Silicon R&D
DT group meeting

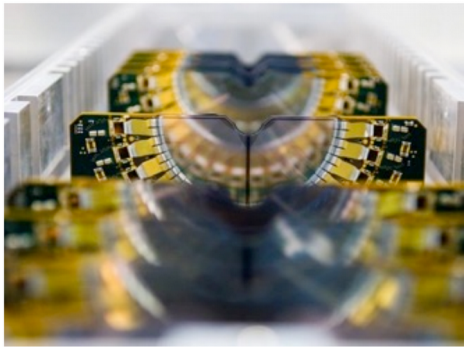
4.7.2018

Matteo Centis Vignali

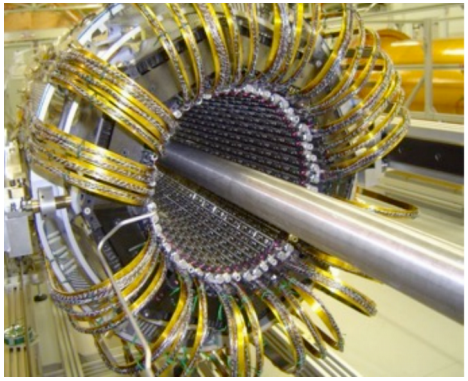
Silicon Tracking Detectors

- Complex systems operated in a challenging high track density environment
- Many developments needed: sensors, electronics, mechanics, cooling, QA, etc.
- EP-DT contributed to many silicon tracking detectors

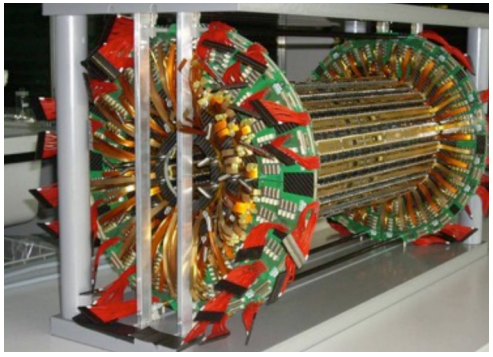
Alice pixel detector



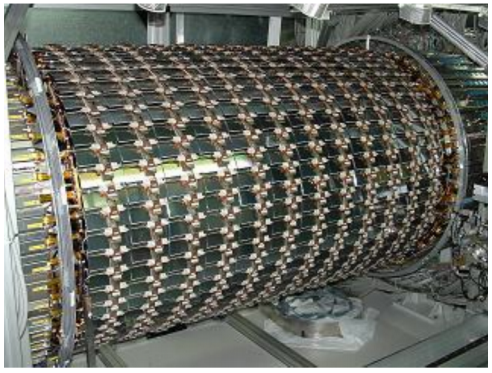
LHCb Velo



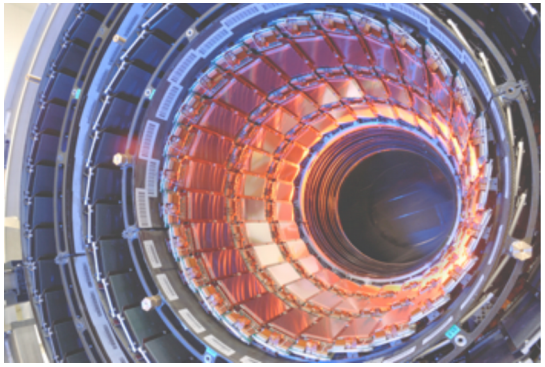
Atlas pixel detector



CMS pixel detector



Atlas SCT barrel



CMS inner barrel

Future Developments

Silicon trackers and calorimeters will be needed in the future

Electron positron colliders

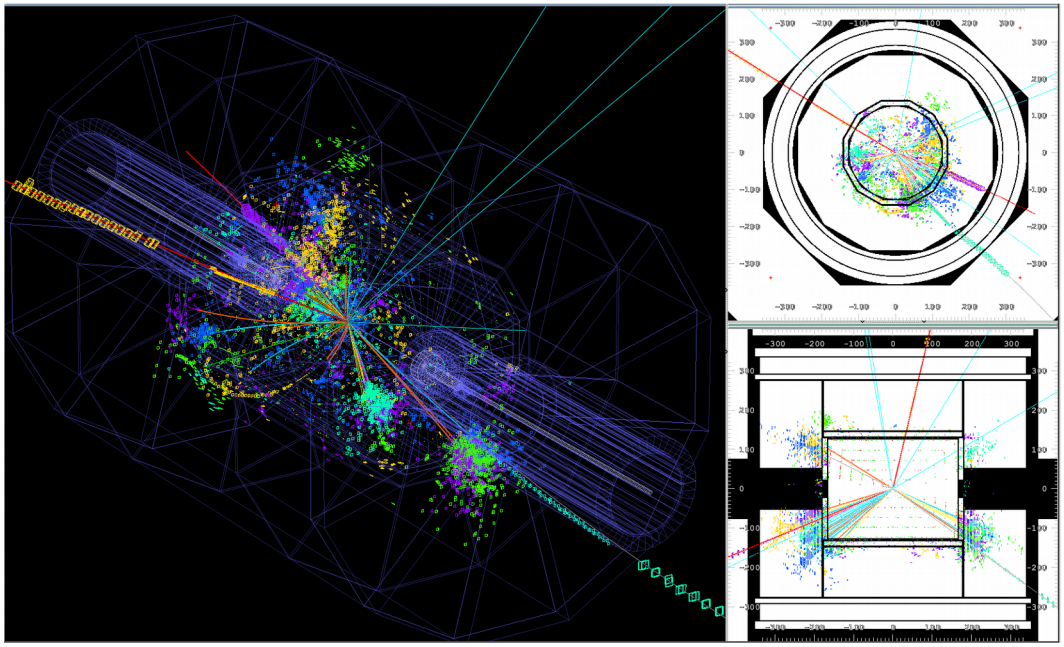
- Clic
- ILC
- FCC-ee

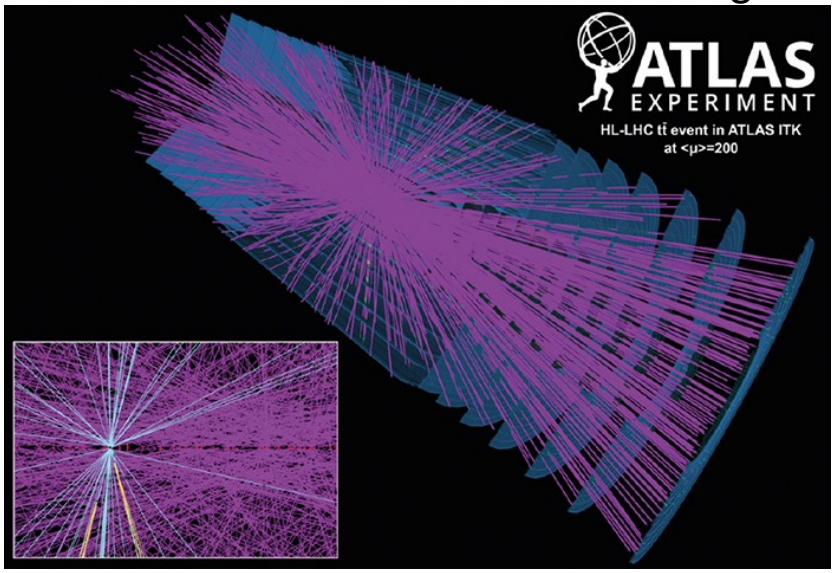
- Reduced material budget
- Low power consumption

Hadron colliders

- HL-LHC
- FCC-hh

- Radiation hardness
- Track density
- Readout speed
- Timing
- Reduced material budget





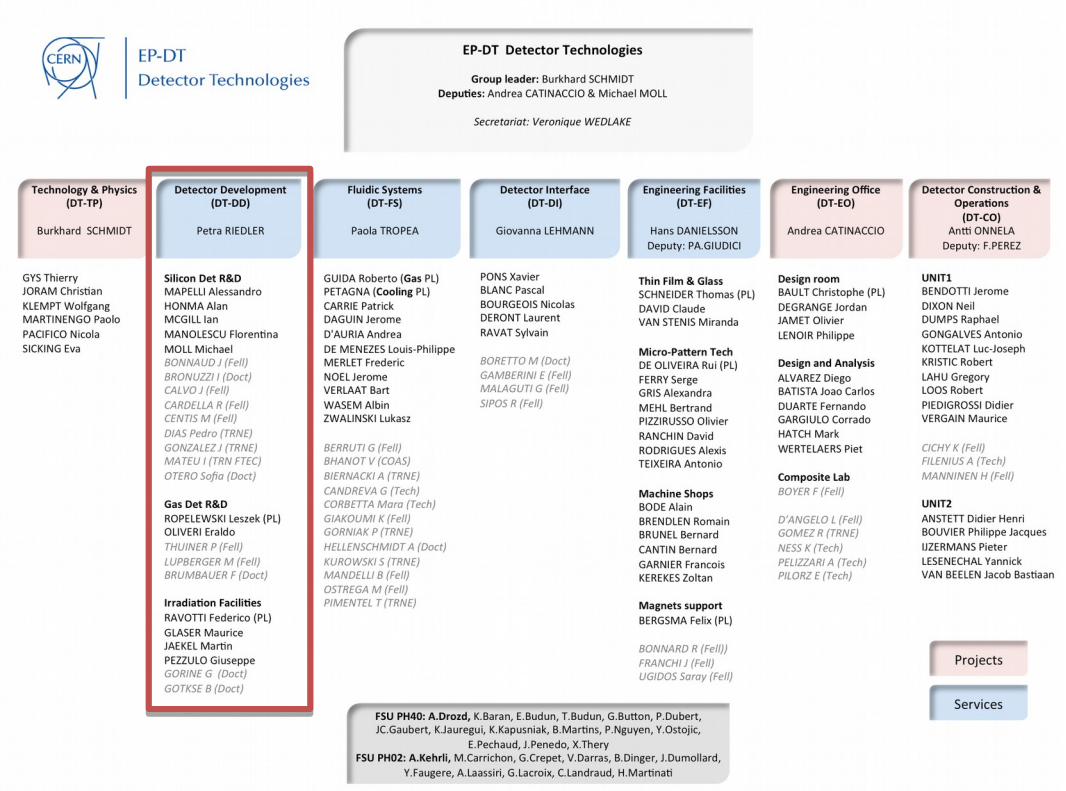
R&D on all aspects of the system is necessary

Silicon R&D in DT

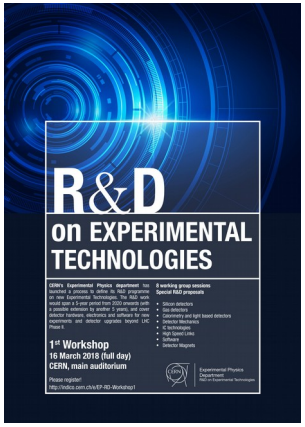
- **EP-DT-DD section provides detector development, R&D and support for**
  - **Silicon detectors** and **gas detectors**
  - Strong involvement in experiments: ALICE, ATLAS, CMS, LHCb, NA62,…
  - Leading roles in R&D collaborations (RD50, RD51)

- **And offers unique services which are also essential ingredients for R&D on silicon**

12 staff
7 fellows (ext. funding)
8 students (doct.+techn.)
2 PJAS
1 trainee



EP R&D WG1 (silicon detectors)
Topics presented in March



CMOS sensors

- Depleted CMOS, small feature size, stitching, timing, ..

Hybrid pixels

- Timing information, design optimisation (active edge,..), extreme environments (radiation, vacuum,..),...

Large pitch silicon sensors and novel developments

- E.g. strips, pads, passive CMOS, LGAD, ...

Device modelling, simulation and characterisation

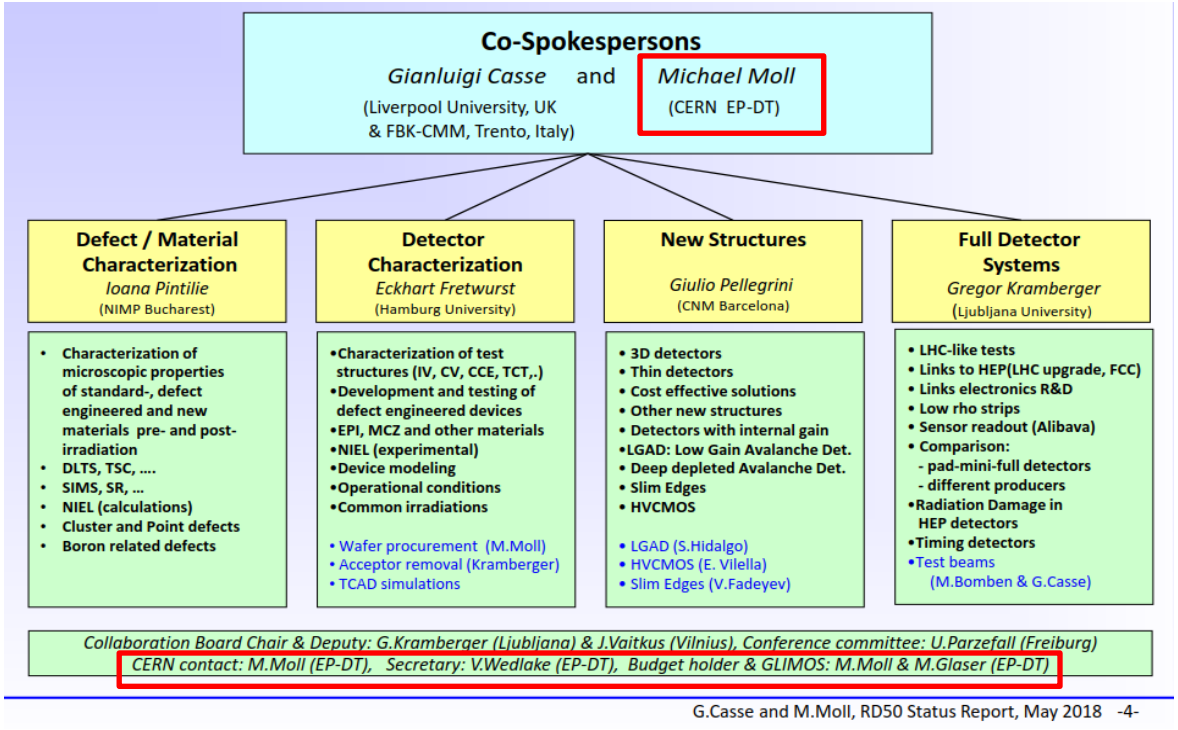
Interconnection and module building

- Industrial techniques, integration of flex functions, post processing, ...

Lab infrastructure and specialized instrumentation

RD50

RD50: Radiation Hard Semiconductor Devices for High Luminosity Colliders
LHC, HL-LHC, FCC, …., fundamental R&D
RD50: *62 institutes and more than 360 members (4 institutes just joined)*




RD50 Prolongation Request: May 2018

CERN, 31 May 2018

RD50

RD50 Prolongation Request

– May 2018 –

The RD50 Collaboration

Abstract

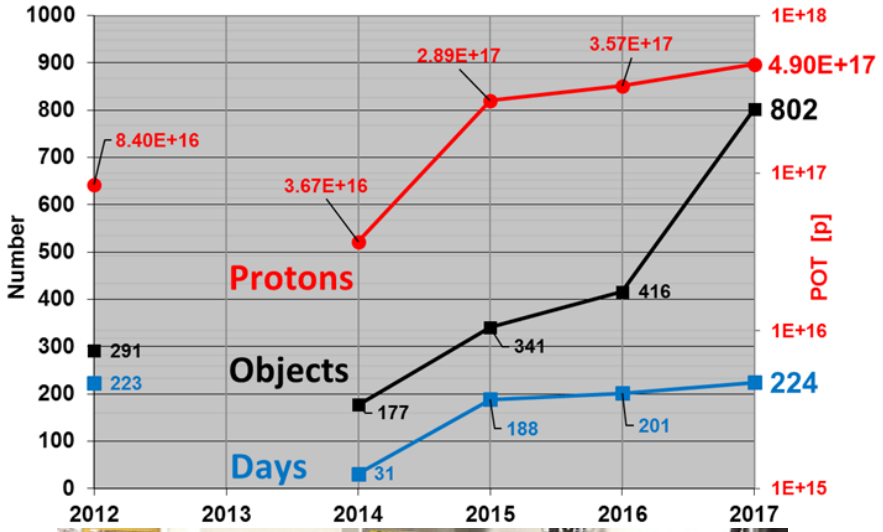
With this document, we request the prolongation of the CERN RD50 research program for 5 years. A very brief historical review of the RD50 research program since the RD50 project approval by the Research Board in the year 2002 is presented and the biggest RD50 achievements are highlighted. The present composition of the collaboration, its organizational structure, and the research methodology are described. The role of RD50 in the present various upgrade and research programs of the LHC Experiments community is given and the overall work plan explained. Finally, a detailed 5-years work program with precise milestones and deliverables for the various research activities is presented. We conclude with our prolongation request towards the LHCC.

CERN-LHCC-2018-017 / LHCC-SR-007

https://cds.cern.ch/record/2320882/files/LHCC-SR-007.pdf

5 years work plan submitted to LHCC on 31 May 2018
Very detailed program, all planned SSD activities are part of this work program
Participation based on assumption continuous budget and personnel level as of today
New MOU (5 years) in preparation; Input for European Strategy Group under preparation

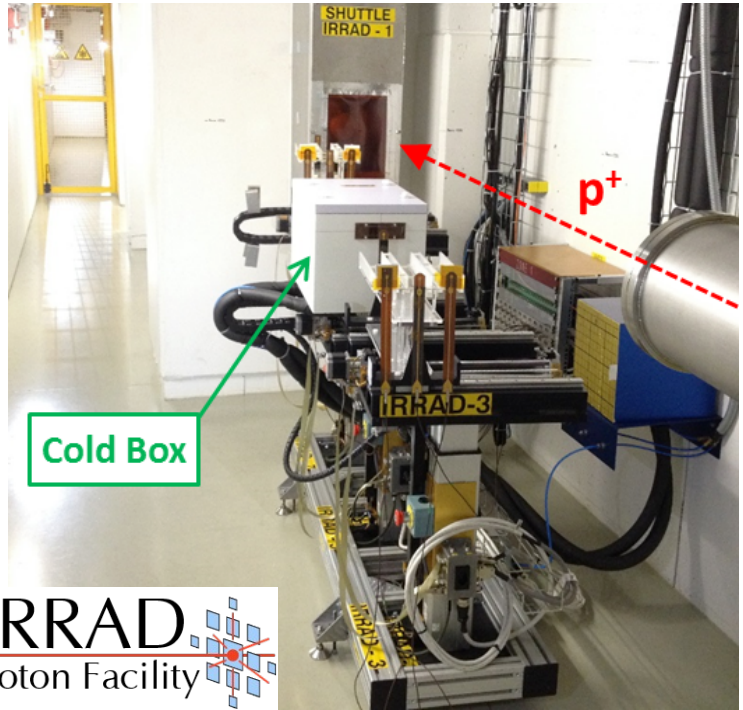
Irradiation Facilities

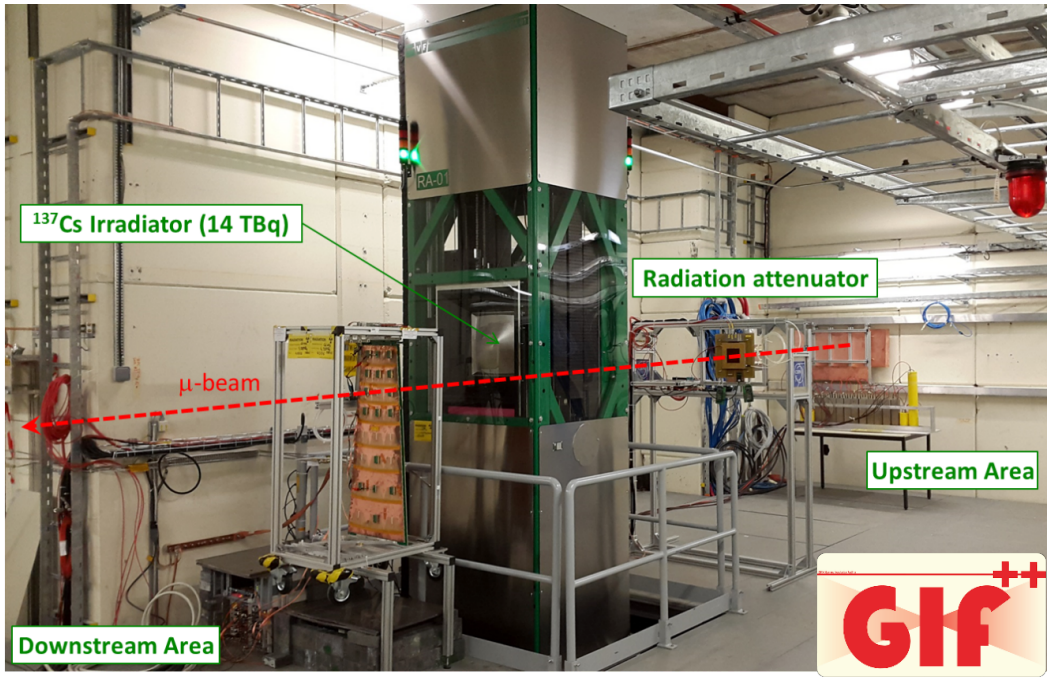


- Proton irradiation facility IRRAD
- Gamma irradiation facility GIF++
- Fundamental for detector development
- Sensors, electronics, materials, etc.
- Irradiation demand increasing

Irrad in 2017:
- 46 experiments
- 802 objects

GIF++ in 2017:
- 26 setups





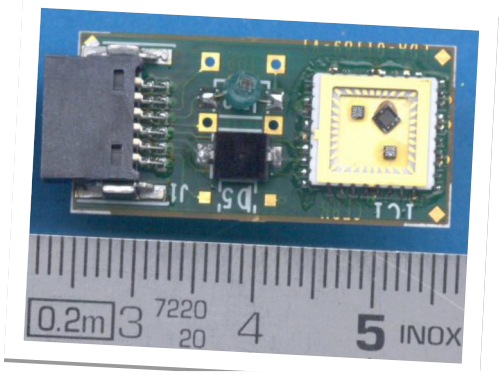
IRRAD Proton Facility

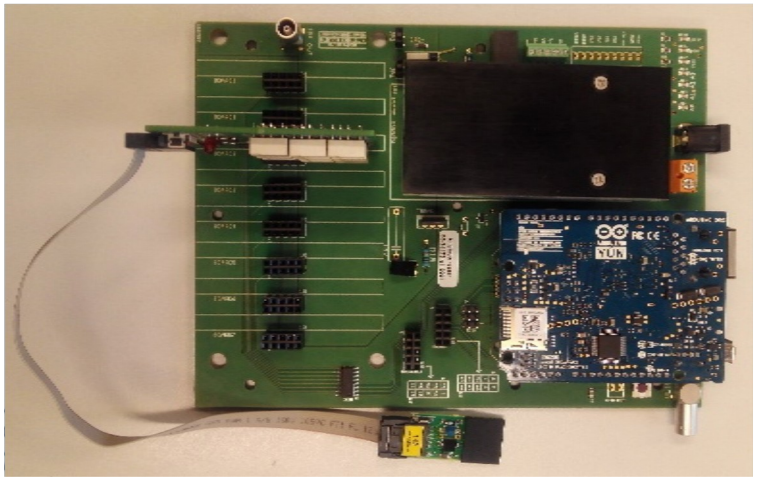
GIF++

Dosimetry

RADMON and ReadMON:

- Dosimetry at LHC experiments
- Measurement of dose and particle fluence
- Development of a compact, portable, and low-cost readout system



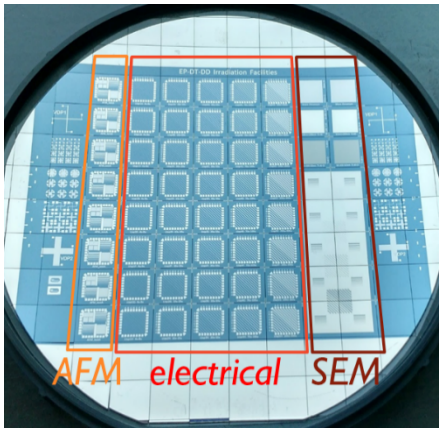


Dosimetry for FCC-hh:

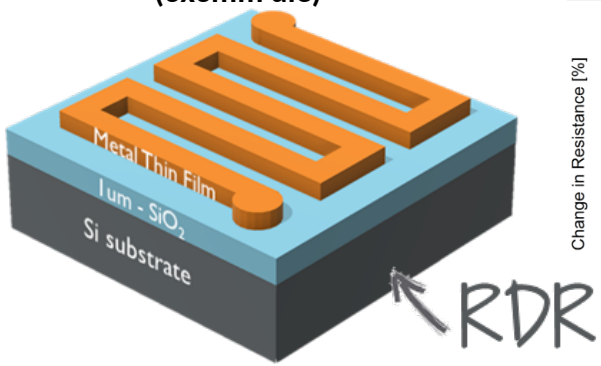
- Unprecedented fluences and doses
- 10-100 MGy
- Radiation Dependent Resistors
- Vacuum transistors
- Microfabrication capabilities fundamental for this application

CMi EPFL Center of MicroNanoTechnology
EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE
✓ *Design and Microfabrication*

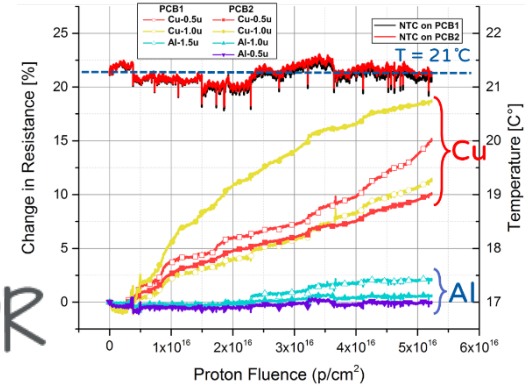
CERN EP DT Irradiation Facilities
✓ *Irradiation and Characterization*



5nm÷1µm (3x3mm die)



Proton Irradiation Results

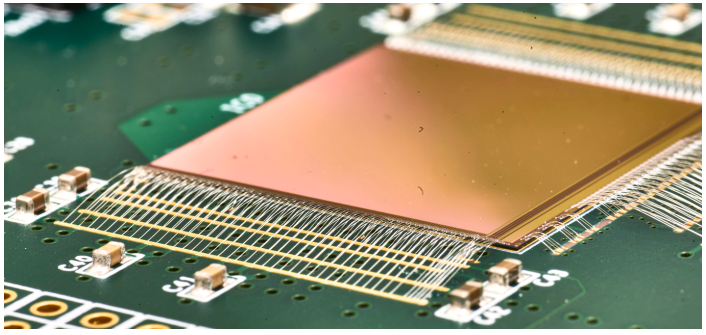


Bondlab

- Providing **Al Wedge Wire Bonding** service to all experiments and Cern related projects.

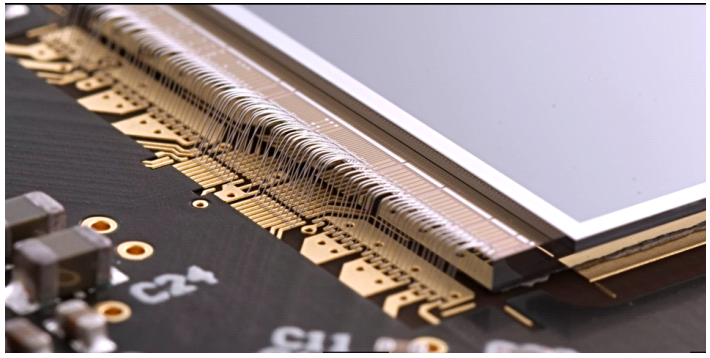
  Until June 2018 worked on 25 projects with ~ 100 pieces per month:

  - ALICE ITS, MFT - production
  - ATLAS STREAM, ITK Demonstrator
  - CMS upgrade, HCAL, GEM
  - NA62 GTK
  - Medipix, TMPX, CLICpix
  - RADMON
  - RD50, RD51,RD53
  - EP-ESE: prototypes



- Providing support and assistance in designing detector modules which regards bonding issues

- Extend communication on fine pitch wire bonding, support and advice to the community



QARTlab / DSF

Quality Assurance and Reliability Testing Laboratory

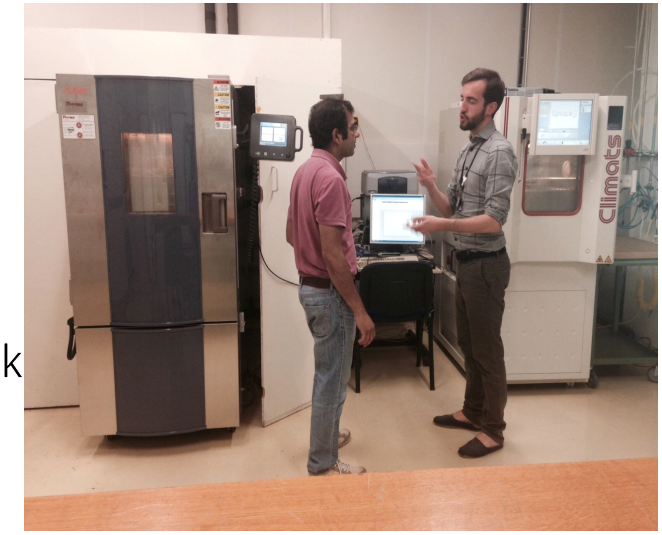
- Guidance and support regarding QA (quality assurance) planning:

methods & processes, risk analysis, standards, specifications, quality control technology development and design feed-back

- Consulting regarding reliability testing :

ageing tests, failure analysis, evaluation & qualification of component or assemblies

- During ffirst halff off 2018 already 18 work requests (tests can last several weeks!)



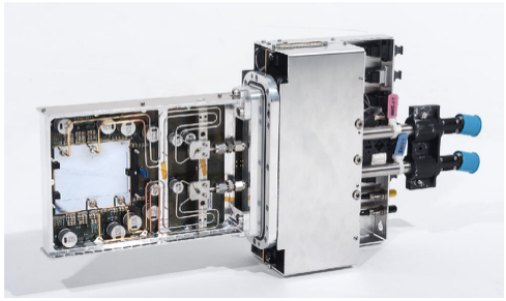
Departmental **S**ilicon **F**acility

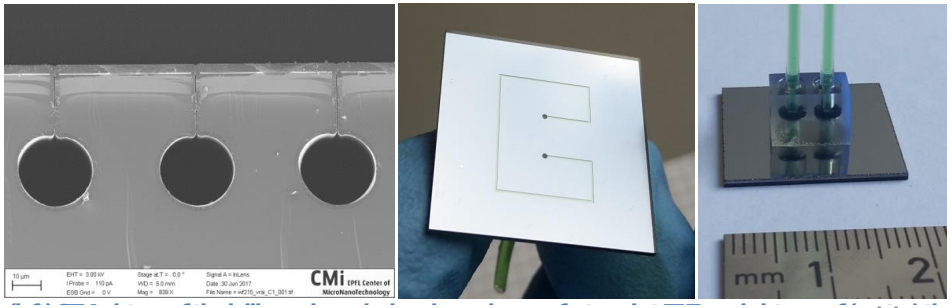
- Shared cleanroom (330 m2)

Users (2018): ALICE ITS, ALICE MFT, LHCb upgrades (chip R&D), Medipix, ATLAS ITK (pixel), CMS phase 2 tracker upgrade, CMS silicon forward ECAL phase 2 upgrade, LCD silicon calorimeter R&D

Microfabrication

- Technical and administrative support to users across CERN for **microfabrication activities in external silicon-processing facilities**.
- **Coordination of EPFL cleanroom activities** (for EP, BE, TE) and R&D on new particle detector concepts.
- **Support to LHC and non-LHC experiments** for microfabrication technologies, microsystems engineering and module assembly
  - NA62 GTK
  - LHCb Velo Upgrade
  - ATLAS ITk Demonstrator





SSD/RD50

Sensor development and characterization for high radiation environments

Current activities

RD50 collaboration:
- Spokesperson
- Acceptor removal
- Timing
- New characterization techniques
- Monolithic detectors
- Contact to IRRAD facility

CMS HL-LHC upgrade:
- 3D pixel sensors
- Endcap timing layer
- HGCAL

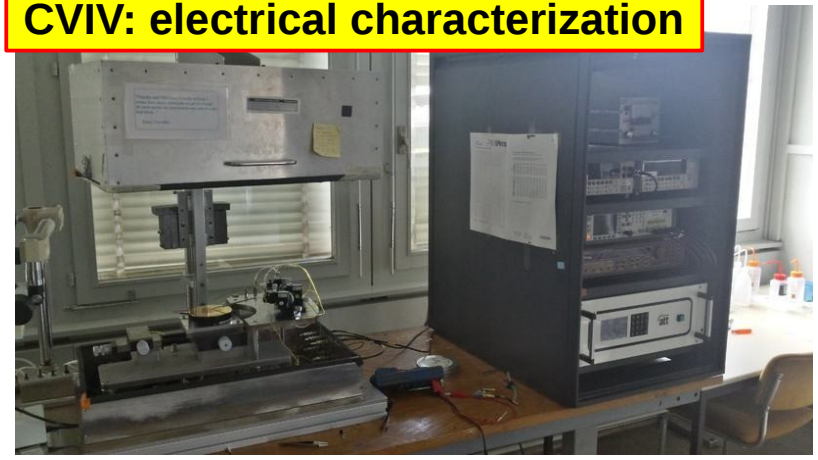
Material characterization:
- Macroscopic properties
- Microscopic effects

Sensor characterization:
- Electric field
- Charge collection
- Time resolution
- Detection efficiency

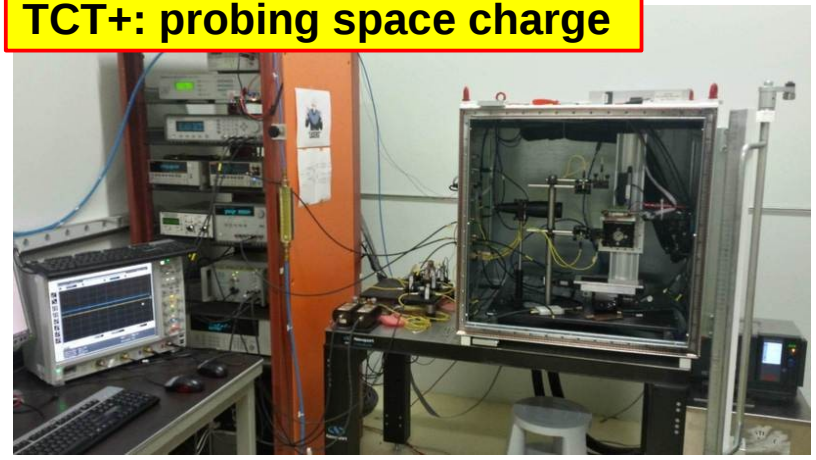
General support to other groups for Si detectors R&D

SSD Setups

CVIV: electrical characterization

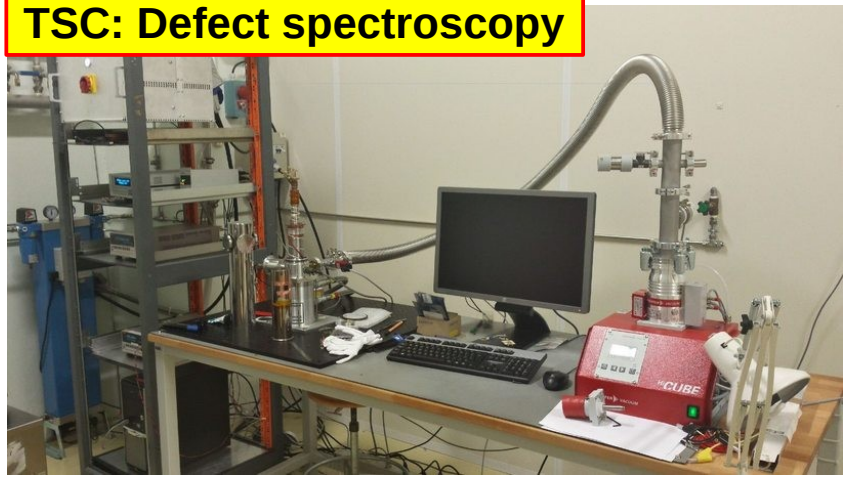


TCT+: probing space charge



Charge collection

TSC: Defect spectroscopy

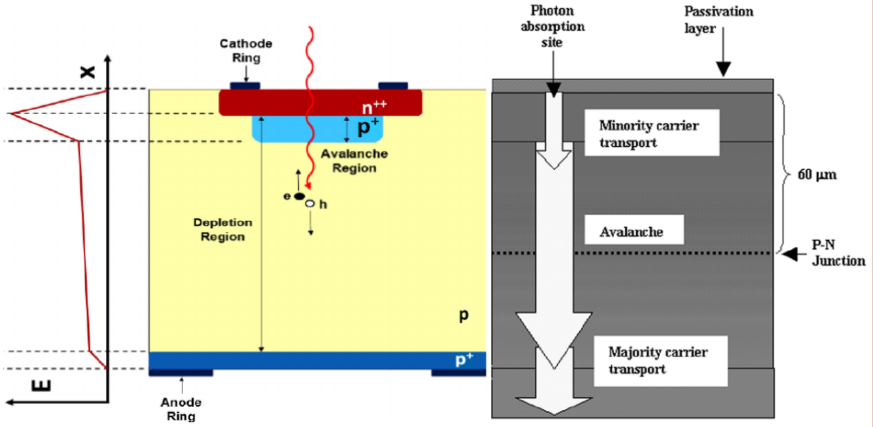


….and TPA-TCT under **construction**

SSD R&D

Timing detectors

- RD50 pioneered concept of detectors with low built-in **gain** (LGAD) to **compensate charge loss by radiation**.
- **Gain** is the driving force for **timing**.
- We study CNM-LGADs and APDs as timing detectors.
- TCT+ setup upgraded for timing measurements



Defect spectroscopy

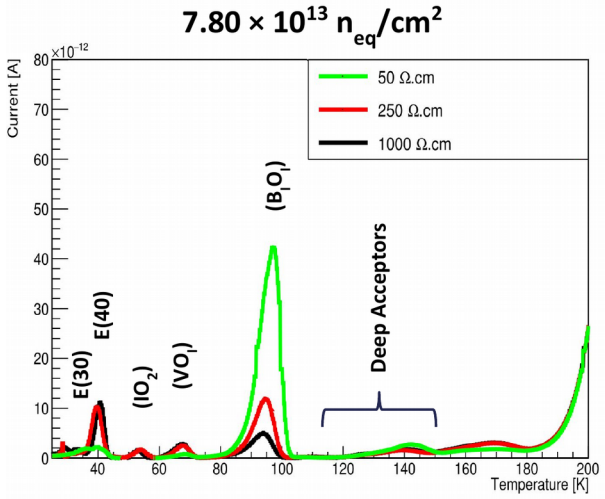
- Interest on acceptors dopant removal in Si recently triggered by:

→ usage of low resistivity bulk for **monolithic detectors** (**CMOS**)

→ multiplication layer of **LGADs**

→ **p-bulk** detectors

- First measurements on a new **TSC setup** where we investigate the microscopic mechanism that leads to B deactivation.



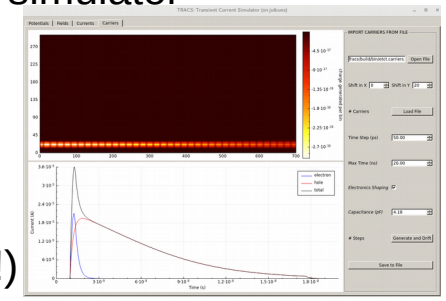
SSD R&D

TPA-TCT

- KT fund to develop 3D-**TCT** laser testing system with a **point-like** light source
- 1PhD student involved in this project.
- Tendering process done. Two best suppliers identified. We just visited most likely laser producer.
- Goal is to have setup assembled by end of 2018.

Software development

Fast Ramo current simulator



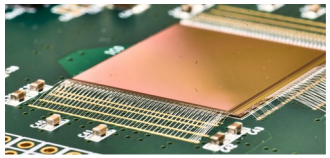
- Fit to data (new!!)
- Parameterize change of doping profile with fluence

Beam tests

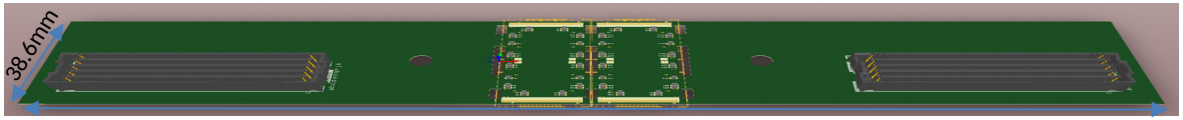
- RD53a pixel modules for CMS
- Timing of APDs, collaboration with RD51

Pixel R&D

Pixel R&D for future detectors working on development and study of pixel chips, module concepts and assembly → **enable novel solutions for future trackers**



Pixel chip



pixel module

STREAM EU Marie Curie training network (started 2016)

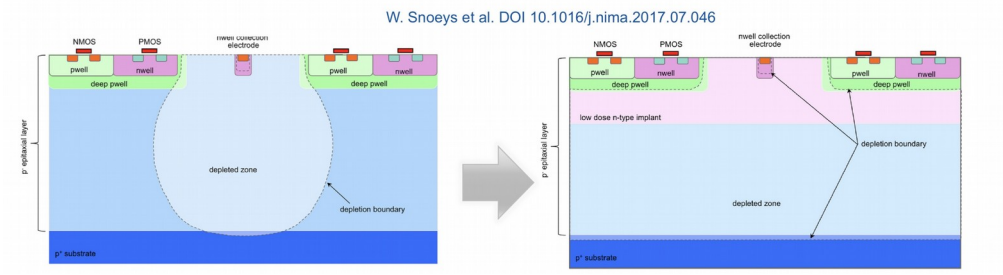
Team composed of STREAM ESRs (DT, ESE, ADE), EP-ESE members, ATLAS members and close collaboration with outside institutes working in the ATLAS CMOS team

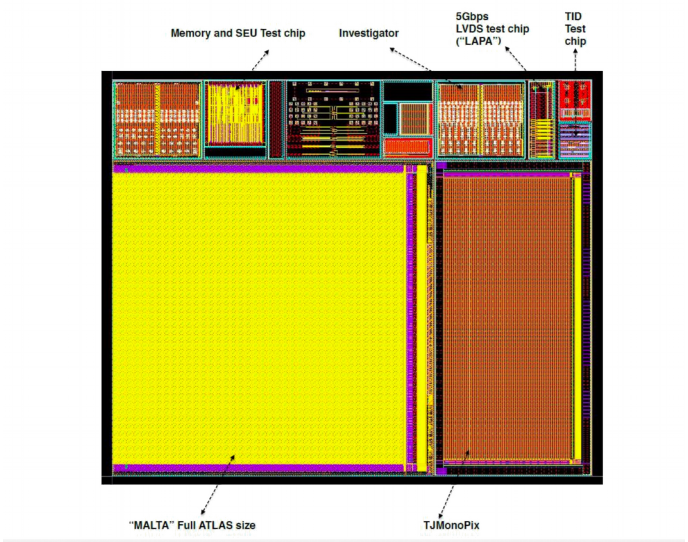
Presently focussing on:

- **CMOS (depleted MAPS) for upcoming projects (e.g. proposed for ATLAS outer pixel layer)**
- **Hybrid pixels** with special interest in interconnection, thinner assemblies,…
- **Module building and system aspects including post processing**

Pixel R&D

- **Design of a novel CMOS pixel sensor** in a commercial CMOS imaging process (0.18 um CMOS povided by TowerJazz)
- Same technology as used by the ALICE ITS but with a process modification to provide **better radiation hardness:**

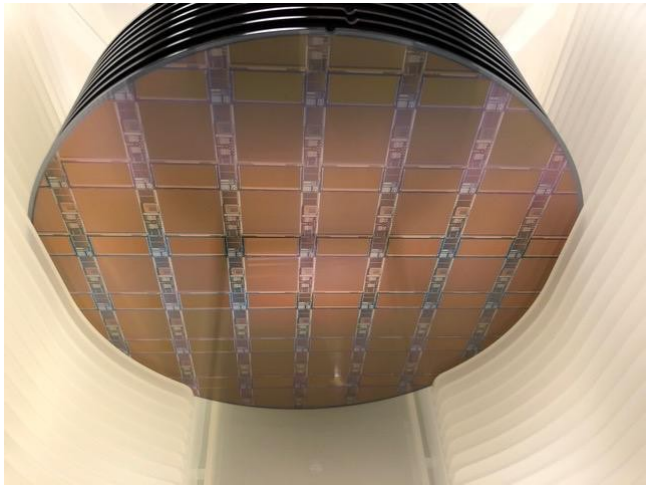




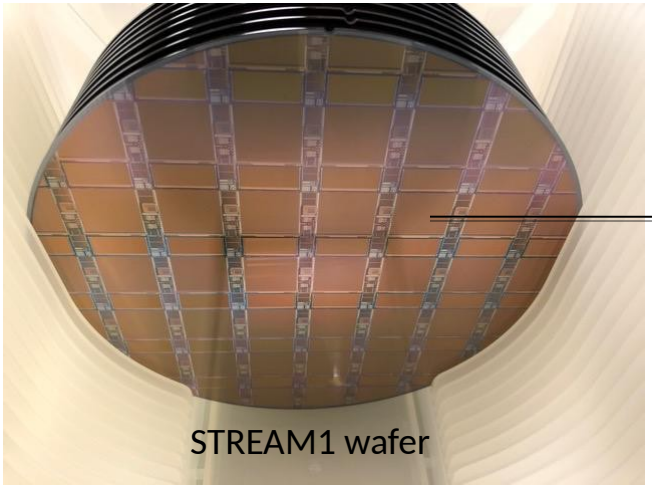
STREAM1 reticule and wafers

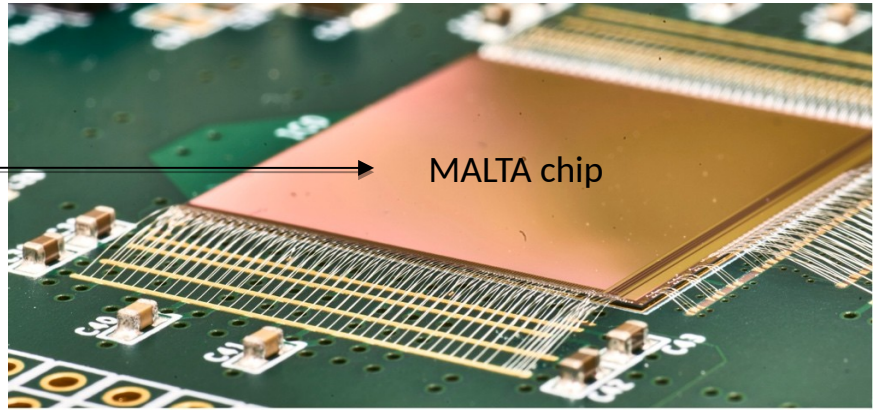
STREAM1 submission (2017):

- 2 large pixel chips (MALTA and MONOPIX) compatible with ATLAS L4 requirements
- Test structures to study interconnections techniques and module assembly
- Processing on two different starting materials (epi thickness)



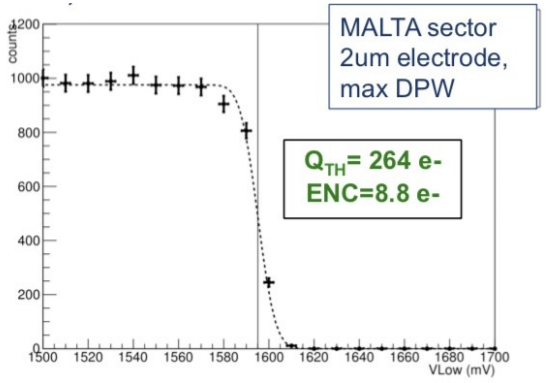
Pixel R&D

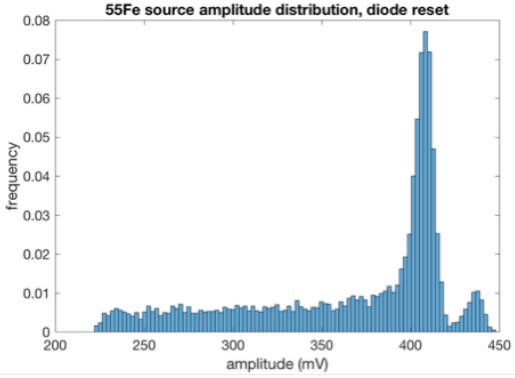




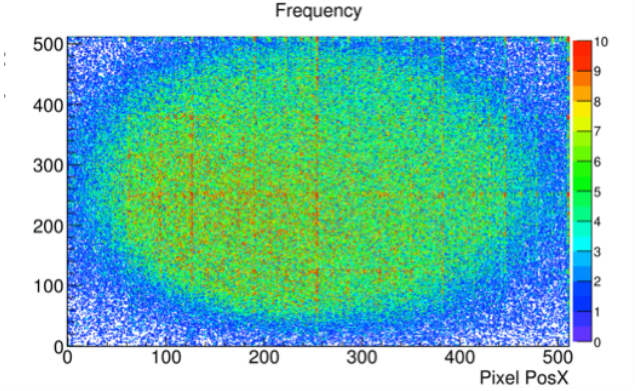
MALTA: full size CMOS pixel chip (2 cm x 2 cm) with novel readout architecture, compatible with the ATLAS outer pixel layer requirements

- 512x512 pixels (36 x 36 µm^2 pixels)
- No hit memory in active matrix
- All hits are asynchronously transmitted over high-speed bus to EoC logic
- **No clock distribution over active matrix**



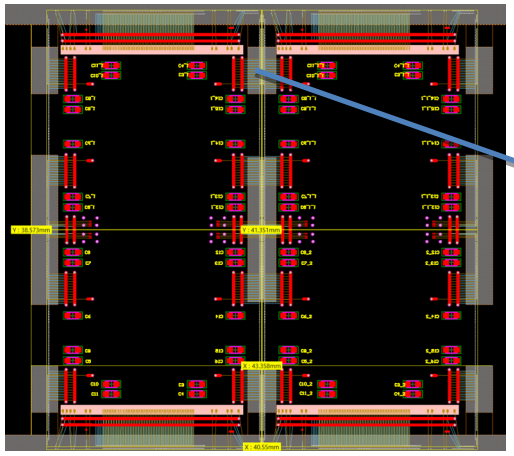


MALTA: ^{55}Fe source 5.9 keV (1640 e- signal)



MALTA Sr90 source measurement
uniform response across all sectors

Pixel R&D: Module and System

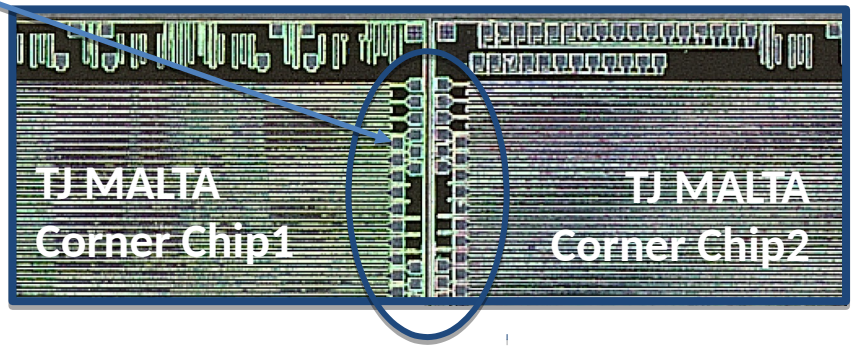


Flex design for 4 MALTA chips

MALTA 4-chip flex design compatible with **ATLAS pixel quad module.**

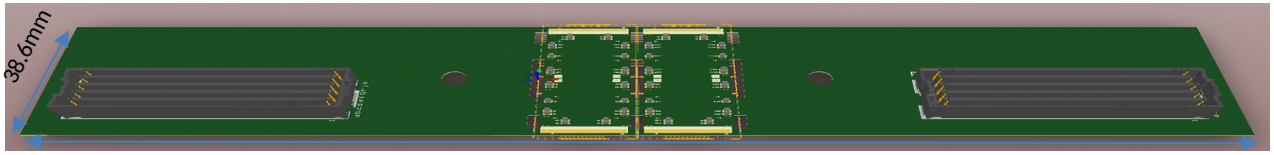
Explore chip-to-chip data transmission and power distribution capability of MALTA:

Corner area between 2 chips:



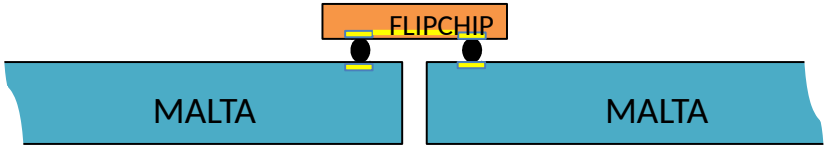
Chip-to-Chip data interconnection

Interface for module testing matched to MALTA test board: will allow using the same test system as for single chip PCBs, but testing full size quad modules (ATLAS type)



Pixel R&D: Module and System

Dedicated **flip-chip structure** included in the STREAM 1 wafers to explore **high speed chip-to-chip data transmission and power distribution** (pad-compatible with MALTA)
→ interconnection studies



LAPA: test chip with 10 data transmission channels to study system aspects included in the STREAM1 submission

- CMOS/LVDS selectable in/out
- 5 Gb/s LVDS I/O
- Successfully tested at 5.12 Gb/s!
- Tests adding flex cable ongoing (already working at 1.28 Gb/s)

- 40 transmitters embedded in MALTA

LAPA eye diagram – 5.12 Gb/s

Summary

- EP-DT has several activities for development of silicon detectors
- All aspects of such complex systems addressed within the group
- Infrastructure is fundamental:
  detector preparation, characterization-irradiation-characterization, QA
- Set of competences across EP-DT allows this line of research

EP-DT-DD is pursuing an ambitious and well defined silicon R&D program that is fully in line with the EP-DT R&D initiative and the recently approved RD50 5 years R&D plan