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CERN Workshop on R&D For Experimental Technologies

An Overview

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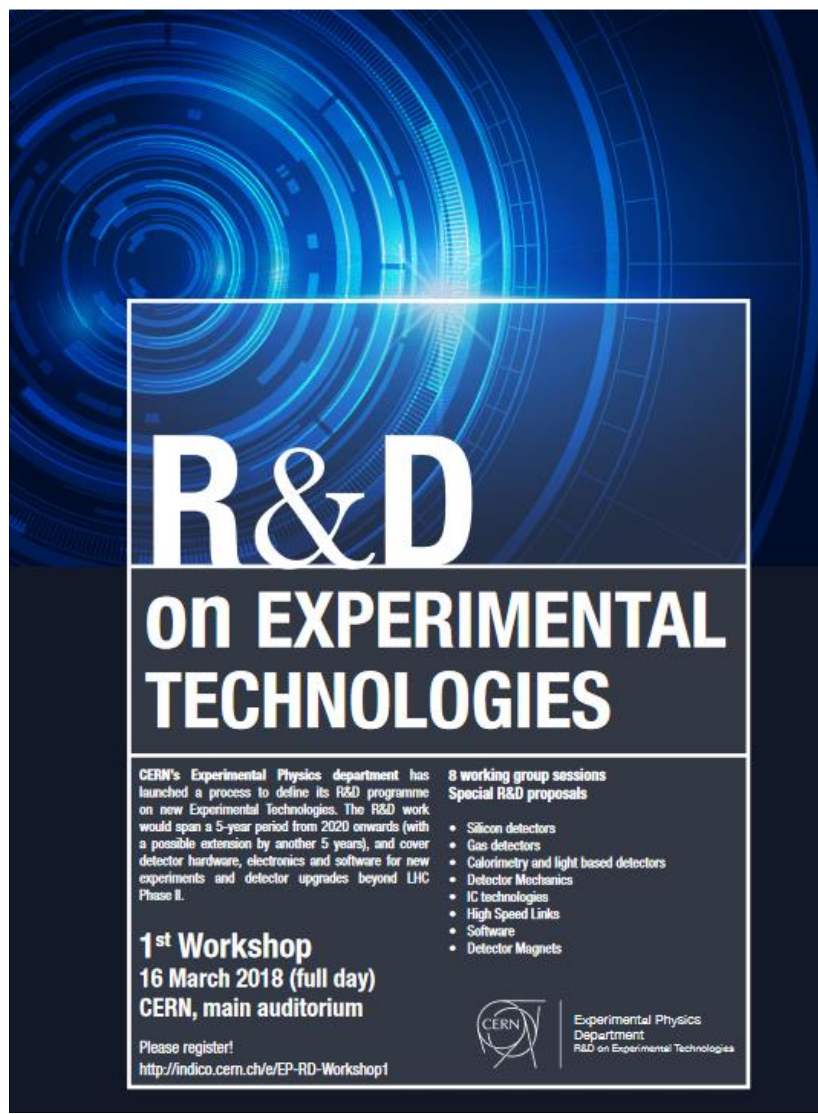
Detector R&D Advisory Group
12 April 2018

1st Workshop on R&D for Experimental Technologies
General



Full Day Workshop on Experimental Technologies
Sponsored by CERN Experimental Physics Department

Many efforts of interest to our group discussed

Organized by Working Groups:

- ***Silicon Detectors***
- Gaseous Detectors
- ***Calorimetry and Light Based Detectors***
- Detector Mechanics
- ***High Speed Links***
- ***IC Technologies***
- Software
- Detector Magnets

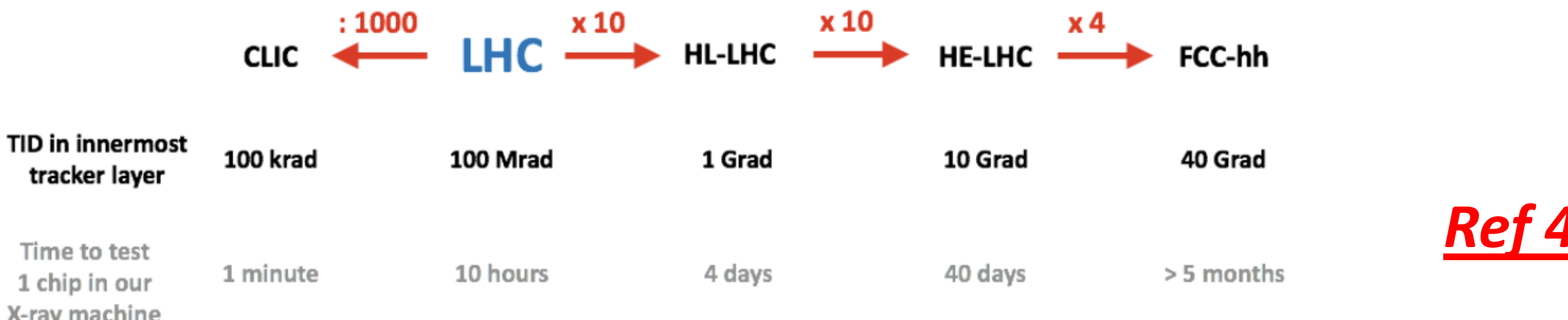
Material Summarized Here Can Be Found At:
https://indico.cern.ch/event/696066/

1st Workshop on R&D for Experimental Technologies General

Scope of the discussions: HL-LHC and Beyond Radiation Environments

Radiation tolerance requirement is strongly machine dependent

Here reference TID levels are in the innermost tracker layer (note that in some cases the forward calorimeters might be exposed to larger doses, such as in FCC-hh).For a lepton FCC machine, no simulation of the detectors' environment is still available.



Ref 4

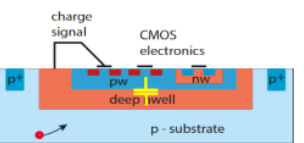
	RHIC STAR	LHC - ALICE ITS	CLIC	HL-LHC Outer Pixel	HL-LHC Inner Pixel	FCC pp
NIEL [n_{eq}/cm^2]	10^{12}	10^{13}	$<10^{12}$	10^{15}	10^{16}	10^{15}-10^{17}
TID	0.2Mrad	<3Mrad	<1Mrad	80 Mrad	2x500Mrad	>1Grad
Hit rate [MHz/cm^2]	0.4	10	<0.3	100-200	2000	200-20000

Ref 1

1st Workshop on R&D for Experimental Technologies
Working Group 1: Silicon Detectors

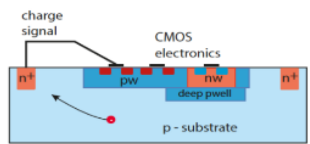
WG1 Topics:
CMOS Sensors

- Large electrodes



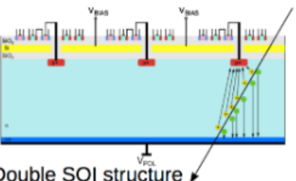
- Electronics in collection well
- No or little low field regions
- Short drift path for high radiation hardness
- Large(r) sensor capacitance (dpw/dnw) ->higher noise and slower @ given pwr
- Potential cross talk between digital and analog section

- Small electrodes



- Electronics outside collection well
- Small capacitance for high SNR and fast signals
- Separate analog and digital electronics
- Large drift path -> need process modification to usual CMOS processes for radiation hardness

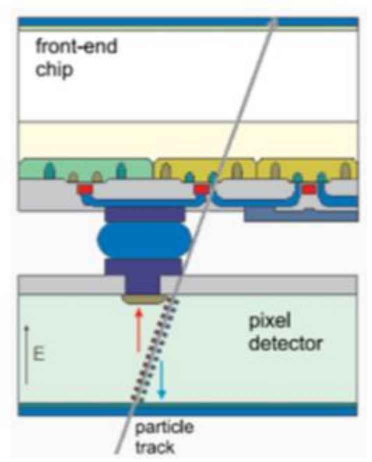
- "Burried" electrodes (SOI)



- Electronics and sensor in separate layer
- Can use thick or thin high resistivity material and HV (>200V)
- Special design/processing to overcome radiation induced charge up of oxides

Hybrid Pixels

Hybrid Pixel Detectors



- Front-end chip
  - Depending on application we need specialized FE-ASIC (covered in ASIC WG), hence we have a clear interface with FE chip development for silicon sensors has much
- Sensor developments
  - For very high radiation and track density (e.g. 3D sensors, active edge planar)
  - Sensors for 4D tracking, i.e. spatial and time information (e.g. pixel sensors with trench electrodes)

Interconnection Issues ($)

Wafer-wafer or wafer-die

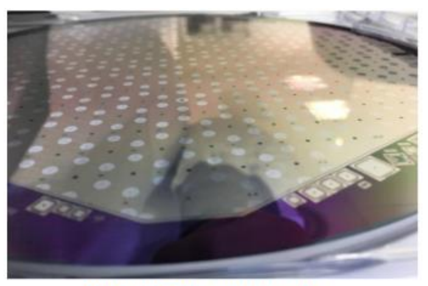
Cu-cu direct
DBI
TSV

WG1 Topics:

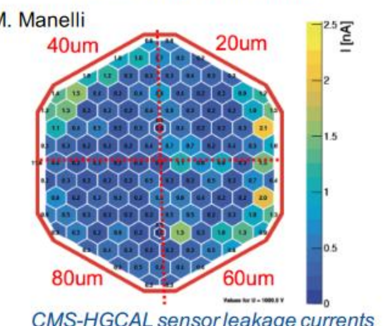
Large Pitch and Timing Detectors

- Many challenges at **system level**:
  readout ASICs, clock distribution,
  module design, interconnects, cooling, automated production

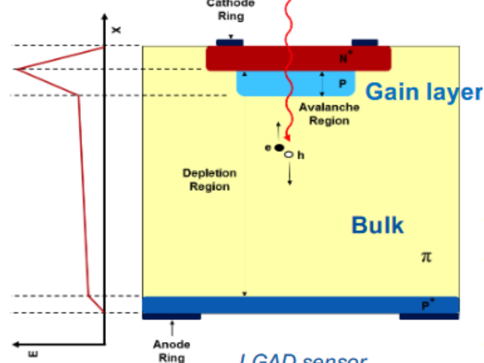
- Silicon-specific R&D needs (WG 1):
  - **Sensor technology**: planar, passive CMOS, LGAD
  - Sensor **characterization** and **simulation**
  - Understanding/mitigation of **radiation effects**



CMS-HGCAL sensor wafer



CMS-HGCAL sensor leakage currents



LGAD sensor

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

Several vendors: CNM, FBK, HPK

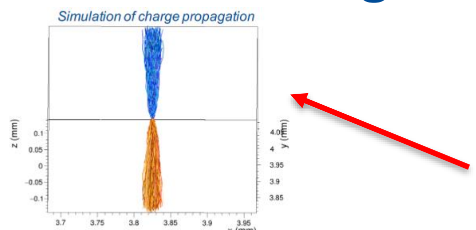
Reached **~20 ps** for few mm^2 size sensors

→ considered for HL-ATLAS/CMS/LHCb **timing layers**

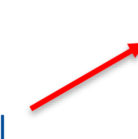
1st Workshop on R&D for Experimental Technologies
Working Group 1: Silicon Detectors

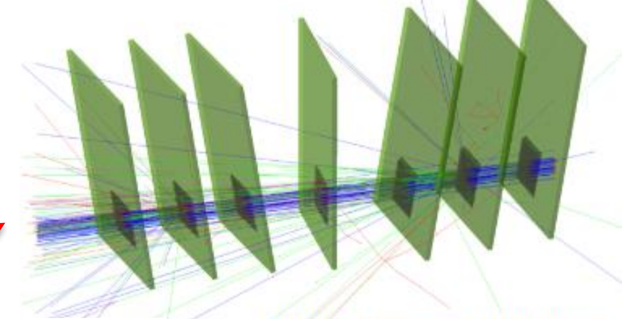
WG1 Topics:

Device Modelling and Simulation



Wide range of simulation scope from Charge level to Plane level

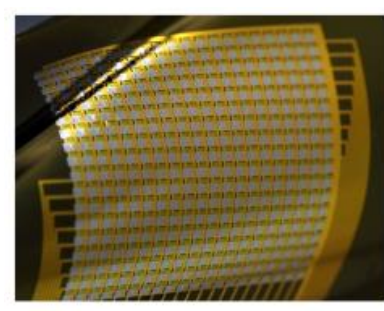



Beam-telescope simulation

Interconnection and Module Construction

LED Professional, 13 Sep 2011, https://goo.gl/aVkLzo

Materials and design for stability and thermal management (CTE, material budget)



Techniques and materials for fabrication and assembly (printing, adhesives)

http://engineering.nyu.edu/press-release/2011/11/14/

Lab Infrastructure and Specialized Instrumentation

Essential Facilities Include:

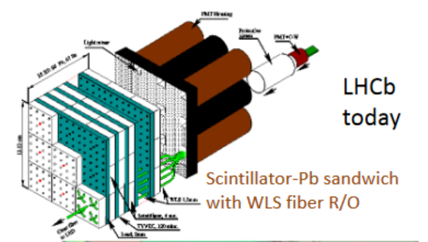
- Prototyping facilities
- Clean rooms
- Irradiation facilities

IRRAD 2017

Registered experiments	46 (3 postponed)
Users / user teams	32
User institutes	19
Irradiated objects	**802**
Measured Al-foils dosimeters	**>600**
Max requested fluence	1×10^{17} p/cm^2

1st Workshop on R&D for Experimental Technologies Working Group 3: Calorimetry

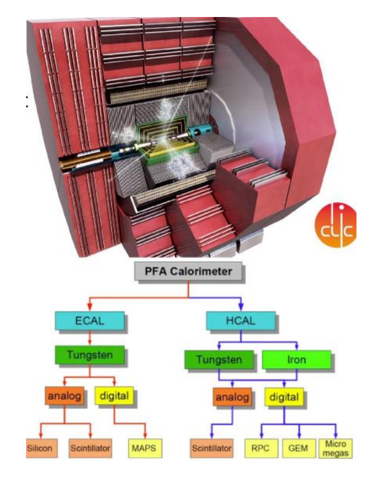
Possible Calorimetry Technologies for Future Detectors (a sample):



LHCb Beyond HL-LHC

Homogeneous crystal calorimeter with longitudinal segmentation
Sampling Calorimeter (e.g. Shaslik or SpaCal type)

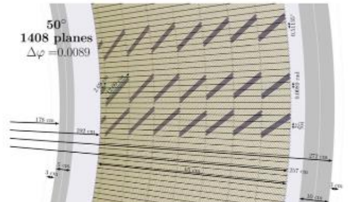
CLIC/ILC – CALICE



Large area Si Arrays
Segmented Gas Amplification Structures
SiPMs on scintillator tiles or strips

FCC-hh

HG EM Calorimeter based in Noble Liquid in Barrel Region
Hadronic Calorimeter: Scintillator/Steel (barrel) Noble Liquid for Endcaps and Forward Calorimeter



1st Workshop on R&D for Experimental Technologies
Working Group 3: Calorimetry

Large variety of active materials considered for calorimetry for future accelerator experiments. R&D needs depend on technology:

- **Scintillator/crystal based**
  - Radiation hardness of crystals, fibres, SiPMs (Photon detection → see next talk)
  - Timing performance: understanding and improving the full detection chain
- **Si based**
  - Cost-effective solutions
  - Radiation hardness
  - Timing resolution (down to 10-20ps hit timing)
- **Noble liquid based**
  - High granularity challenge → read-out electrodes, feedthroughs
  - Noble liquid properties under high ionization rates
  - Cryostats with minimal material
  - Timing performance (down to 20ps for showers)
- **Gaseous detectors based**
  - Homogeneity, mechanical structures, reliability

Presented projects clearly not exhaustive! Please contact us, if you find important ideas missing!

The next step is to further evaluate the challenges in each field and converge on proposals of R&D projects

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Working Group 6: High Speed Links

Development of Links is highly dependent on:

- **Machine** being considered
  - Radiation environment
    - HL – LHC: > 100 Mrad
    - CLIC: < 1 Mrad
    - FCC: > 1Grad
  - Timing requirements (beam structure)

- Type of **detector** (e.g. Pixel-Detectors, Trackers or Calorimeters)
  - Data rates / aggregation
  - Distances
  - Power consumption

If a projection can be made in the horizon of 2020 to 2025 the HEP systems **should be targeting 20 - 40 Gb/s systems**:

- Well within the capability of today's FPGAs

Important for Links and ASICs to maintain compatibility with FPGA technology

Radiation resistance is not changing with new generations of opto electronic components (in our observations)

Commercial high speed driver ASICs are usually SiGe-BiCMOS based (not CMOS)

Data rates in HEP have historically been limited by the serializer (Rad-hard GOL or GBTx)

Time-division multiplexing hits a limit around 25-50Gbps (VCSELs)

- Higher bit-rates achieved through
  - Wavelength multiplexing
  - Multi-level signaling (PAM-4 and others)

More on future technologies to take the next step in another talk…

ASICS and IC Technology Issues Appear Across the Board

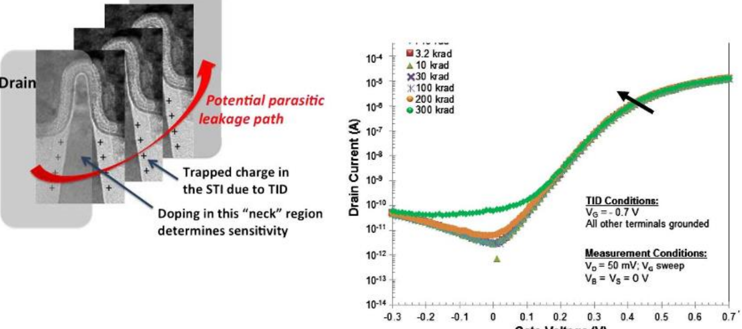
List of topics were drawn up:

- Pixel detector readout (hybrid) – monolithic is in Si WP
- Strip detector readout
- Calorimeter readout
- Muon Detector readout
- Control and monitoring
  - Slow control ADC, DACs etc
- Trigger generation
- Fast timing
- Power supply distribution
  - DCDC
  - Linear regulators
- Serial powering

Start to test 28nm and FinFET devices to understand the physics

Put in the place the necessary infrastructure to allow us access to these processes

- NDA's
- Technology files and support
- Foundry access
- Training



ASIC interconnect technology (TSV, bump bonding) should be included in the work package as it depends on or is inseparable from the ASIC Technology chosen

Below 28nm FinFETs become the workhorse

- Increased gain, faster switching, lower leakage current
- Increased layout restrictions (already at planar 28nm)
- Radiation tolerance largely unknown (although initial indications not promising)

1st Workshop on R&D for Experimental Technologies References

Thank you for your attention.

For more details, consult the excellent presentations at:

https://indico.cern.ch/event/696066/

1. https://indico.cern.ch/event/696066/sessions/268661/attachments/1618325/2573737/wg1_slides_all.pdf
2. https://indico.cern.ch/event/696066/contributions/2926622/attachments/1618427/2573489/EPWG3-WS1-Calorimetry-20180316.pdf
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