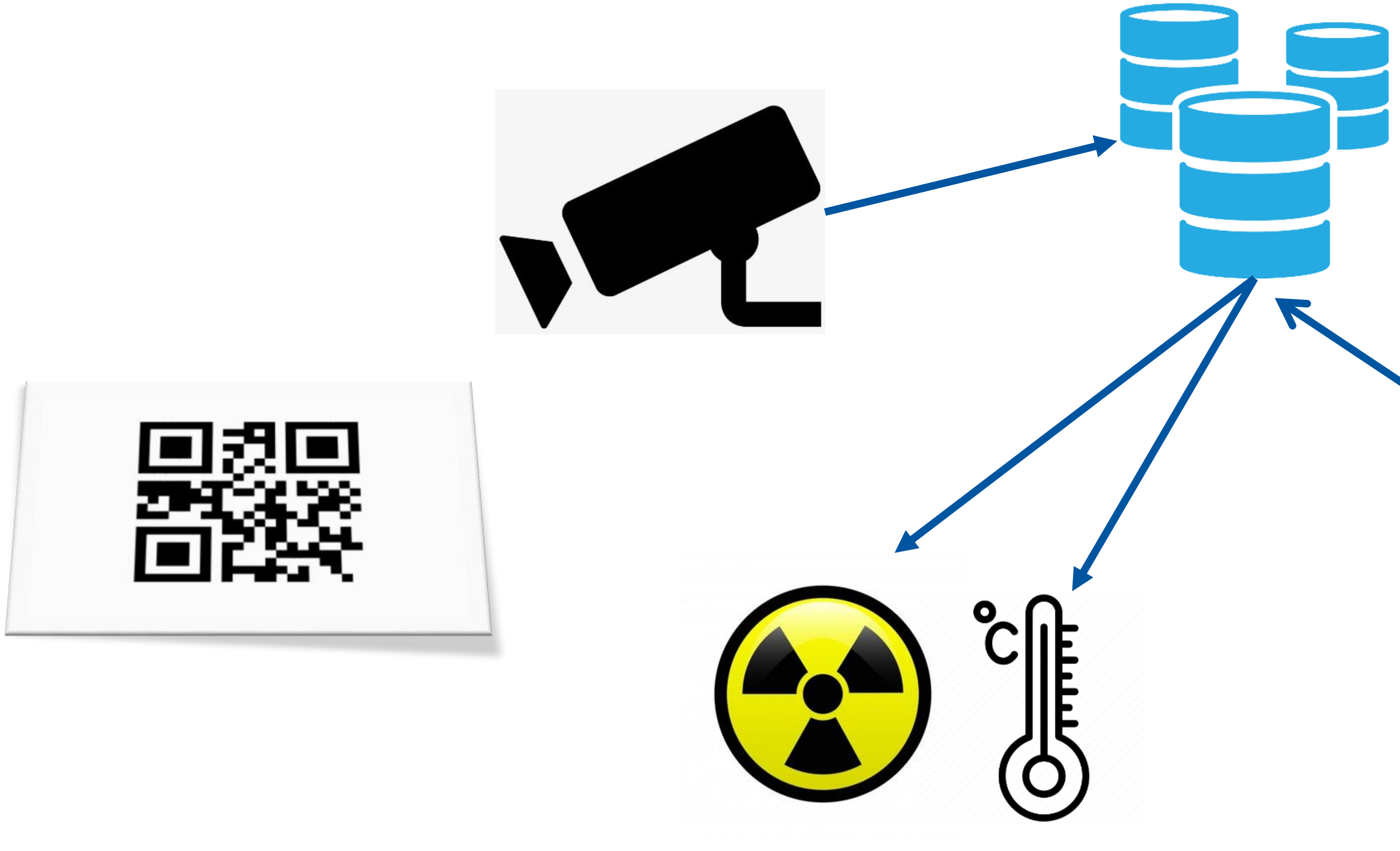
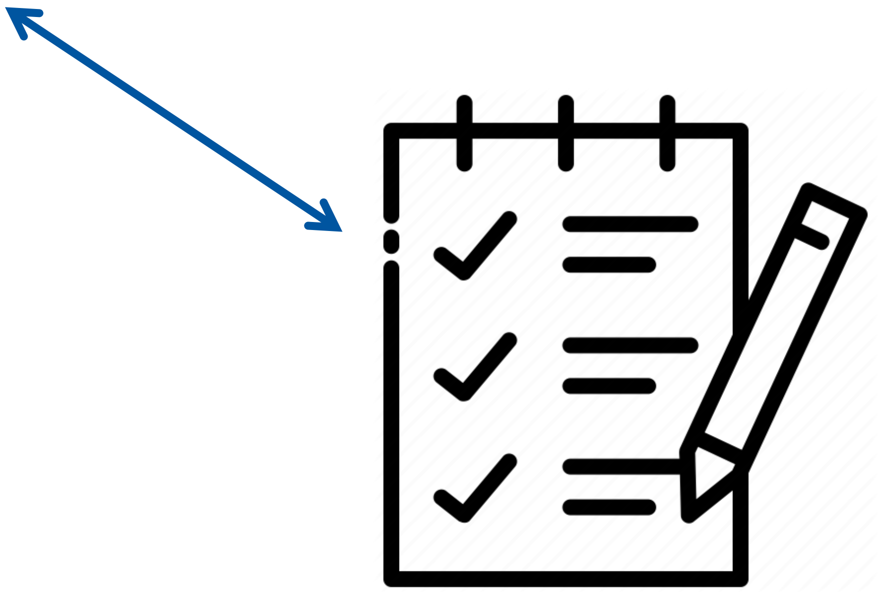
Assuming that the MIP sensor/board has a negligible contribution (~30 ps): The time precision measured for the thin sensor is **~90 ps**.

Still work to do…

Fully automated test of devices

All DUTs can be identified by a SN using a QR code

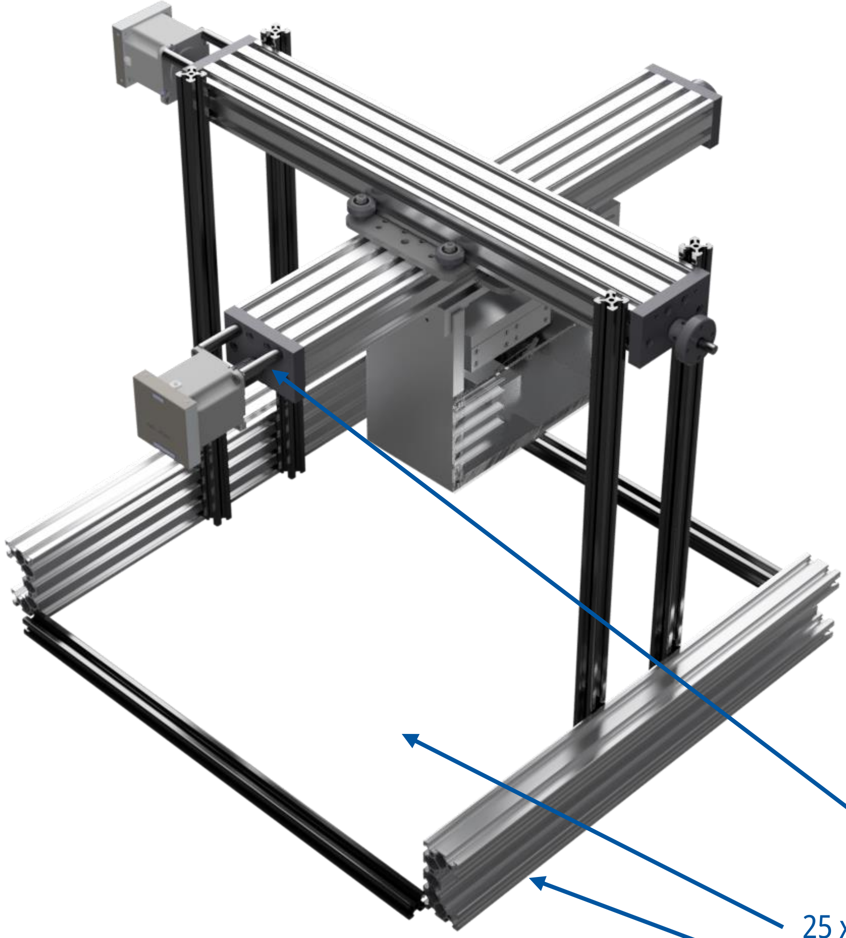
SN	Sensor Type	Sensor SN	Max Bias	Tested	...
ETLTEST1	S10938-6130	EXX33760-WNo42	250V	OK	
...					

The SN is linked to a database with all relevant information, then the module is tested and results are stored in the database

S c a n n i n g P la tfo r m

Precise XY positioning of the spectrometer



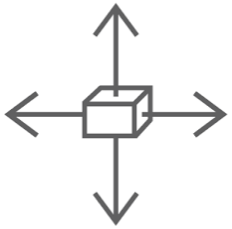
Precision ~10 um
Accuracy ~100um over 20 cm

25 x 25 cm^2 available

Easy encapsulation for light and dry air

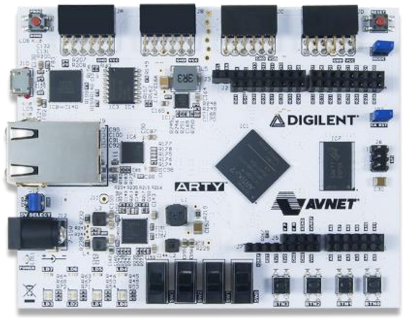
Raspberry PI 4 for “smart” processing

Camera acquisition, object recognition, data base, etc…



Arduino for “easy” processing

Motor control, shutter control, laser control, etc..

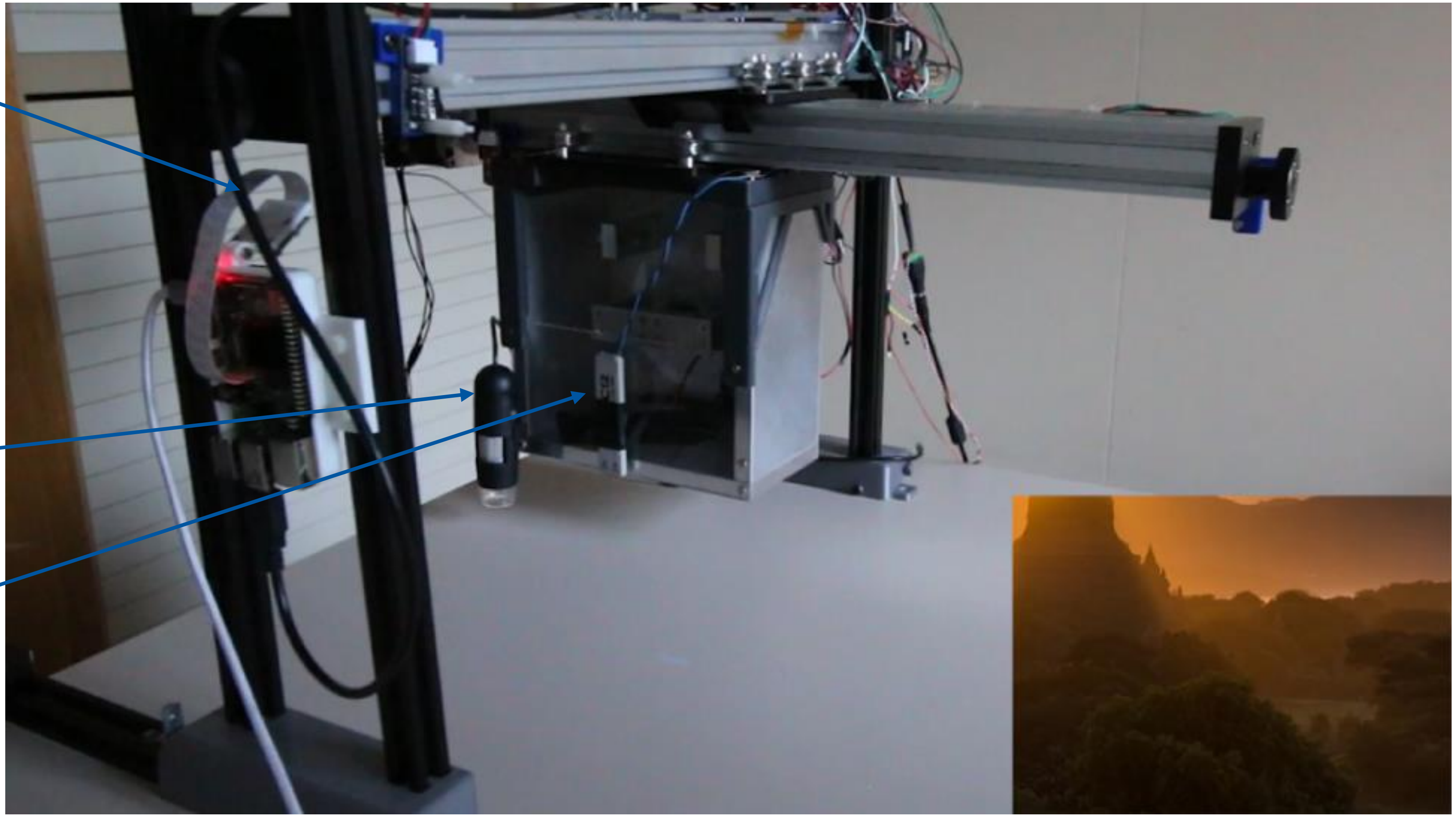


FPGA for “fast” processing

Trigger control, coincidences, counters, etc..

Scanning Platform: automated object location

XY movement with automatic object recognition



Full video: https://youtu.be/R01_67eKrPA

Scanning Platform: a technical slide!

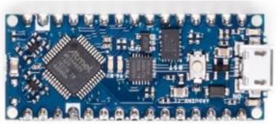
Motor control

The motors need two signals: DIR and STEP
(open loop)

Low jitter and fast: timers

Acceleration: very demanding

2 independent axis: even more demanding



Arduino Nano Every

Object recognition

Pi Camera or WebCam (bird-eye)

USB microscope (detail)

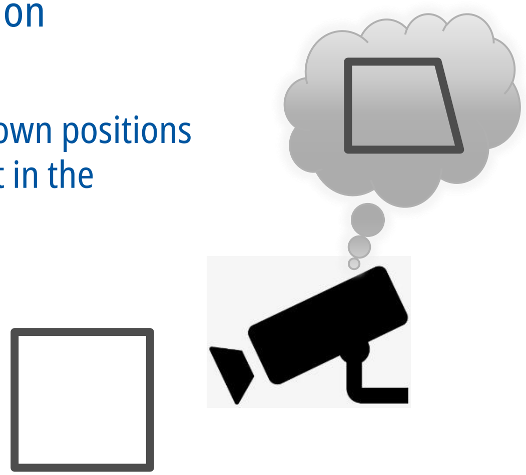
Acquired and processed using OpenCV framework

OpenCV

Coordinate transform

Camera: Perspective correction

Point the laser at 3 (or more) known positions and use those as reference point in the camera reference system



XY platform:

Rotation and scaling

- Z might not be perfectly perpendicular
- X and Y could be rotated

Compatible with our probe station...

Conclusions

- Within the upgrade program of the CMS MIP Timing Detector an automated test platform has been designed
- The platform has 2 axis precise motion (XY) and fully custom control hardware/firmware
  - The platform can be also modified to be used with particle beams (YZ movement)
- The platform has cameras for object recognition and precise positioning
- The platform is equipped with a Sr90 radioactive element and with a magnetic spectrometer to select electrons > 1MeV
- A “thin” trigger/time reference system is under development: **further research and tests are needed**, but promising results.