Università degli Studi di Padova

Istituto Nazionale di Fisica Nucleare

Sezione di Padova

R&D on novel 4D trackers (3D+timing)

Workshop Laboratori Progetto di Eccellenza

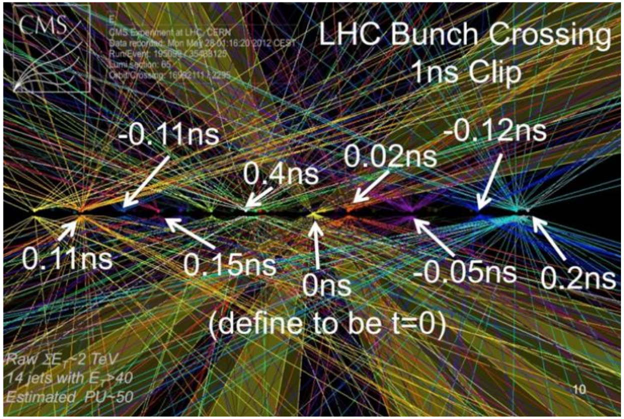
Serena Mattiazzo

on behalf of TimeSPOT, APIX and CMS BTL groups

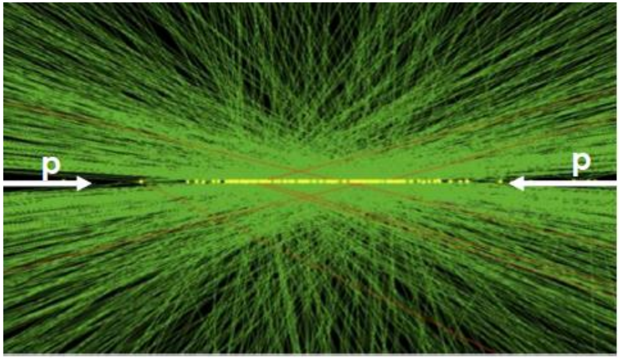
Outline

- Scientific motivation for R&D activities on 4D trackers
- Activities at DFA and Padova INFN Section
- Present expertise and equipment
- Future perspectives (within “Progetto Dipartimenti di Eccellenza”)

Timing



- Current situation: ~ 50 vertexes per bunch crossing
- Vertexes **do not overlap** in space → tracking **resolves** the vertexes

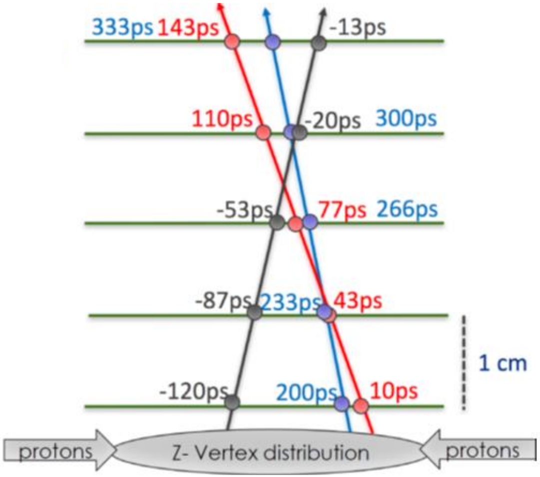


- HL-LHC situation: ~ 150 – 200 vertexes per bunch crossing
- Vertexes **overlap** in space → tracking **does not resolves** all vertexes
  - Spread of ~ 180 ps in time collisions → 30 ps to reject pile-up of a factor 6 (CMS)
  - with 35 ps time resolution, instances of vertex merging are reduced from 15% in space to 1% in space-time (like CMS LHC conditions)

Tracking in 4 dimensions

- The inclusion of time in the event information would greatly simplify tracking capability

Use time-compatible points



- Timing can be available at different levels of the event reconstruction:

  1. Timing in the event reconstruction → Timing layers (time associated to each track)

  2. Timing at each point along the track→ 4D tracking (3D space tracking + 1D time)

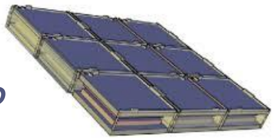
R&D activities on 4D trackers

- Detector testing capabilities
- Fast electronics design and production

TimeSPOT

G. Simi, S. Mattiazzo, D. Pantano, G. Collazuol

APIX/ASAP



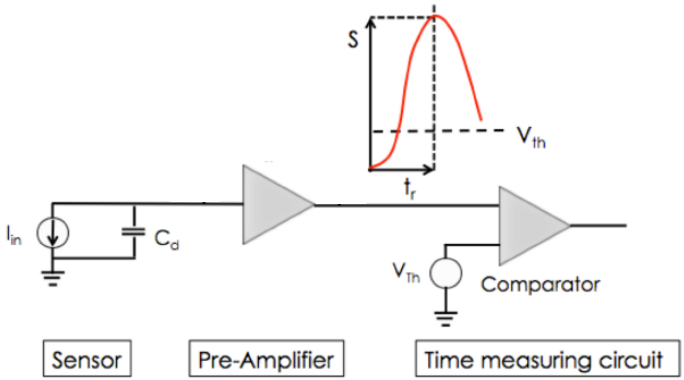
G. Collazuol, L. Silvestrin, S. Mattiazzo

- Mechanics design and development
- Thermal measurements

CMS

P. Checchia, U. Dosselli, R. Rossin, S. Ventura, R. Isocrate, N. Bez, D. Mazzaro, F. Veronese

Silicon pixel detectors for timing: the challenge



Time is set when the signal crosses the comparator threshold

$$\sigma_t^2 = \sigma_{TimeWalk}^2 + \sigma_{LandauNoise}^2 + \sigma_{Distortion}^2 + \sigma_{Jitter}^2 + \sigma_{TDC}^2$$

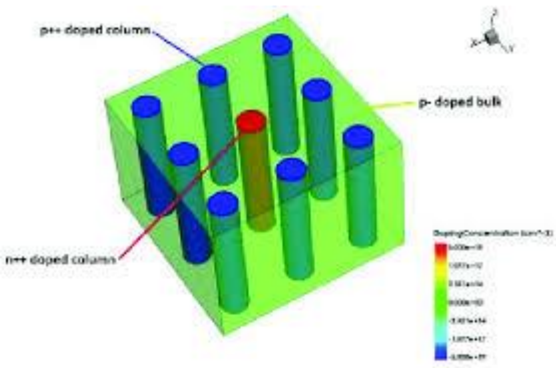
- $\sigma_{TimeWalk}^2 + \sigma_{LandauNoise}^2$: Physics of energy deposition
- $\sigma_{Distortion}^2$: Sensor Electric Field
- σ_{Jitter}^2: Electronics
- σ_{TDC}^2: Digitization

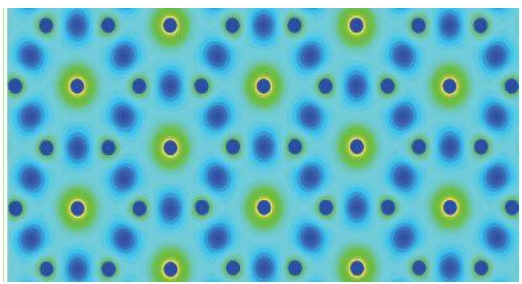
- **Uniform electric field** ⟹ **Sensor R&D**
- **Fast slew rate** $\sigma_t = \frac{\sigma_V}{dV/dt}$ ⟹ **Fast electronics development**

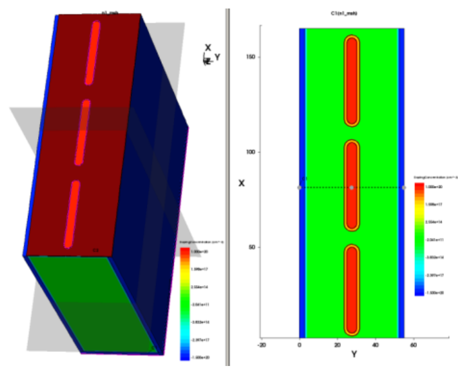
Timespot

- **Typical column 3D sensors** show very weak spots in electric field which correspond to much slower charge collection times whenever a track crosses the sensor

- Better results can be obtained **with trench electrodes**
  - trench structures increase pixel capacitance,
  - silicon trench geometries have never been produced so far.

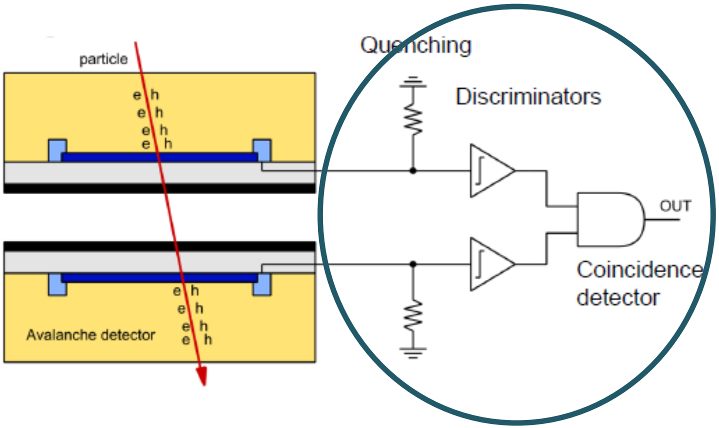




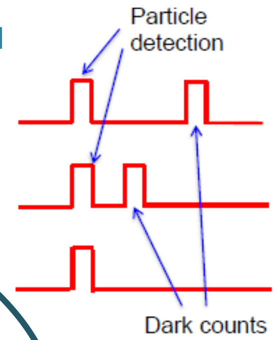


APIX/ASAP

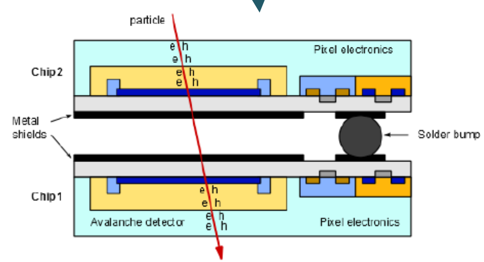
- It is a matrix of **Geiger-mode avalanche detectors**, suitable for particle tracking and imaging, formed by two vertically-aligned pixelated detectors,
- Two vertically-aligned cells are **readout in coincidence** to discriminate between particle-triggered detections and dark counts



In-pixel coincidence: integrated electronics is needed (CMOS avalanche detectors)



- reduced material budget
- reduced power consumption
- “simple” electronics → digital readout
- high rate capability
- high timing resolution

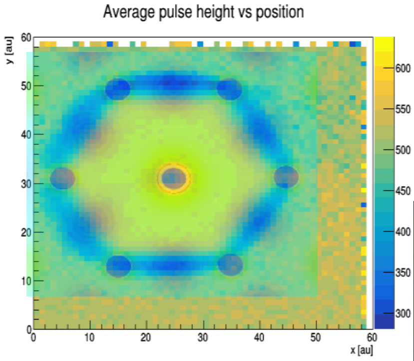


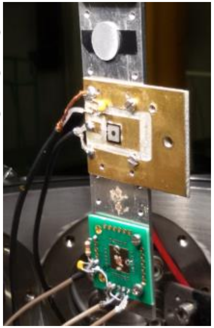
Pixel mapping with proton microbeam

- Tests both on **APIX and TIMESPOT** sensor at the LNL AN2000 proton microbeam
  - 2 MeV protons in a spot of 3-4 μm of diameter.
  - Possibility to rasterize the microbeam over an area of 5×5 mm^2 on the focal plane.
  - Can be used both for functionality studies and radiation damage tests.

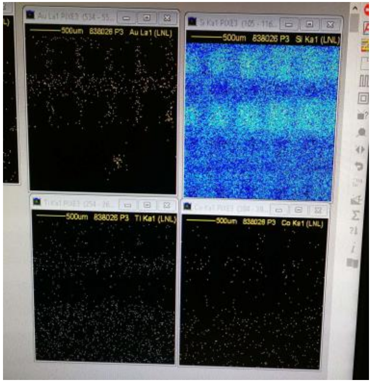
- **Pixel mapping** to evaluate uniformity of charge collection efficiency (CCE), timing uniformity (3 days of beam time assigned and still to be scheduled)

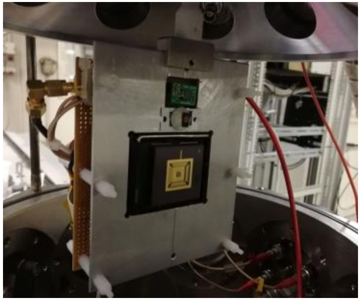
- **Sample preparation**: scintillating material (p-terphenyl) deposition on sensor surface possible thanks to the colleagues from the Material Physics group (G. Maggioni)





Timespot

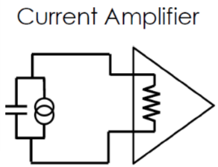




APIX

Presently available instrumentation (1)

Few broadband amplifiers (GALI55 from Minicircuits, 4 GHz current amplifier)



Large bandwidth oscilloscope (model MSO 64 Tektronix, 4 GHz BW)

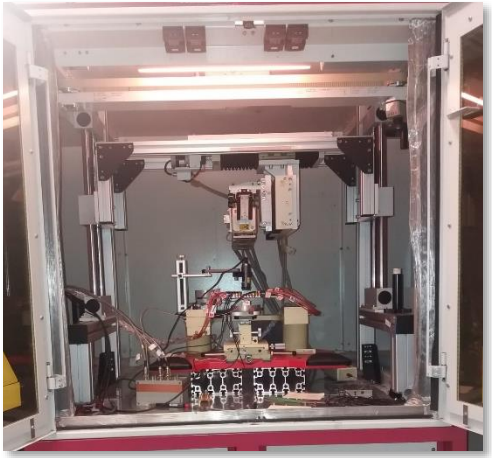
Pulse generator HP 8110A (ns pulses, again too slow)

- IR laser 910 nm and 1064 nm (home-made) , ~ ns pulses (too slow for this application)
- Blue laser 409 nm, 40 ps pulses (not optimal wavelength for test on silicon)

Presently available instrumentation (2)

Spectrum analyzer
Semiconductor parameter analyzer (HP4156)
Switching matrix (Keithley 707)

X-ray irradiation facility
(60kV, 50 mA)



Semi-automatic probe station

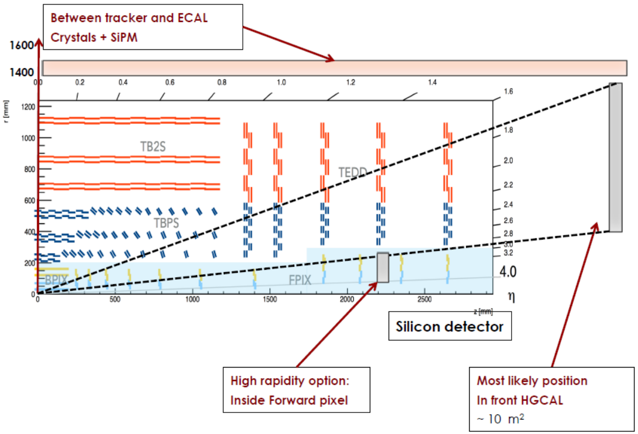
Manual probe station

Wishing list

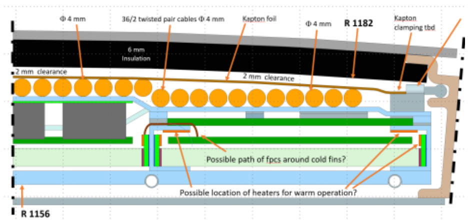
- Complete set of fast current amplifiers (different bandwidths, different gain, etc)
- **Sub ps IR laser** (nJ are sufficient for our purposes), with external trigger, fiber optic coupling and splitting (to shine two different detectors)
- **Optics** for focusing
- **Time-To-Digital (TDC) converters** with ps time resolution (ex SAMPIC)
- Micrometric x-y **motor stages**
- Fast **pulse generator**
- Even faster **oscilloscope (20 GHz)**

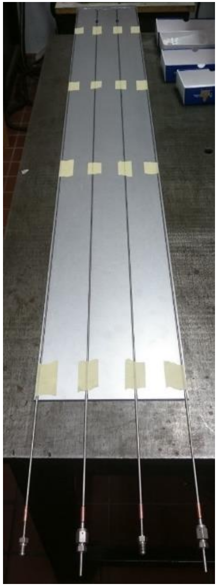
Full chip test in lab

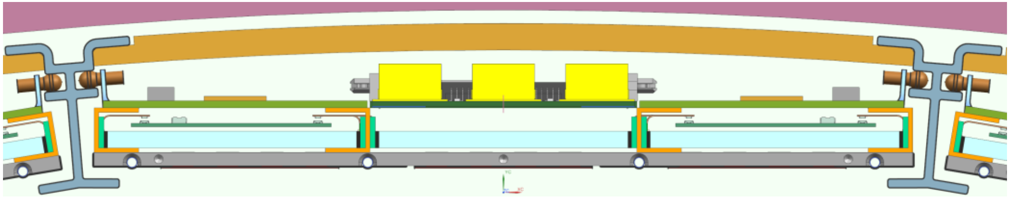
CMS Barrel Timing Layer (BTL) activities in Padova

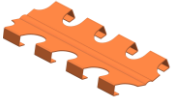


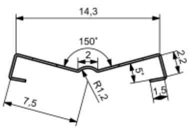
- Tray CAD design and modeling
- FEA thermal simulation
- Tray prototyping of various sizes and solutions
- Assembly and installation study

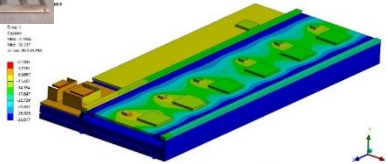








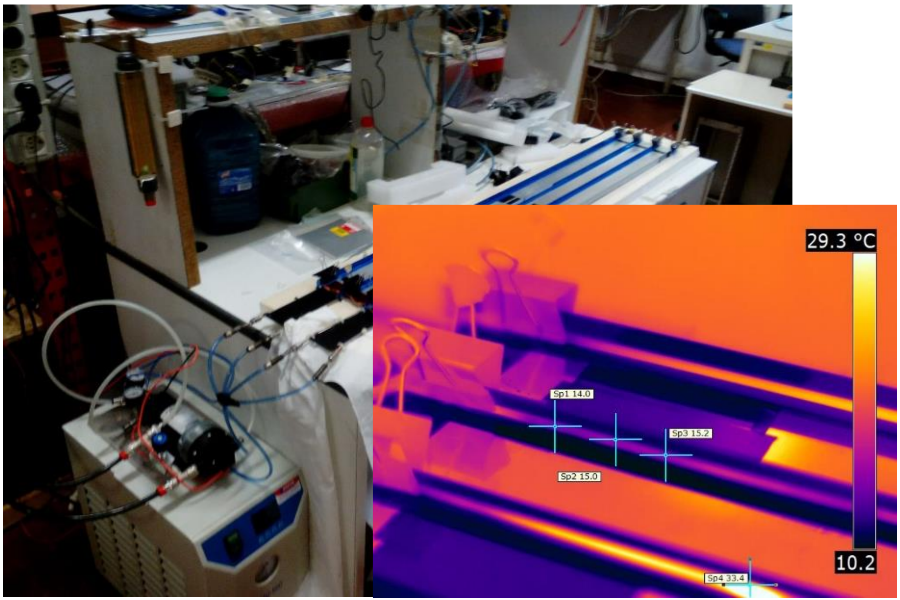




BTL measurements in Padova Labs

- Room temperature setup with half tray mockup for ΔT measurement between cold plate and SiPMs

- Laboratory fridge acquired to perform temperature measurements up to -40°C on small (1 RU) mockup.
- Model LGT 2325, dimensions: **91 x 114 x 74 cm**



Lab: Lab1 67-68
Time: 2 years

Existing expertise

- **Design and development of analog front-end for silicon pixel sensors**
  - Design of fast, low noise analog front-end electronics (with discrete components, no chip design), good for prototyping and testing of a limited number of channels
  - Design, development and production of DAQ (hardware, firmware, software) for silicon sensors R&D (MAPS, SiPM, etc)
- **Silicon sensor testing capabilities**
  - Electrical characterization of silicon sensors
  - Use of different radiation sources (lasers, calibration sources,) for functional characterization
  - Testing facilities for radiation damage studies and dedicated dosimetry systems (X-ray tube, heavy ions, protons, etc)
  - Facilities for interconnection between (very small) sensors and electronics and characterization test equipment (Al wire bonding, probe stations, probe cards, etc)
- **Mechanical design**
  - Team of designer and engineers, mechanical workshop

Expertise which we are acquiring

- **Design and development of analog front-end for silicon pixel sensors**
  - Capability to design and assembling electronics working at very high frequencies (≈ GHz)
  - Capability to work with Time-To-Digital converters (ps time resolution!)

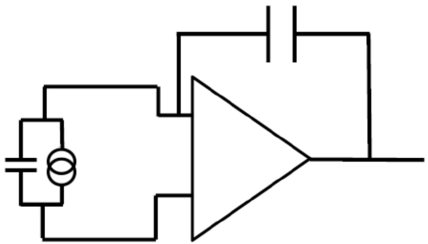
- **Silicon sensor testing capabilities**
  - Capability to build setups using fast lasers

Thanks for attention

backup

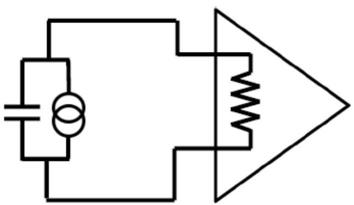
Fast frontend electronics

Integrating Amplifier

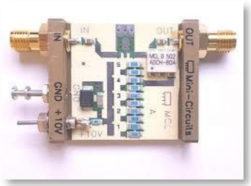


- Slower slew rate
- Lower noise
- Signal smoothing
- Less power

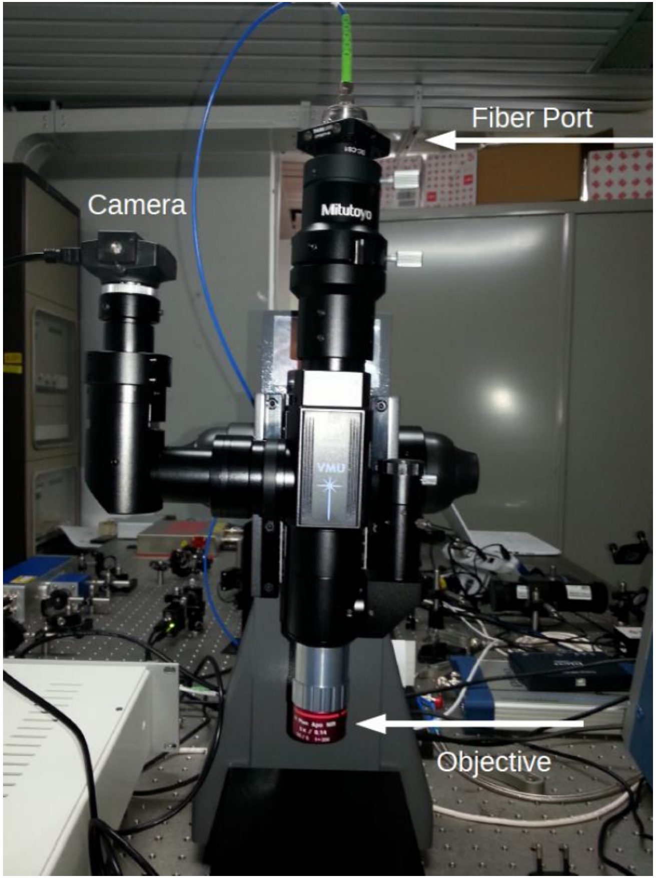
Current Amplifier



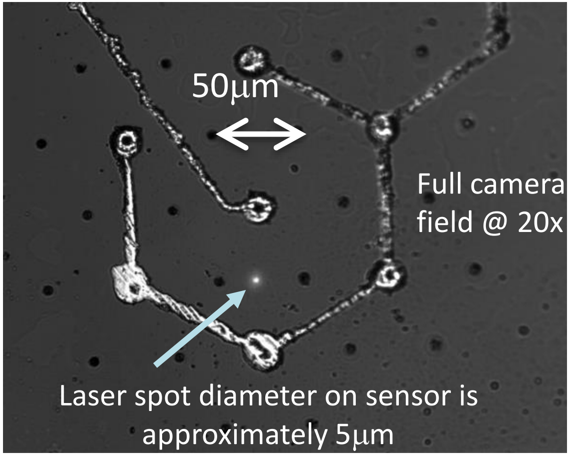
- Fast slew rate
- Higher noise
- Sensitive to Landau bumps
- More power



$$\sigma_t = \frac{\sigma_V}{\frac{dV}{dt}}$$



Fiber Port
Camera
Mitutoyo
VMU
Objective



50μm
Full camera
field @ 20x
Laser spot diameter on sensor is
approximately 5μm