Department of Physics
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Modern Silicon Sensor Devices and their use in HEP, space and medical applications

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INTRODUCTION

The aim of these lectures is to give to the audience a general overview on Silicon Detectors mainly from an experimental point of view:
the focus will be mainly on possible application, assembling and testing procedure, facility description etc.. , while links will be provided for more detailed description of semiconductors theory description.

Due to the amplitude of this field only few topics and examples will be described in more detail, while many other relevant topics will be skipped completely.

Feel free to contact me anytime for questions or suggestions:
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Outline

Lecture 1:

Introduction to silicon sensors.
General (tentative) classification: Strips sensors, Hybrid and Monolithic (MAPS) pixel sensors, SiPM, LGAD, others.
Overview of applications in HEP and space missions.
MAPS assembling procedure: the ALPIDE chip and the Alice ITS2 construction.
Trends for Monolithic Active Pixel Detector: studies for large area bent sensors.

Lecture 2:

Overview on the effects of radiation on silicon detectors and electronic devices:
Total Ionizing Dose (TID), Displaced Damage (DD), Single Event Effects (SEE).
Dose delivered measurement for silicon devices.
Procedures for dose evaluation and radiation hardness characterization of devices:
Useful software tools (SPENVIS, TRIM, SpekPy).
The Trento proton and x-ray Irradiation Facilities and their use.

Lecture 3:

Overview on the use of radiations for cancer treatment.
Dose measurement for medical application. Beam monitoring and beam Quality Assurance (QA) devices.
Flash irradiation.
Ion therapy facilities: the CNAO and the Trento Proton Therapy Center.
Examples of HEP technologies for to medical applications:
the iMPACT project and the FOOT Experiment.

Lecture 1

References A

Suggested web reference for lecture 1

Gianluigi Casse: Solid state detectors

XXXII International Seminar of Nuclear and Subnuclear Physics "Francesco Romano" June 2021

https://agenda.infn.it/event/21318/timetable/#all.detailed

Daniela Bortoletto CERN Summer Student Lecture Programme Course July 2015

Detectors for Particle Physics: lectures 1-5:

https://indico.cern.ch/event/243648/

Semiconductor Detectors:lecture 4

https://indico.cern.ch/event/243648/attachments/415356/577104/daniela_l4_post.pdf

Vito Manzari: Instrumentation in HEP, silicon detector lectures

The 5th Egyptian School on High Energy Physics (2015)

https://indico.cern.ch/event/453690/timetable/#all.detailed

References B

Suggested web reference for lecture 1

Gino Bolla: Introduction to Silicon Detectors

Edit School 2012, Fermilab

https://conferences.fnal.gov/EDIT2012/materials/EDIT_Silicon_Intro-Day1.pptx

Other general suggested lectures

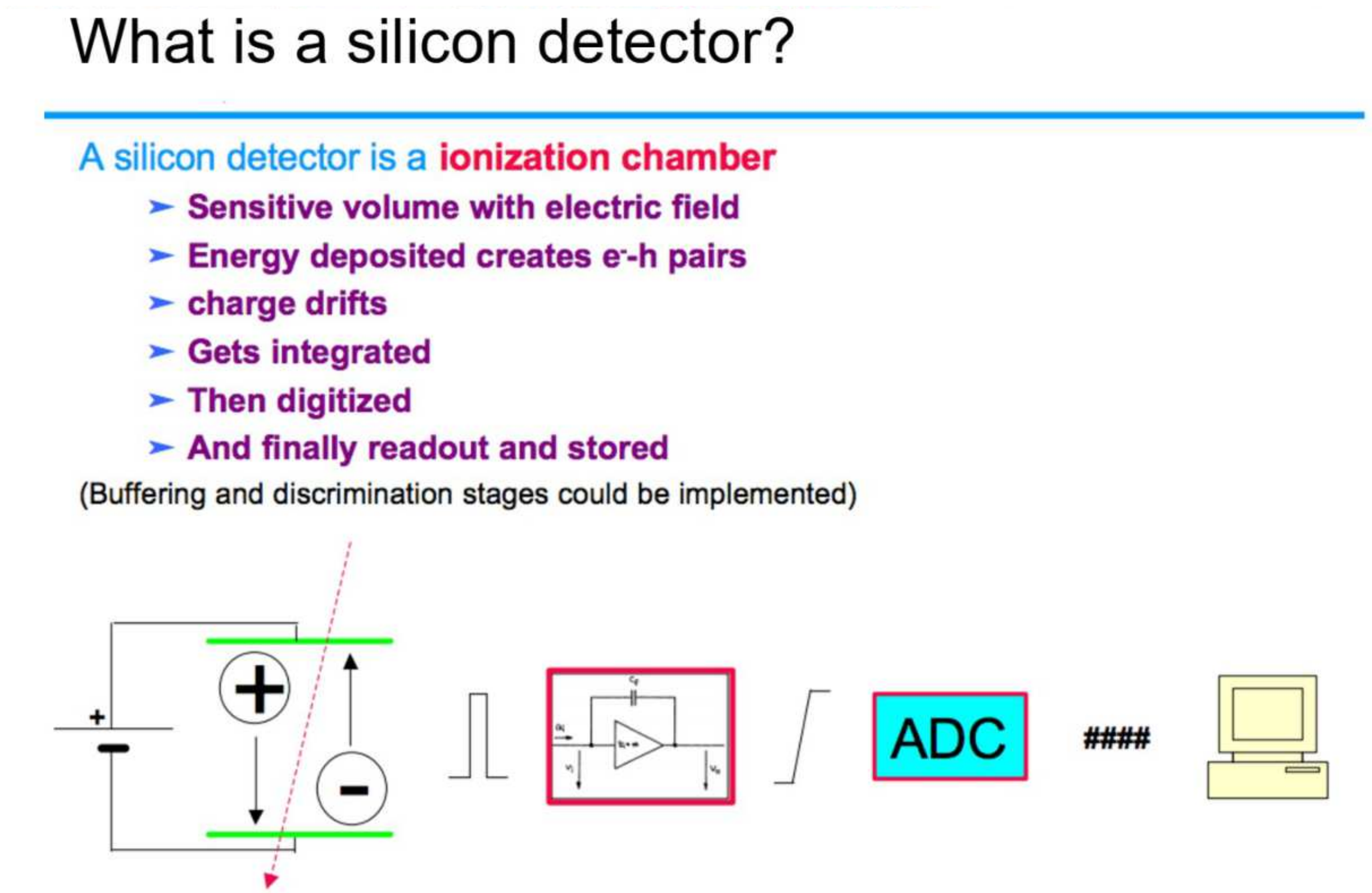
David Nygren: History of Particle Detection

https://conferences.fnal.gov/EDIT2012/Lectures/2_Nygren_HistoryPP.pdf

Dan Green: Hadron Collider Detectors (2012)

https://conferences.fnal.gov/EDIT2012/Lectures/3_DGreen_HadColliderDet.pdf

A special thanks to Gino Bolla and Simon Kwan for inspiring me



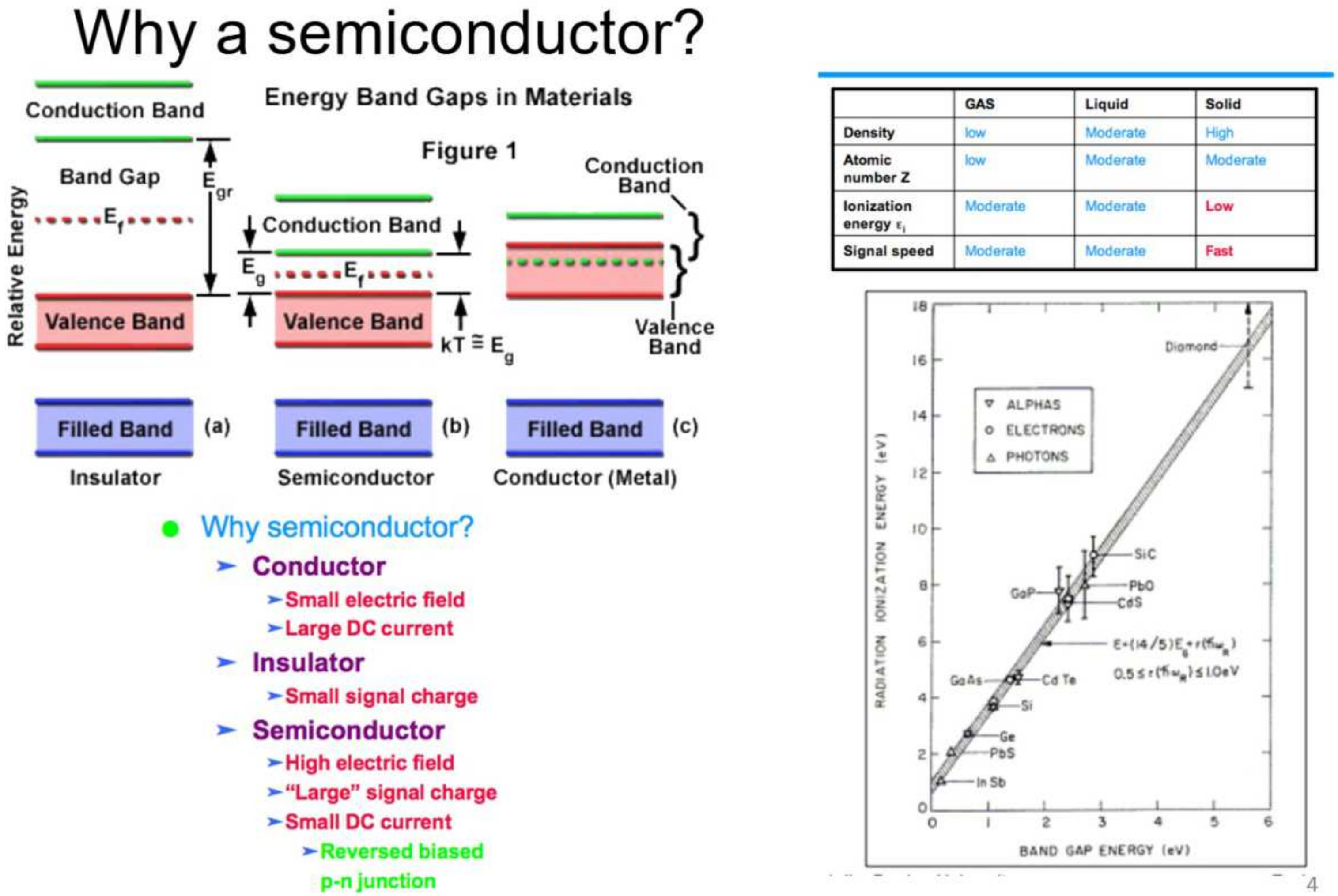
What is a silicon detector?

A silicon detector is a **ionization chamber**

- **Sensitive volume with electric field**
- **Energy deposited creates e^--h pairs**
- **charge drifts**
- **Gets integrated**
- **Then digitized**
- **And finally readout and stored**

(Buffering and discrimination stages could be implemented)

Slide from Gino Bolla, EDIT School Fermilab 2012



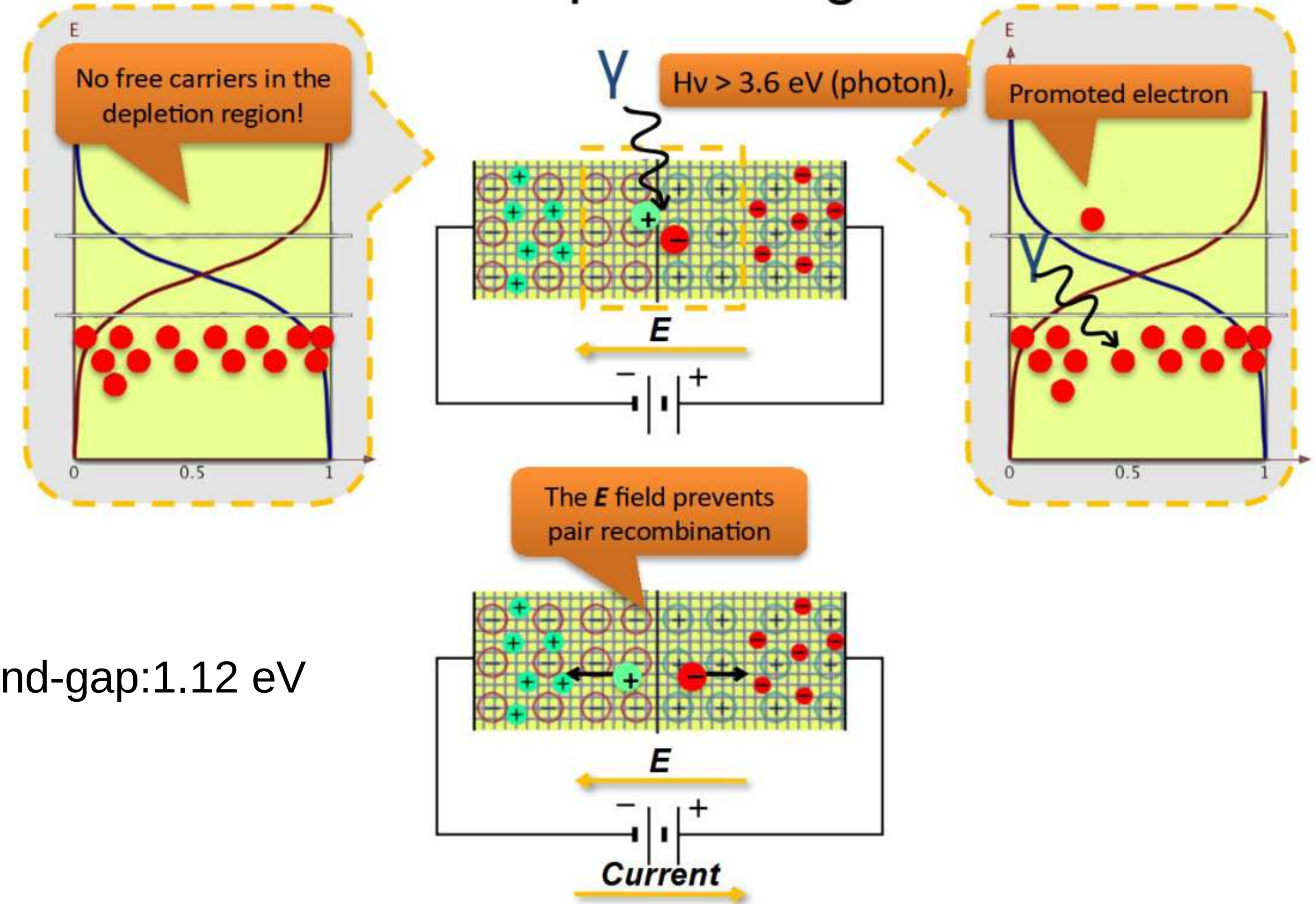
Why a semiconductor?

- Why semiconductor?
  - **Conductor**
    - Small electric field
    - Large DC current
  - **Insulator**
    - Small signal charge
  - **Semiconductor**
    - High electric field
    - “Large” signal charge
    - Small DC current
      - Reversed biased p-n junction

	GAS	Liquid	Solid
Density	low	Moderate	High
Atomic number Z	low	Moderate	Moderate
Ionization energy ε_i	Moderate	Moderate	Low
Signal speed	Moderate	Moderate	Fast

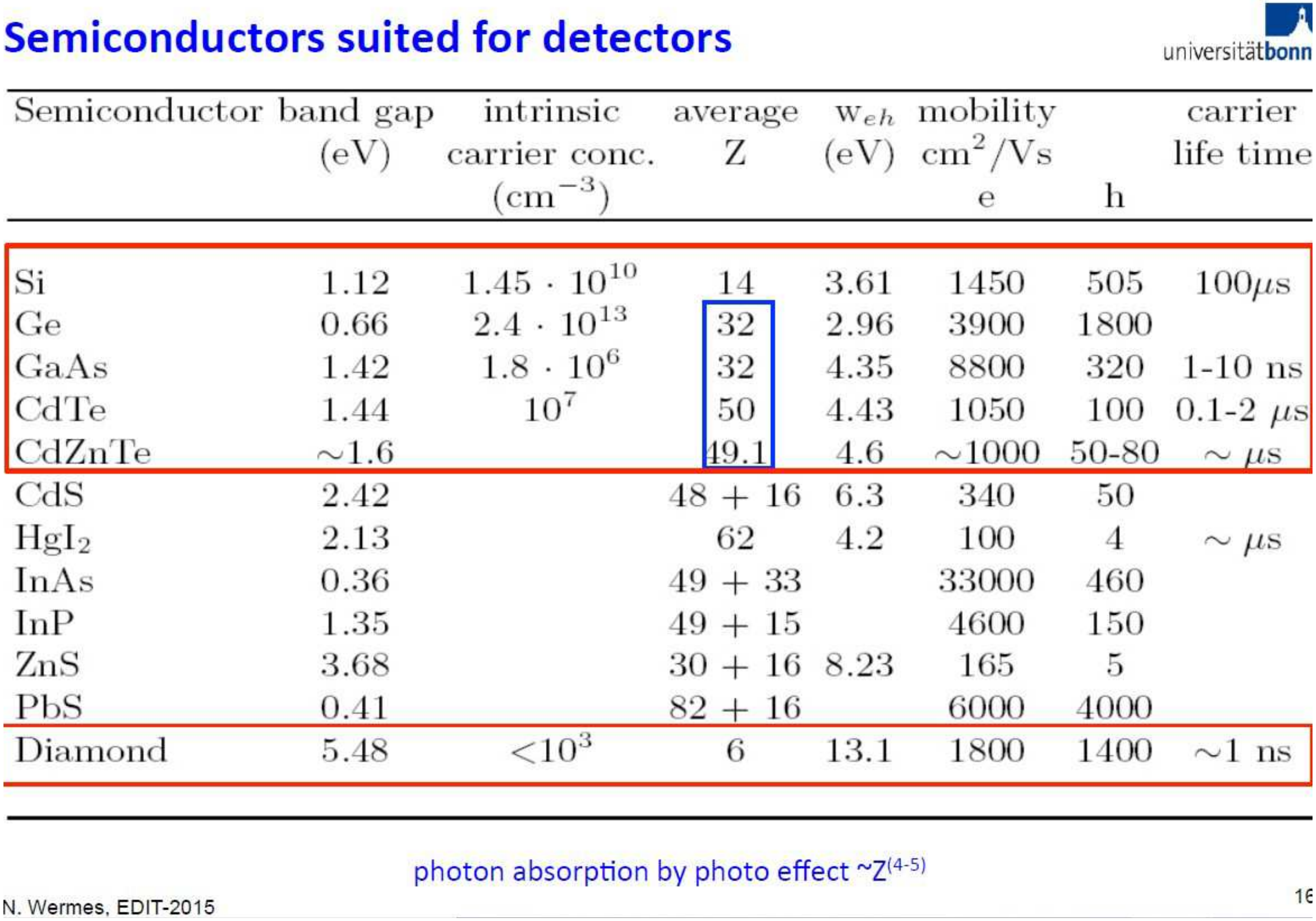
Slide from Gino Bolla, EDIT School Fermilab 2012

Ionization in the depleted region



Silicon band-gap:1.12 eV

Slide from Gino Bolla, EDIT School Fermilab 2012



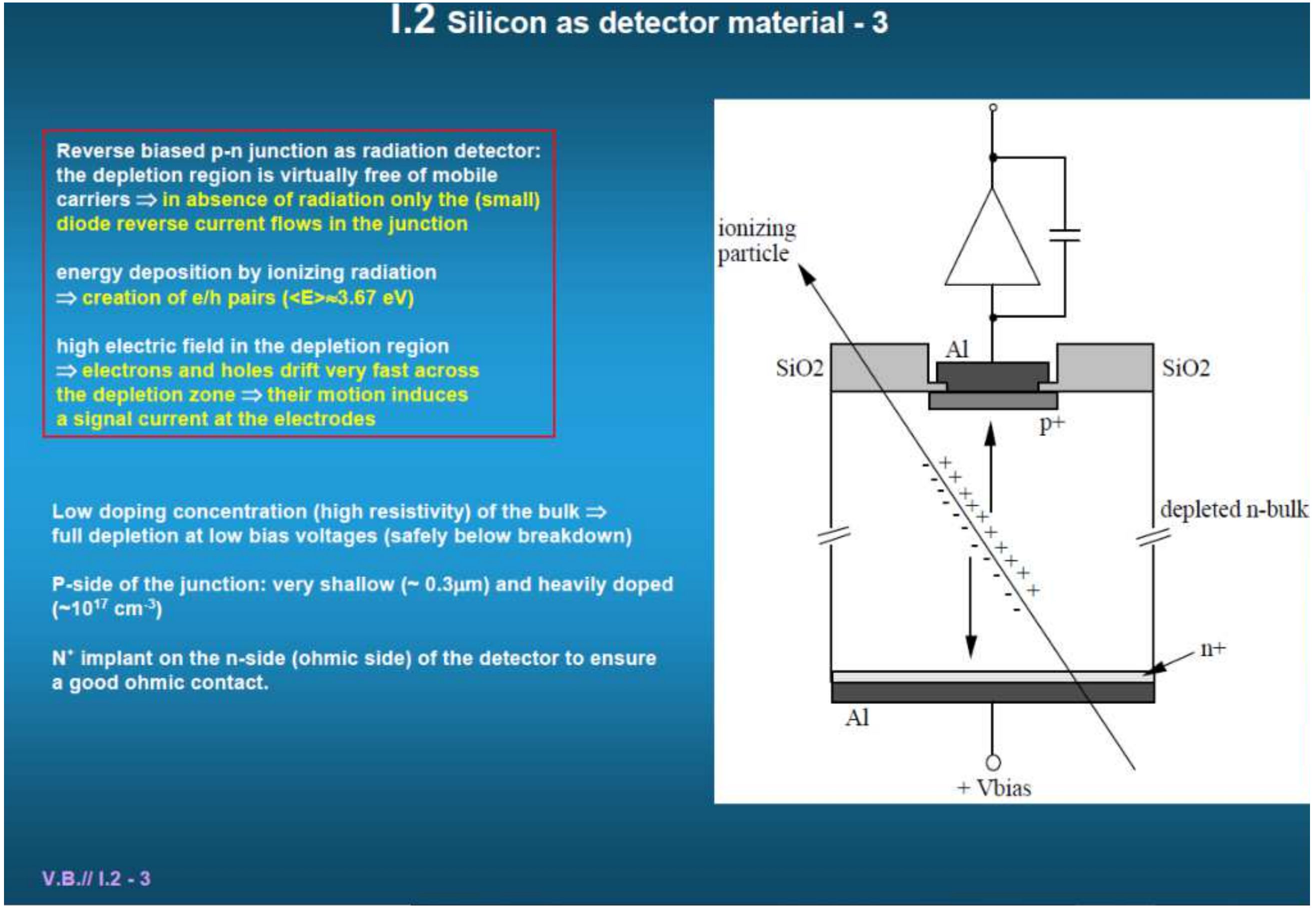
Semiconductors suited for detectors

Semiconductor	band gap (eV)	intrinsic carrier conc. (cm^{-3})	average Z	w_{eh} (eV)	mobility cm^2/Vs		carrier life time
					e	h	
Si	1.12	$1.45 \cdot 10^{10}$	14	3.61	1450	505	100μs
Ge	0.66	$2.4 \cdot 10^{13}$	32	2.96	3900	1800	
GaAs	1.42	$1.8 \cdot 10^{6}$	32	4.35	8800	320	1-10 ns
CdTe	1.44	10^{7}	50	4.43	1050	100	0.1-2 μs
CdZnTe	$\sim$1.6		49.1	4.6	$\sim$1000	50-80	$\sim$ μs
CdS	2.42		48 + 16	6.3	340	50	
HgI_2	2.13		62	4.2	100	4	$\sim$ μs
InAs	0.36		49 + 33		33000	460	
InP	1.35		49 + 15		4600	150	
ZnS	3.68		30 + 16	8.23	165	5	
PbS	0.41		82 + 16		6000	4000	
Diamond	5.48	$<10^{3}$	6	13.1	1800	1400	$\sim$1 ns

photon absorption by photo effect ~$Z^{(4-5)}$

N. Wermes, EDIT-2015

Slide from N. Wermes, EDIT School 2015



I.2 Silicon as detector material - 3

Reverse biased p-n junction as radiation detector: the depletion region is virtually free of mobile carriers ⇒ in absence of radiation only the (small) diode reverse current flows in the junction

energy deposition by ionizing radiation
⇒ creation of e/h pairs ($<E>\approx 3.67$ eV)

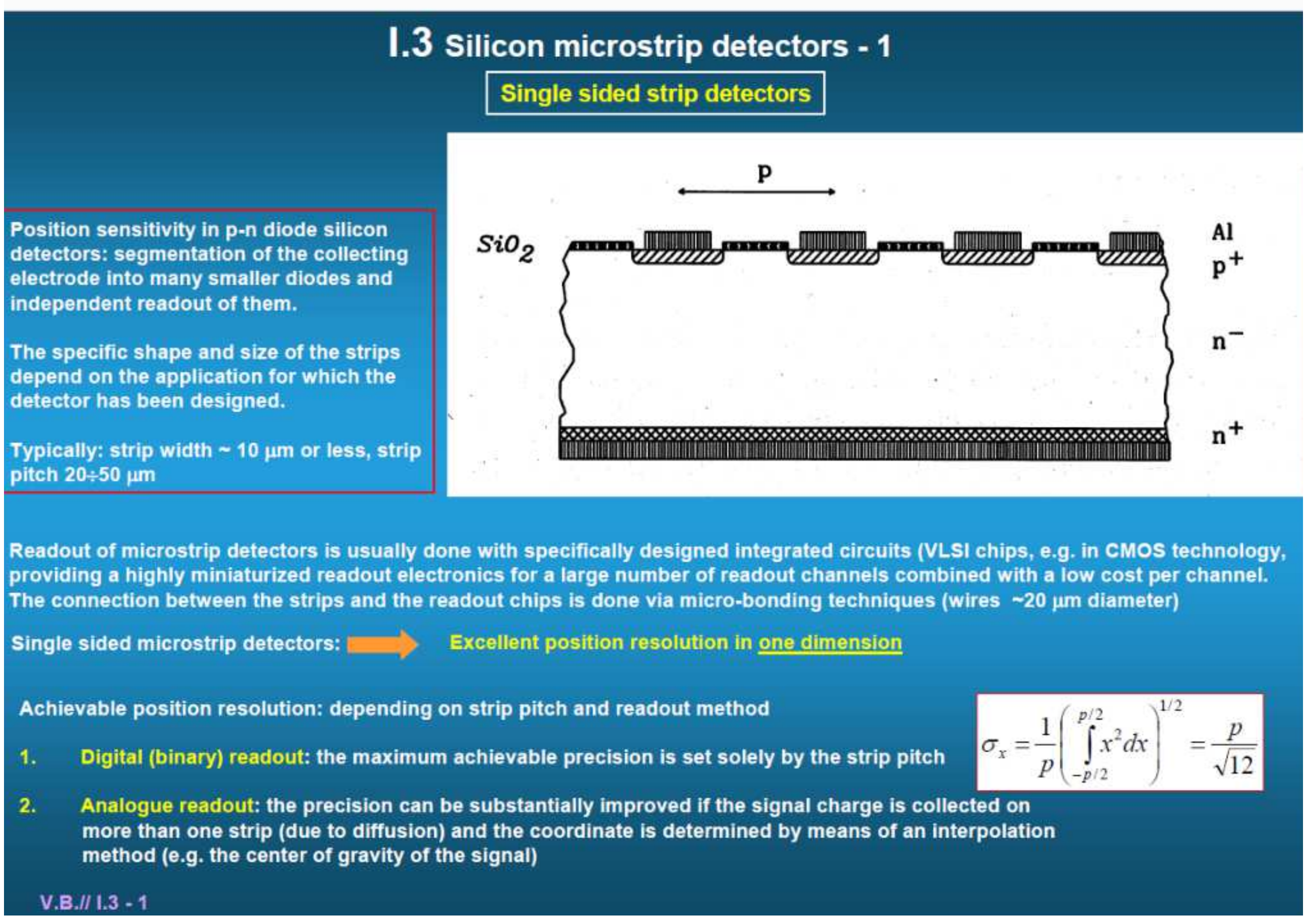
high electric field in the depletion region
⇒ electrons and holes drift very fast across the depletion zone ⇒ their motion induces a signal current at the electrodes

Low doping concentration (high resistivity) of the bulk ⇒ full depletion at low bias voltages (safely below breakdown)

P-side of the junction: very shallow (~ 0.3μm) and heavily doped (~10^{17} cm^{-3})

N^+ implant on the n-side (ohmic side) of the detector to ensure a good ohmic contact.

V.B.// I.2 - 3



I.3 Silicon microstrip detectors - 1

Single sided strip detectors

Position sensitivity in p-n diode silicon detectors: segmentation of the collecting electrode into many smaller diodes and independent readout of them.

The specific shape and size of the strips depend on the application for which the detector has been designed.

Typically: strip width ~ 10 µm or less, strip pitch 20÷50 µm

Readout of microstrip detectors is usually done with specifically designed integrated circuits (VLSI chips, e.g. in CMOS technology, providing a highly miniaturized readout electronics for a large number of readout channels combined with a low cost per channel. The connection between the strips and the readout chips is done via micro-bonding techniques (wires ~20 µm diameter)

Single sided microstrip detectors: ➡ Excellent position resolution in one dimension

Achievable position resolution: depending on strip pitch and readout method

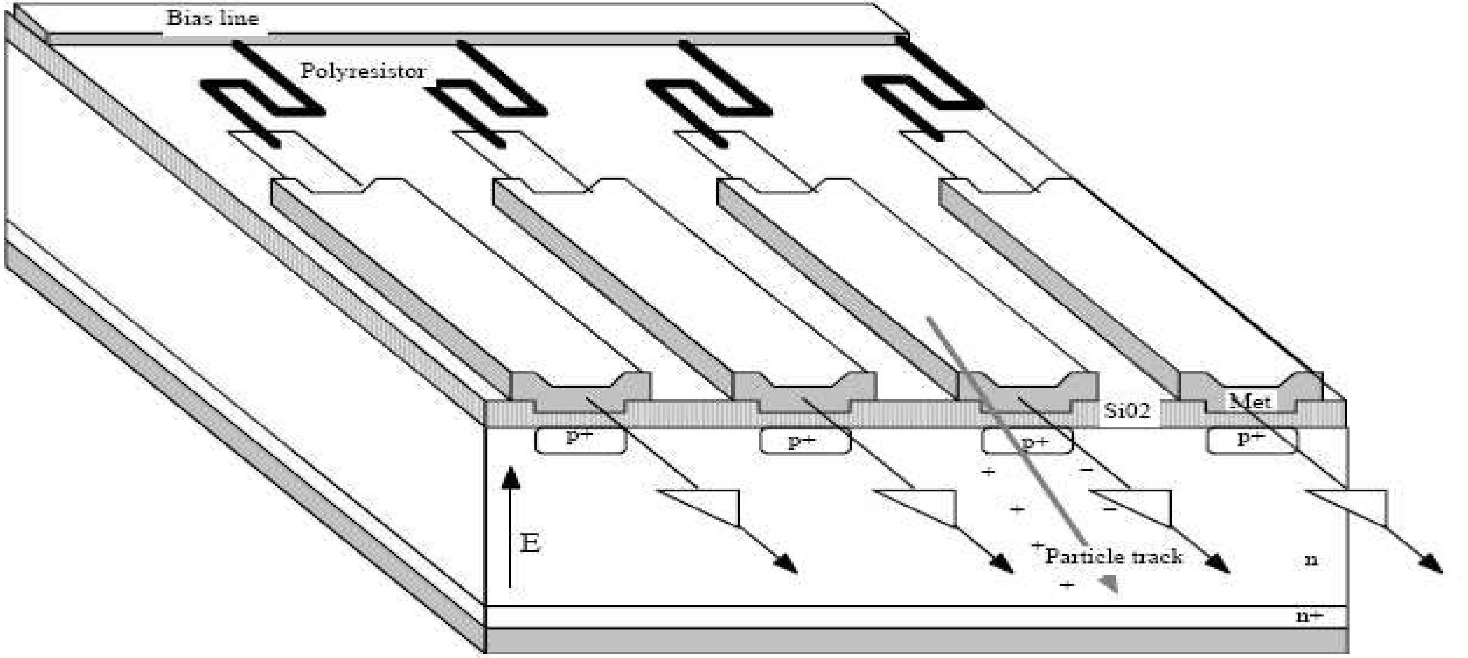
1. Digital (binary) readout: the maximum achievable precision is set solely by the strip pitch

$$\sigma_x = \frac{1}{p}\left(\int_{-p/2}^{p/2} x^2 dx\right)^{1/2} = \frac{p}{\sqrt{12}}$$

2. Analogue readout: the precision can be substantially improved if the signal charge is collected on more than one strip (due to diffusion) and the coordinate is determined by means of an interpolation method (e.g. the center of gravity of the signal)

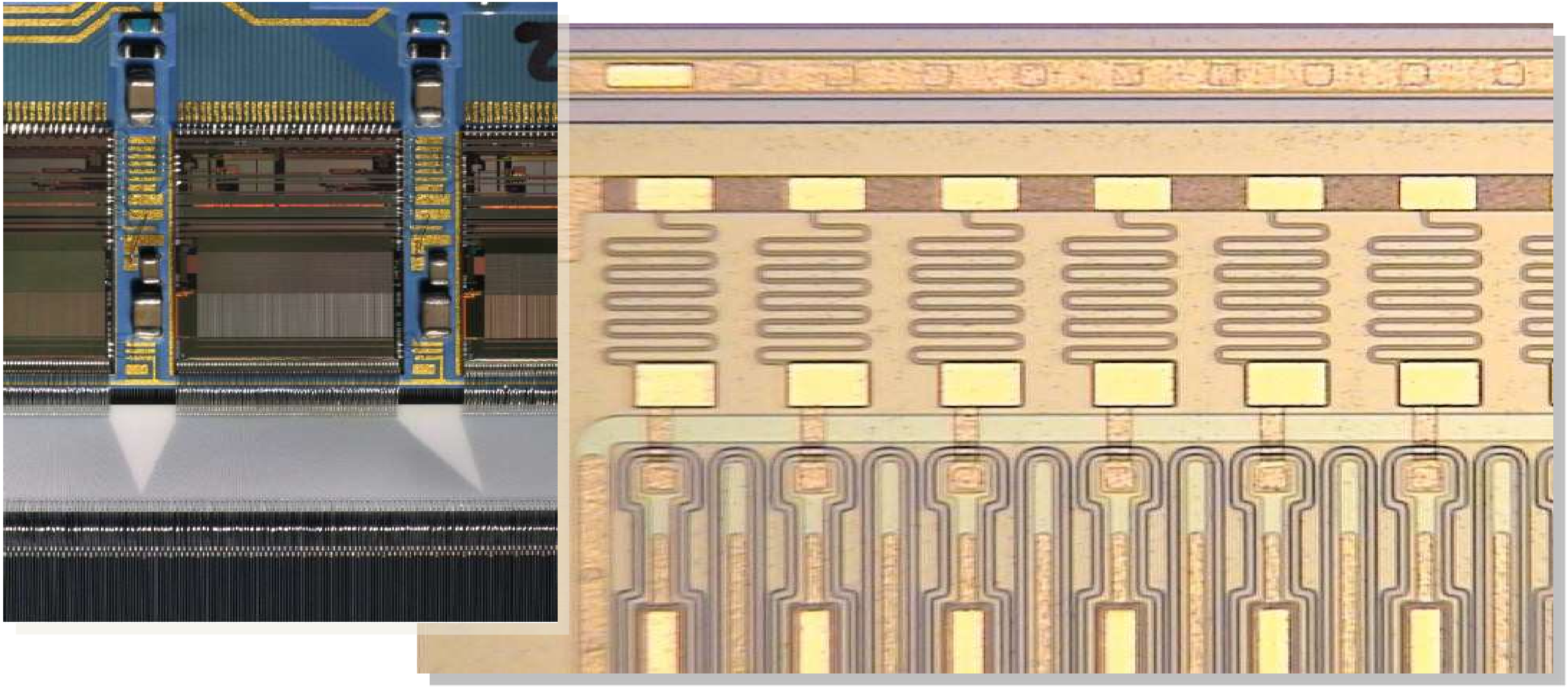
V.B.// I.3 - 1

Microstrip Detectors (1D segmentation)



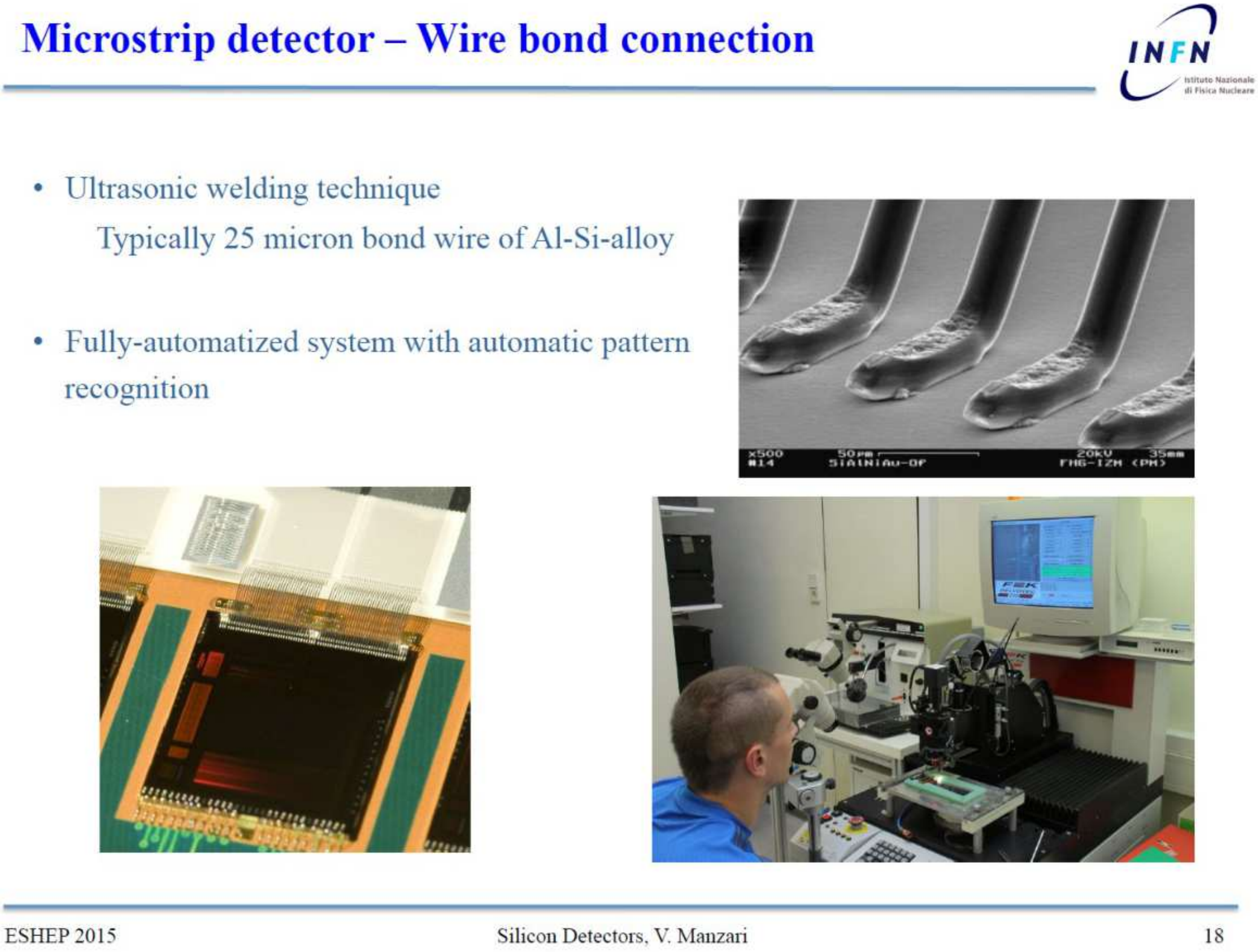
Marco Battaglia EDIT School Fermilab 2012

Microstrip Detectors



25 μm pitch microstrip with S/N=75 → σ_{point} = 1.3 μm

Straver et al., NIM 348 (1994)



Microstrip detector – Wire bond connection

- Ultrasonic welding technique
  Typically 25 micron bond wire of Al-Si-alloy
- Fully-automatized system with automatic pattern recognition

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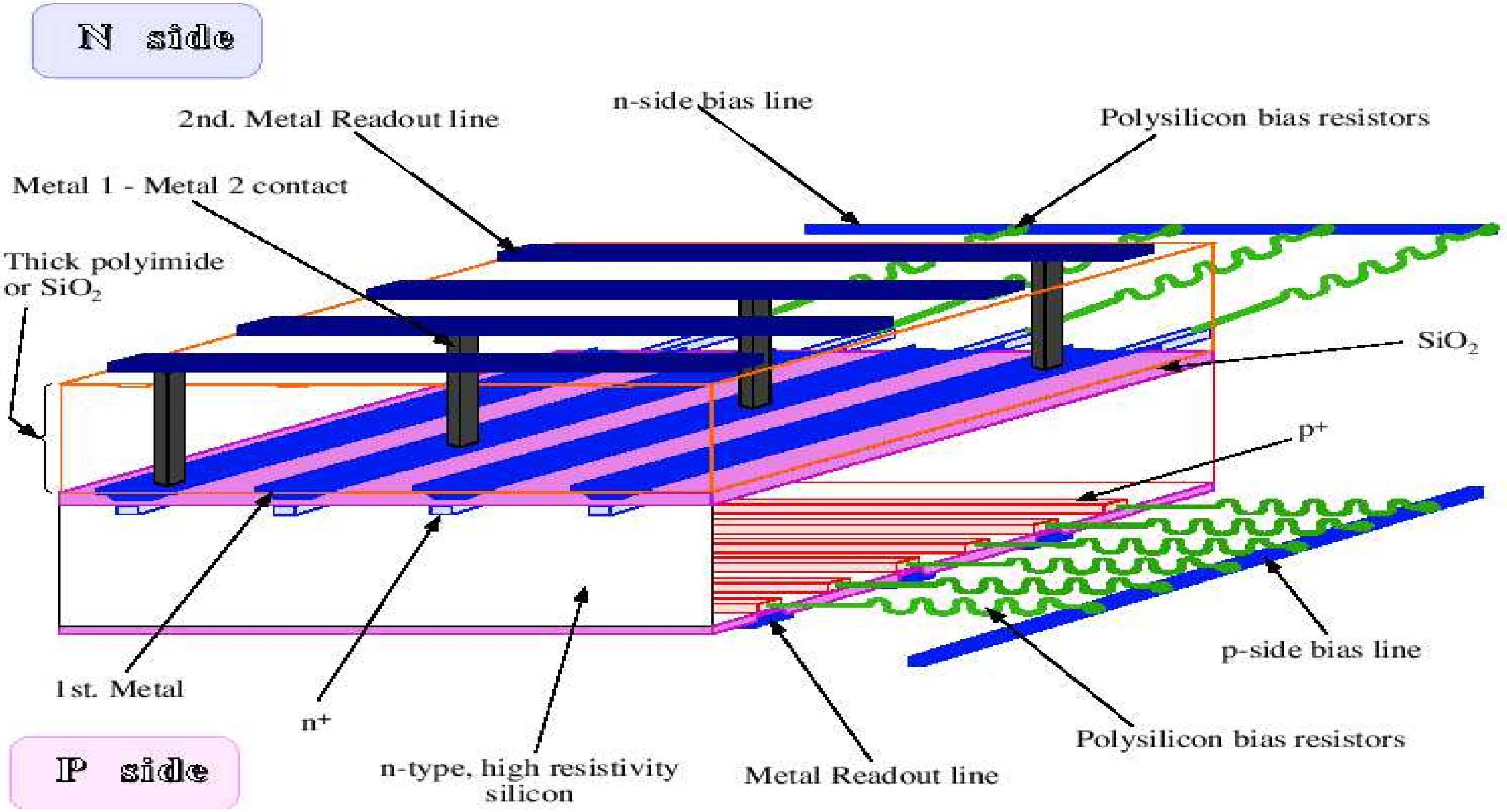
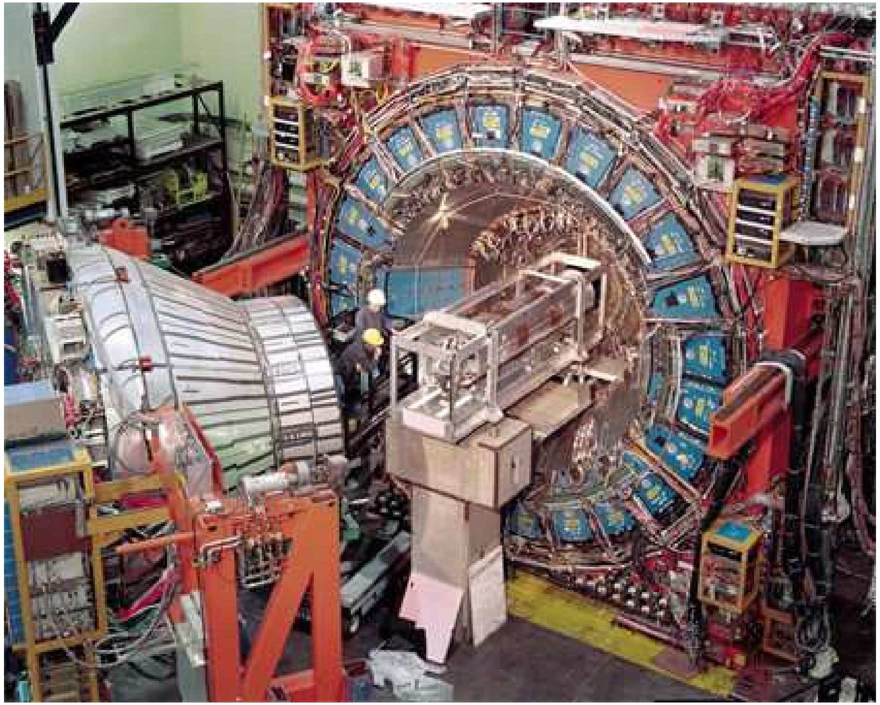
Double-sided Strip Detectors (1+1D segmentation)



Marco Battaglia EDIT School 2012, Fermilab

Silicon strip for HEP:
The CDF silicon detector

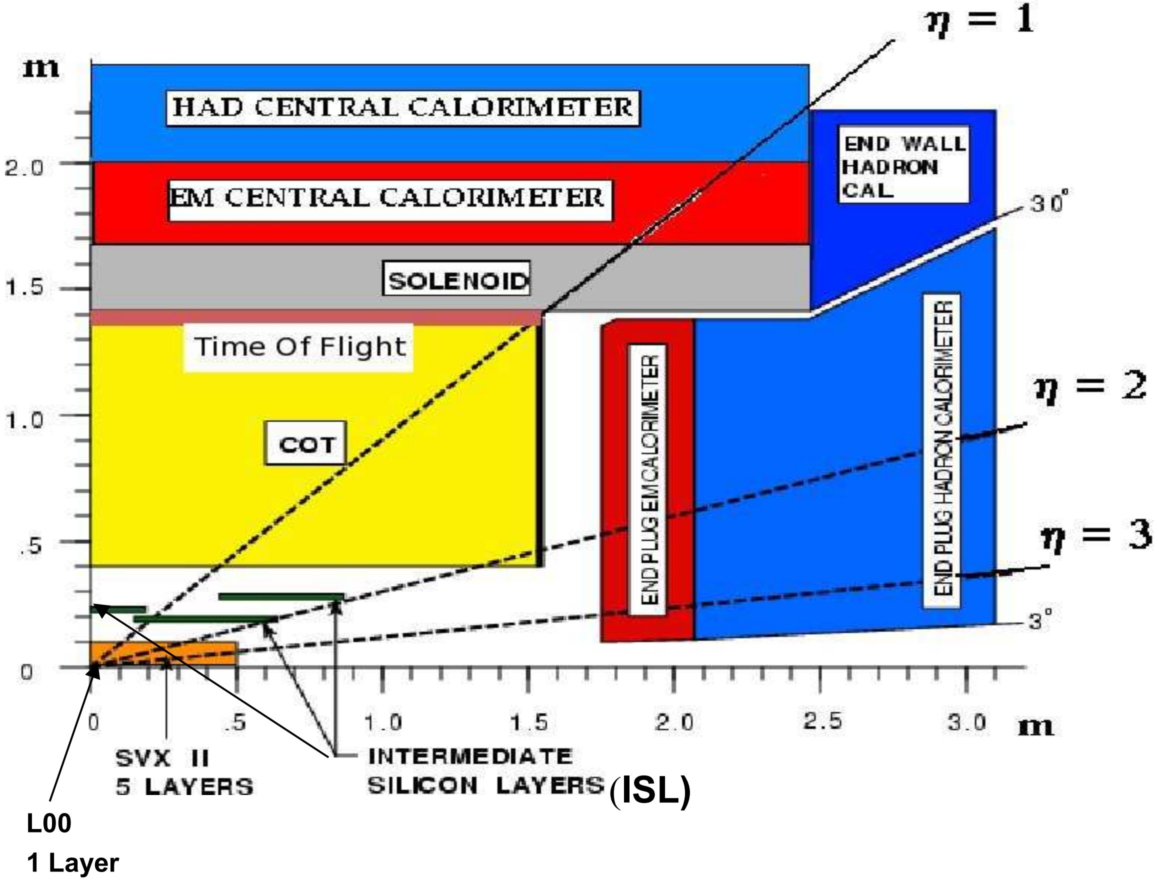


CDF silicon vertex detector being installed in 2001 (foto credit Fermilab).

https://www.fnal.gov/pub/tevatron/experiments/cdf.html

Benedetto Di Ruzza TIPP2011
https://indico.cern.ch/event/102998/contributions/16939/

The Silicon Detectors



The CDFII Silicon detectors

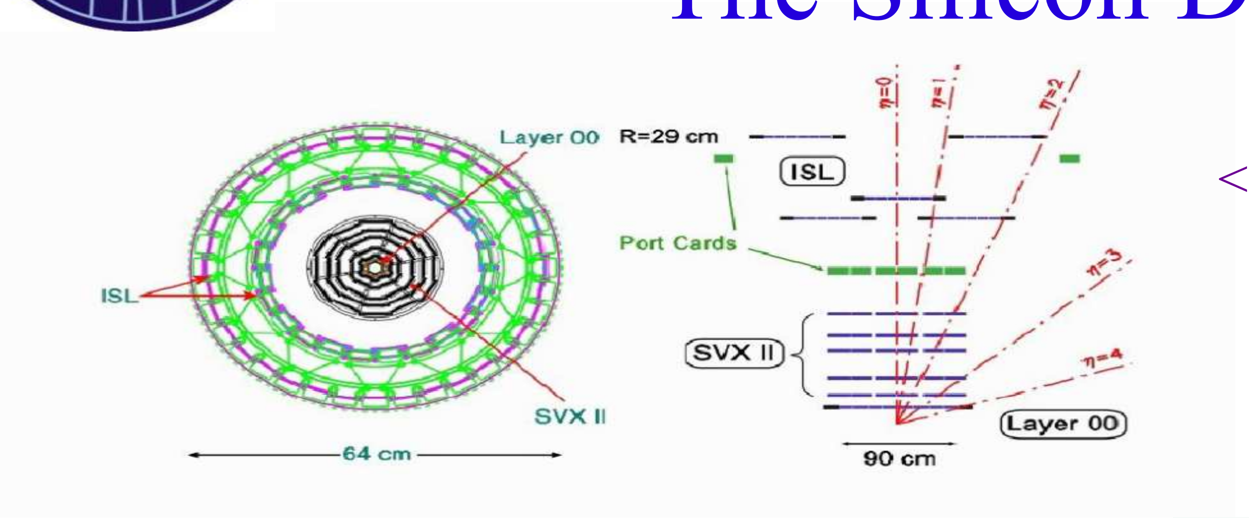
OVERVIEW

L00: Single-sided strips: “Narrows” (SGS Thomson and 2 Microns)
“Wides” (Hamamatsu).

SVX: Double-sided strips: Layers 0,1,3 (Hamamatsu) perpendicular strips,
Layers 2,4 (Micron) small angled strips.

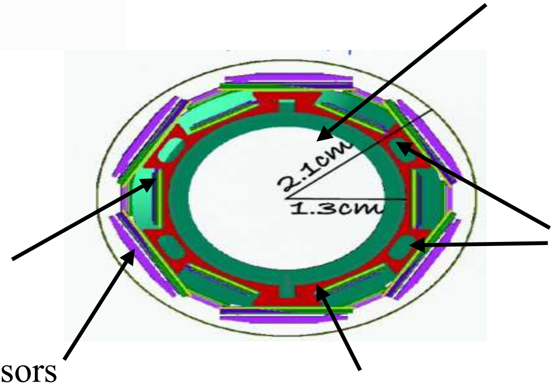
ISL: Double-sided strips: (Hamamatsu+Micron) small angled strips

The Silicon Detectors



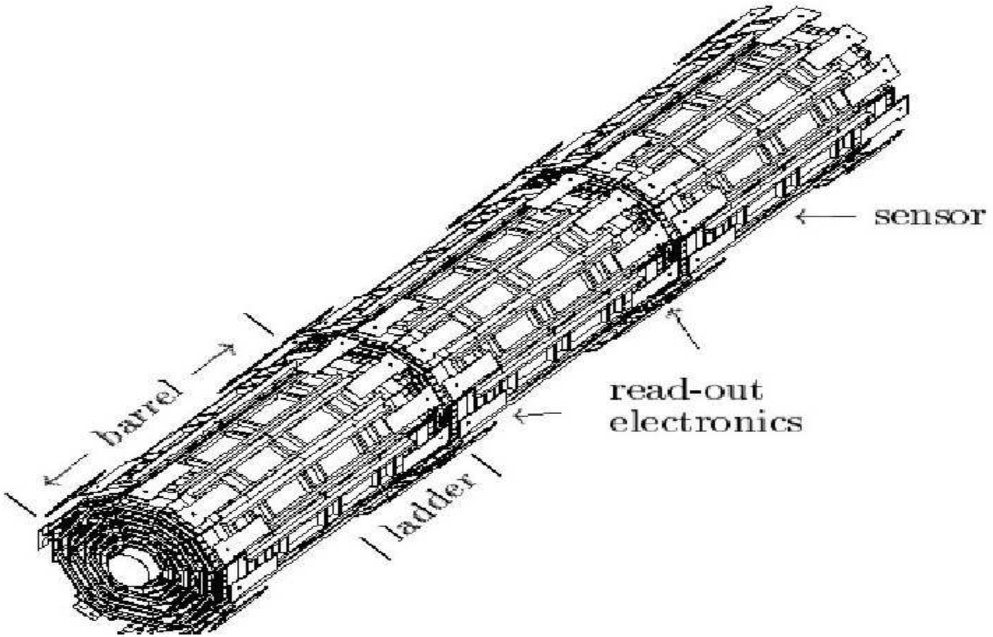
<== X-Y (r-phi) and Y-Z (r-z) views

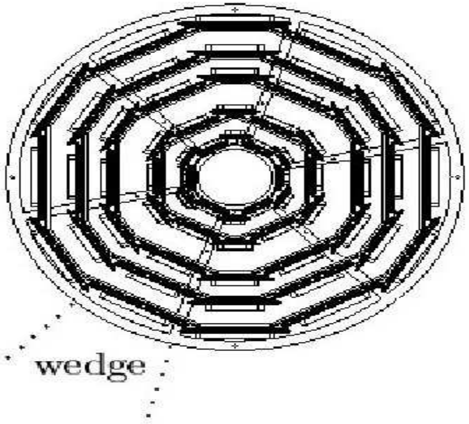
L00 detail ==>



The Silicon Detectors

SVXII detail:
3 barrels
5 layers
12 wedges

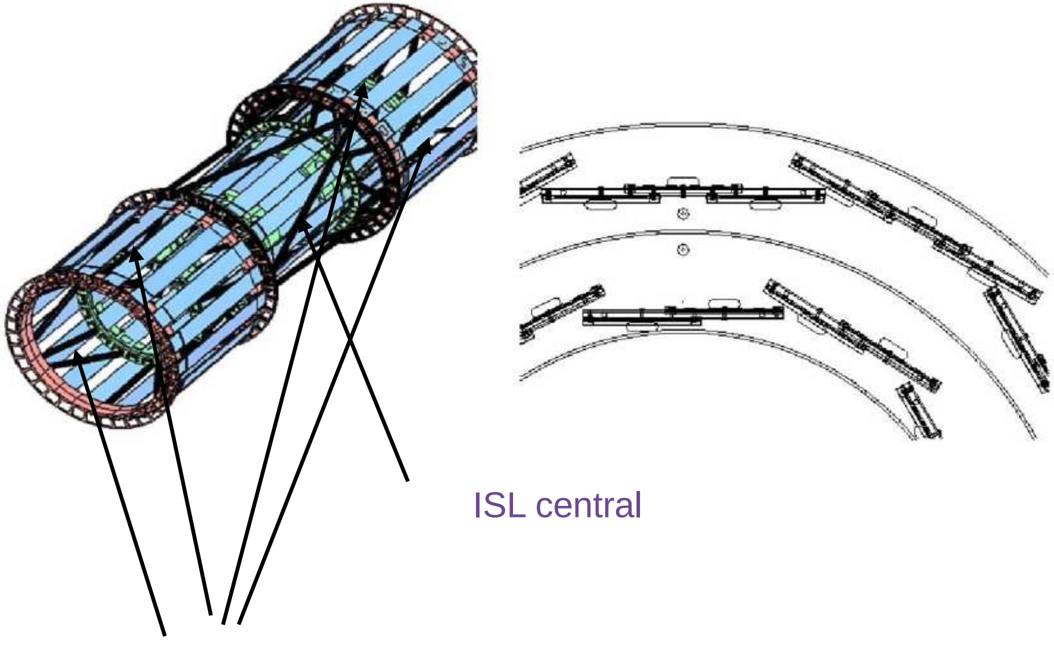




SVXII: the readout is used in the trigger too

The Silicon Detectors: ISL

ISL detail

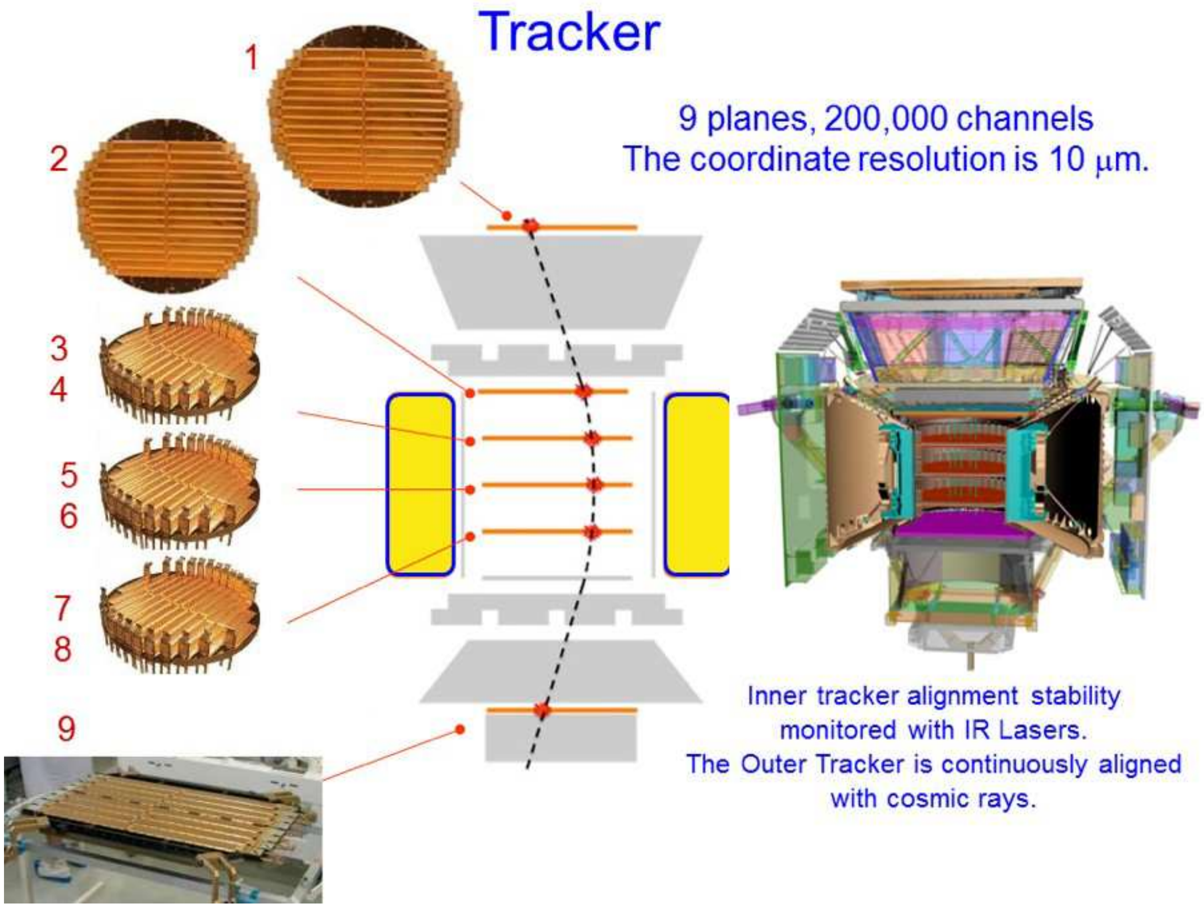


ISL central

ISLforward:
(inner and external barrels)

Space applcation of silicon strip sensors: the Silicon Traker in AMS-02

Foto credit
AMS-02



Tracker

9 planes, 200,000 channels
The coordinate resolution is 10 μm.

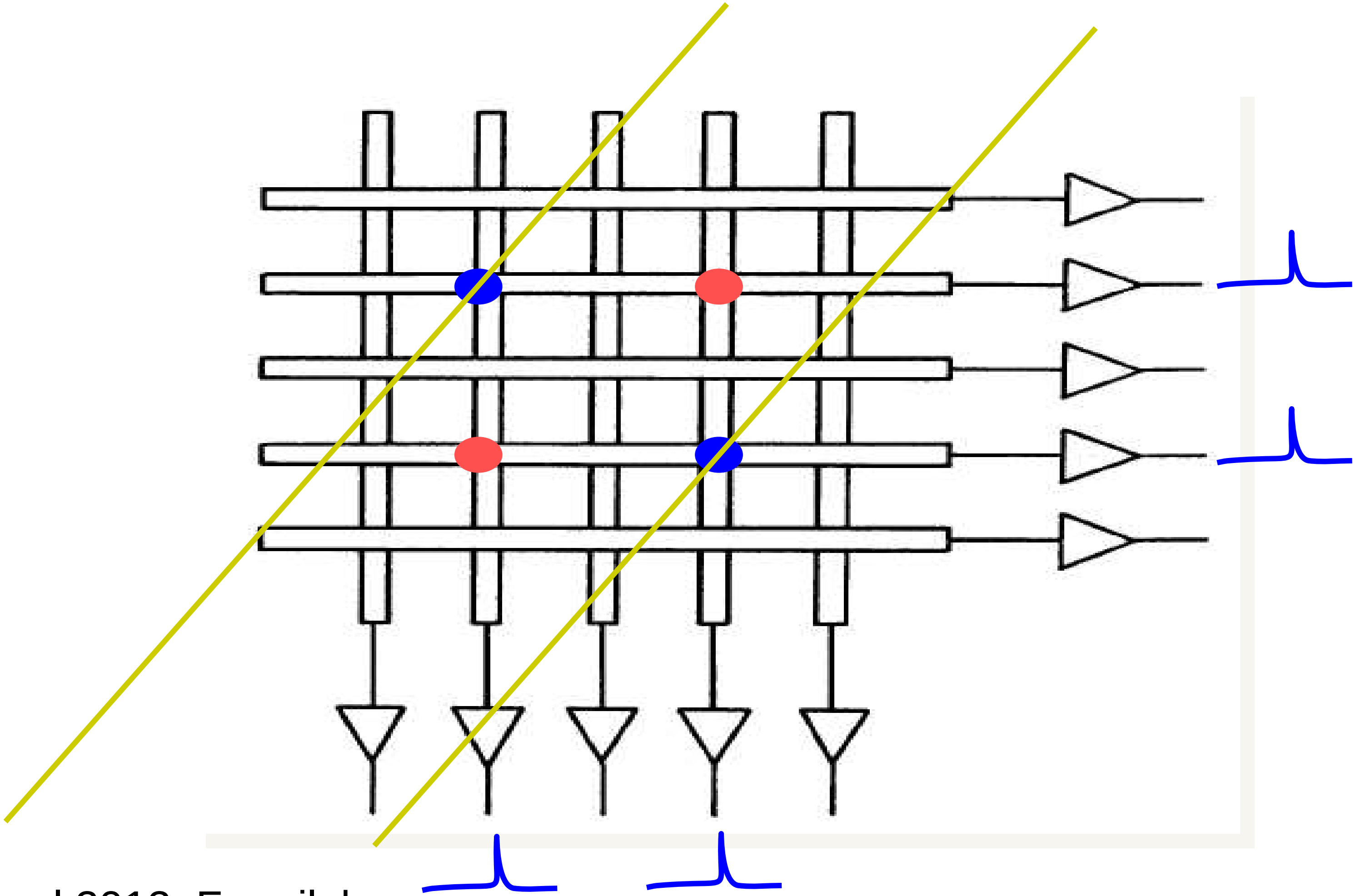
Inner tracker alignment stability
monitored with IR Lasers.
The Outer Tracker is continuously aligned
with cosmic rays.

https://ams02.space/detector/silicon-tracker

Combining two orthogonal 1D strips can we have 2D information?

2 X 1D information
generates ambiguities:

n hits ≈ n^2 combinations
of which n^2-n are ghosts



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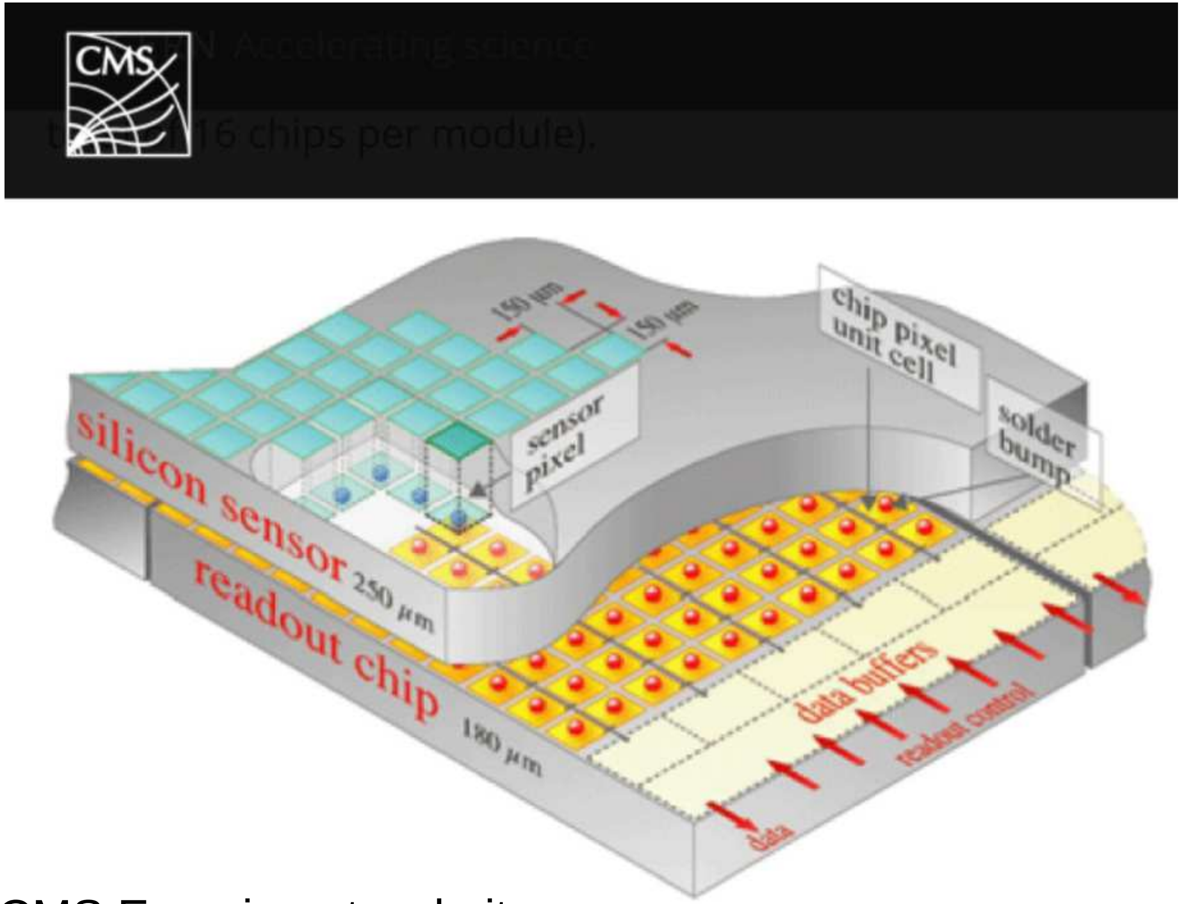
From Strips (1D) to Pixel (2D) Detectors

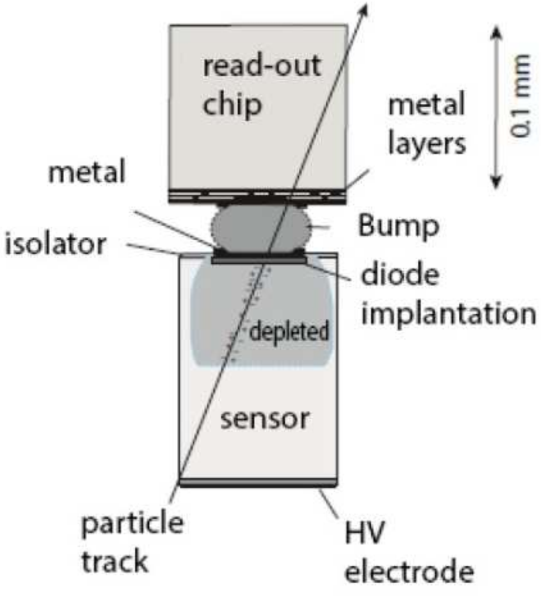


N: Accelerating science

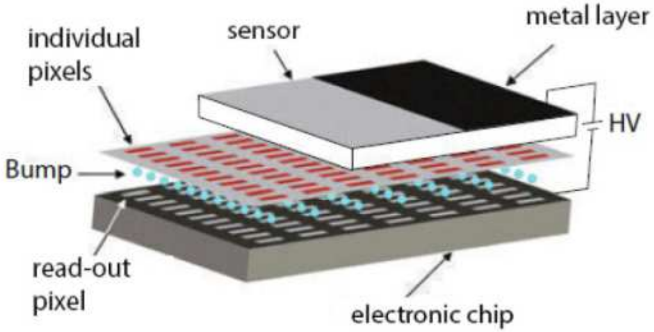
t 16 chips per module).

Picture from CMS Experiment website

Hybrid Pixel detector



(a) hybrid pixel cell



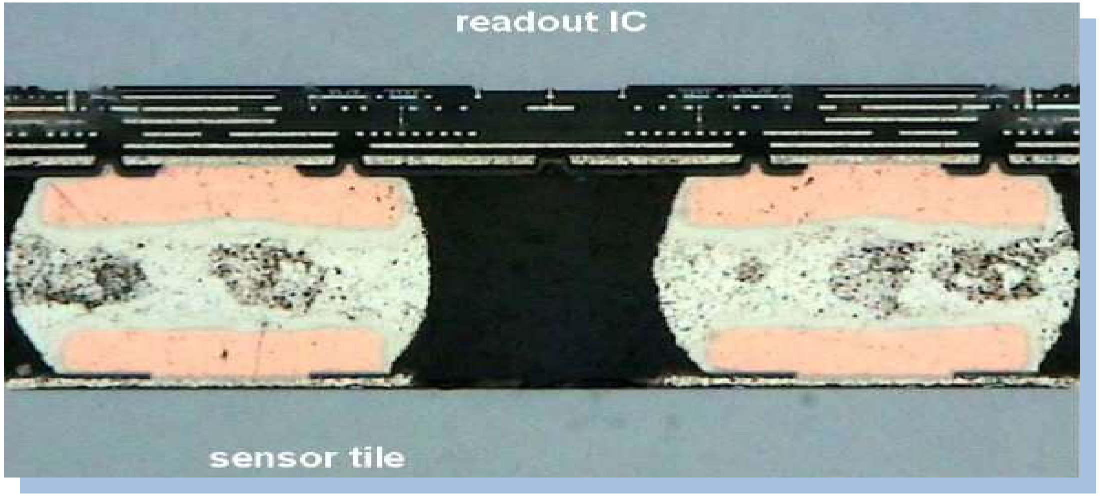
(b) pixel matrix

2D Sensor + 2D Readout: Hybrid Pixels

Pioneered in DELPHI at LEP
and extensively used at LHC;

Great progress in bump bonding
pitch and yields;

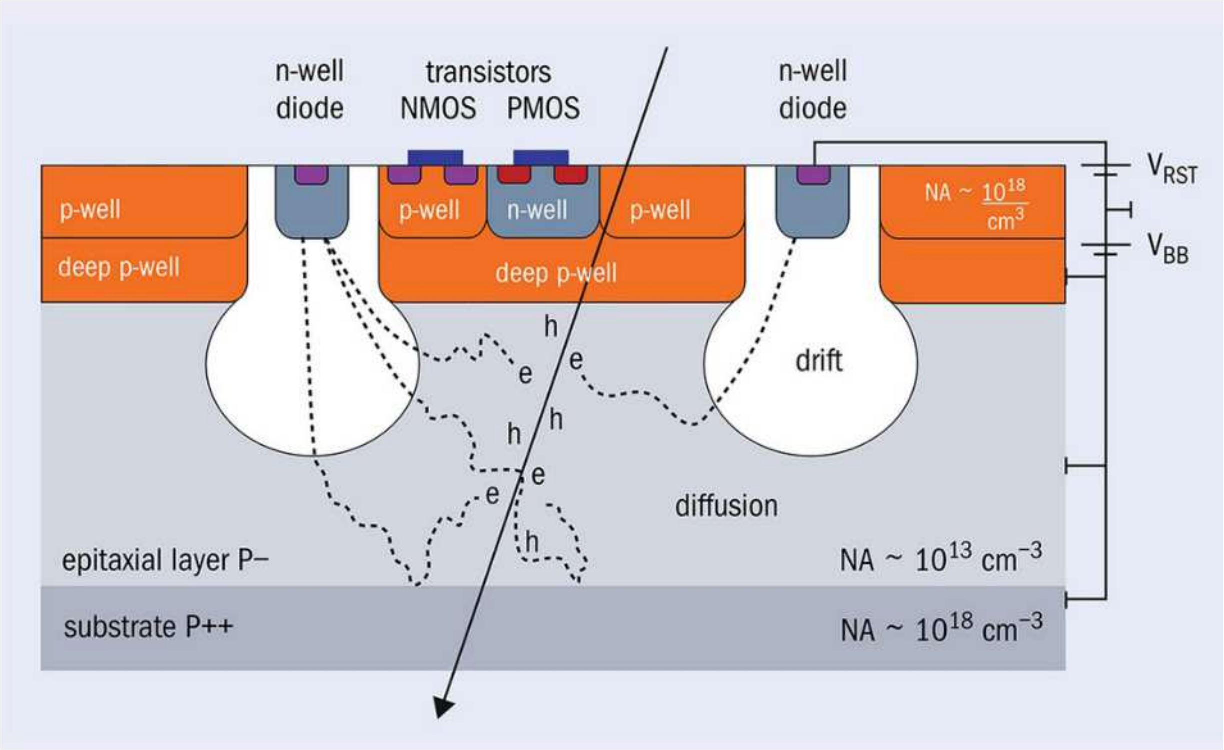
Spinoff to imaging (MediPix)



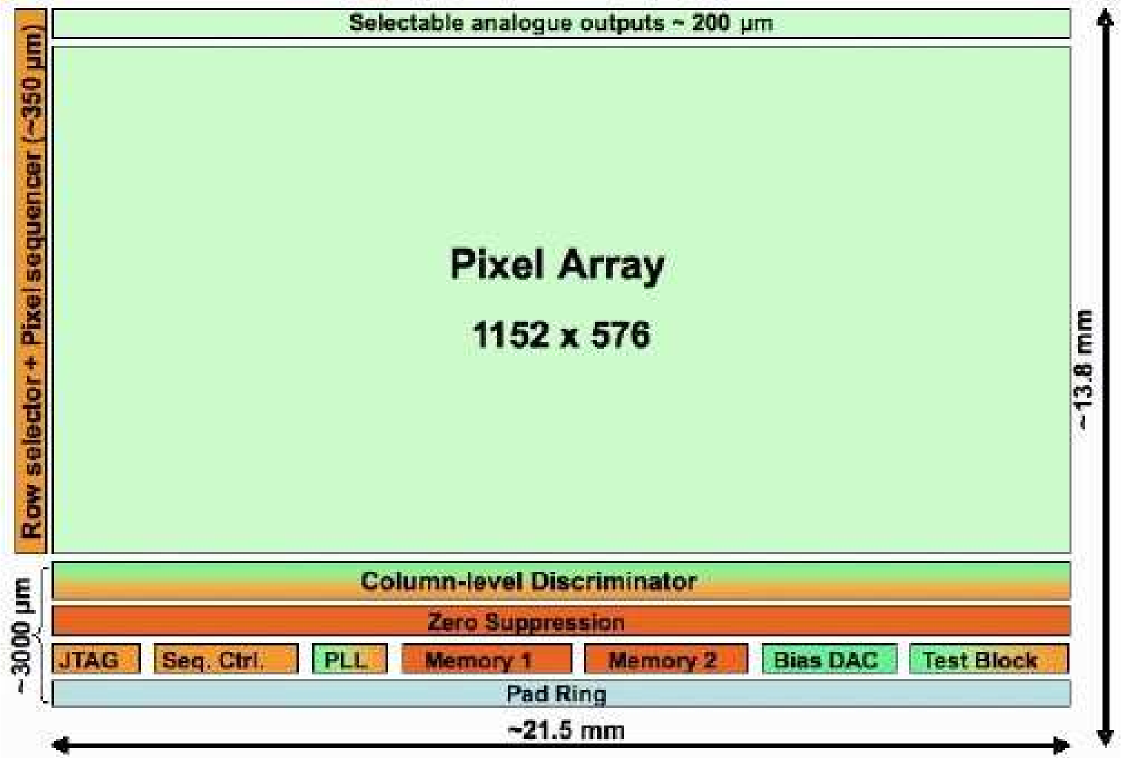
Advantages include:
sophisticated signal processing on-pixel
(TOT, trigger, sparsification, calibration, autocorrelation);
decouple process for sensor and readout electronics;

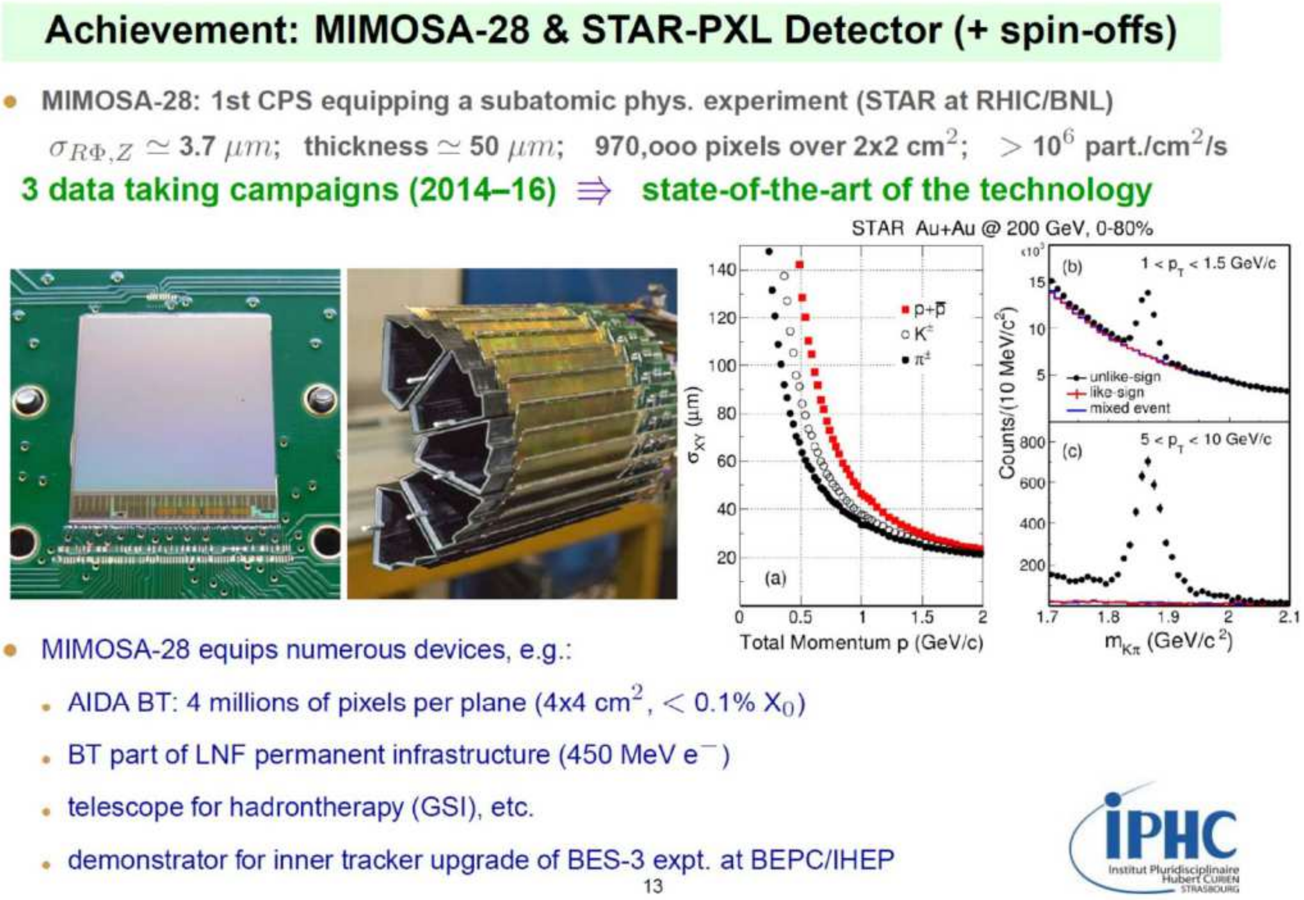
Main Limitations are:
large(r) material budget, pixel cell size limited by electronics cell
and interconnect (bump bonding) pitch (~40 μm).

Monolithic Active Pixel Silicon sensor (MAPS)



The MIMOSA 26 MAPS sensor





Achievement: MIMOSA-28 & STAR-PXL Detector (+ spin-offs)

- MIMOSA-28: 1st CPS equipping a subatomic phys. experiment (STAR at RHIC/BNL)

  $\sigma_{R\Phi,Z} \simeq$ 3.7 μm; thickness $\simeq$ 50 μm; 970,ooo pixels over 2x2 cm^2; $>$ 10^6 part./cm^2/s

3 data taking campaigns (2014–16) ⇛ state-of-the-art of the technology

- MIMOSA-28 equips numerous devices, e.g.:
  - AIDA BT: 4 millions of pixels per plane (4x4 cm^2, $<$ 0.1% X$_0$)
  - BT part of LNF permanent infrastructure (450 MeV e$^-$)
  - telescope for hadrontherapy (GSI), etc.
  - demonstrator for inner tracker upgrade of BES-3 expt. at BEPC/IHEP

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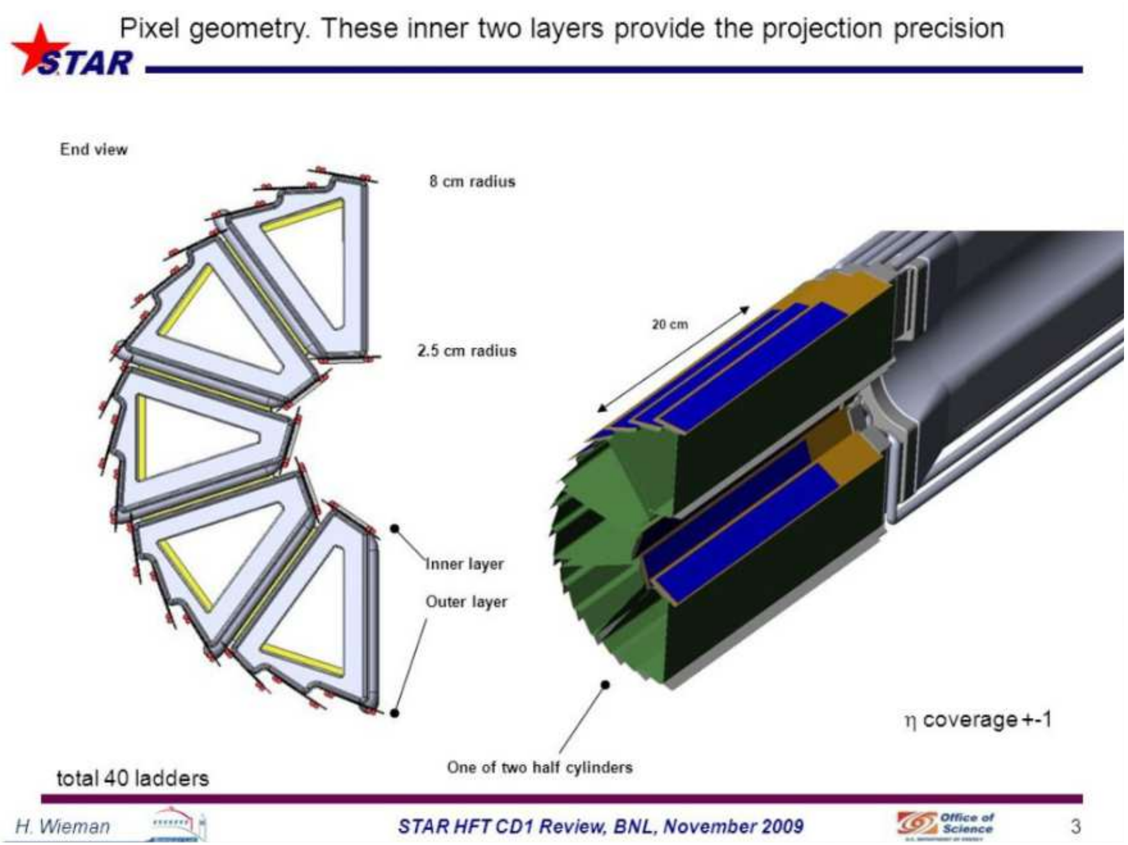
Yasuo Arai TYL-FJPPL@Strasbourg May 11, 2017
https://rd.kek.jp/project/soi/TYL-FJPPL/1705TYL_arai_v1.pdf

The HFT PXL at the STAR Detector in BNL



STAR

Pixel geometry. These inner two layers provide the projection precision

total 40 ladders

H. Wieman STAR HFT CD1 Review, BNL, November 2009 Office of Science 3

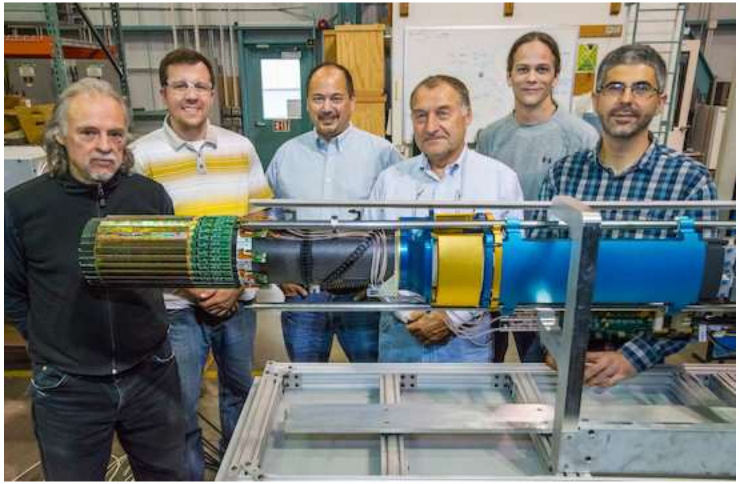
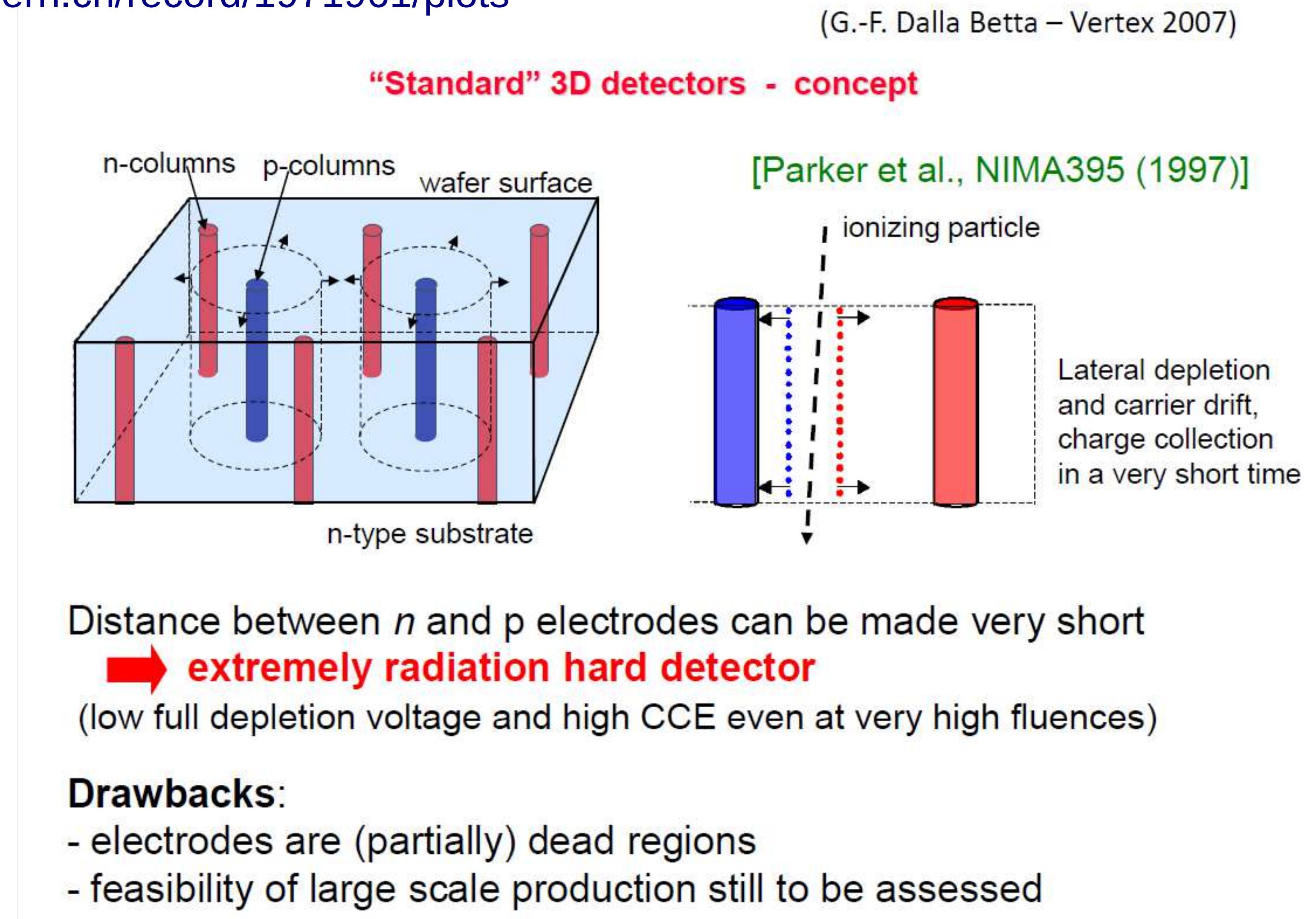


Foto credit BNL (2014)

https://www.bnl.gov/newsroom/news.php?a=24657

Used in Atlas IBL detector sides a and c
https://cds.cern.ch/record/1971961/plots



(G.-F. Dalla Betta – Vertex 2007)

"Standard" 3D detectors - concept

[Parker et al., NIMA395 (1997)]

Lateral depletion
and carrier drift,
charge collection
in a very short time

Distance between *n* and p electrodes can be made very short

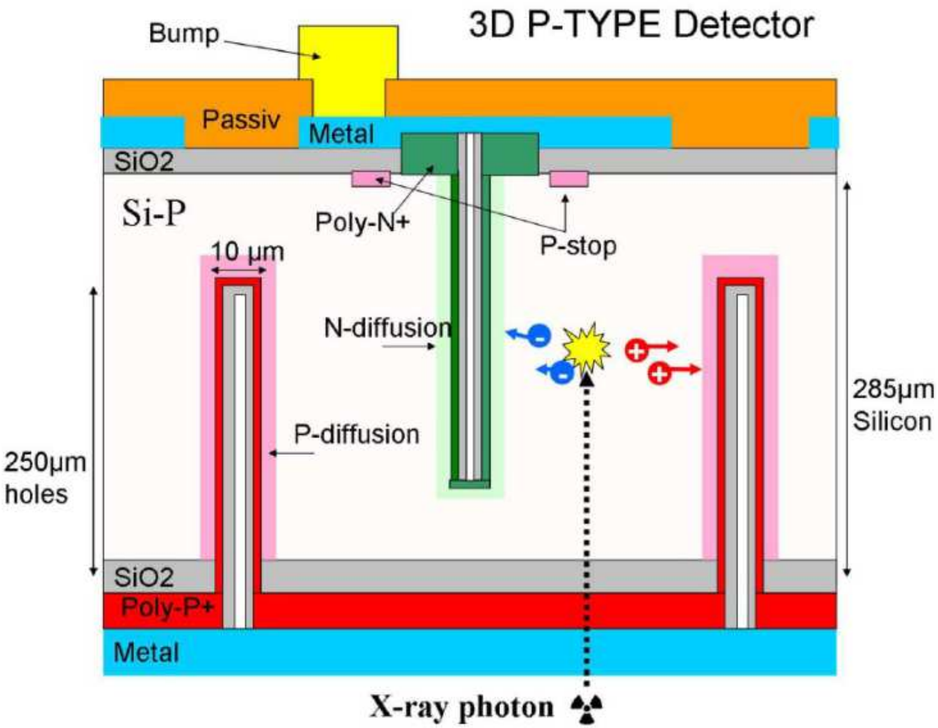
➡ **extremely radiation hard detector**

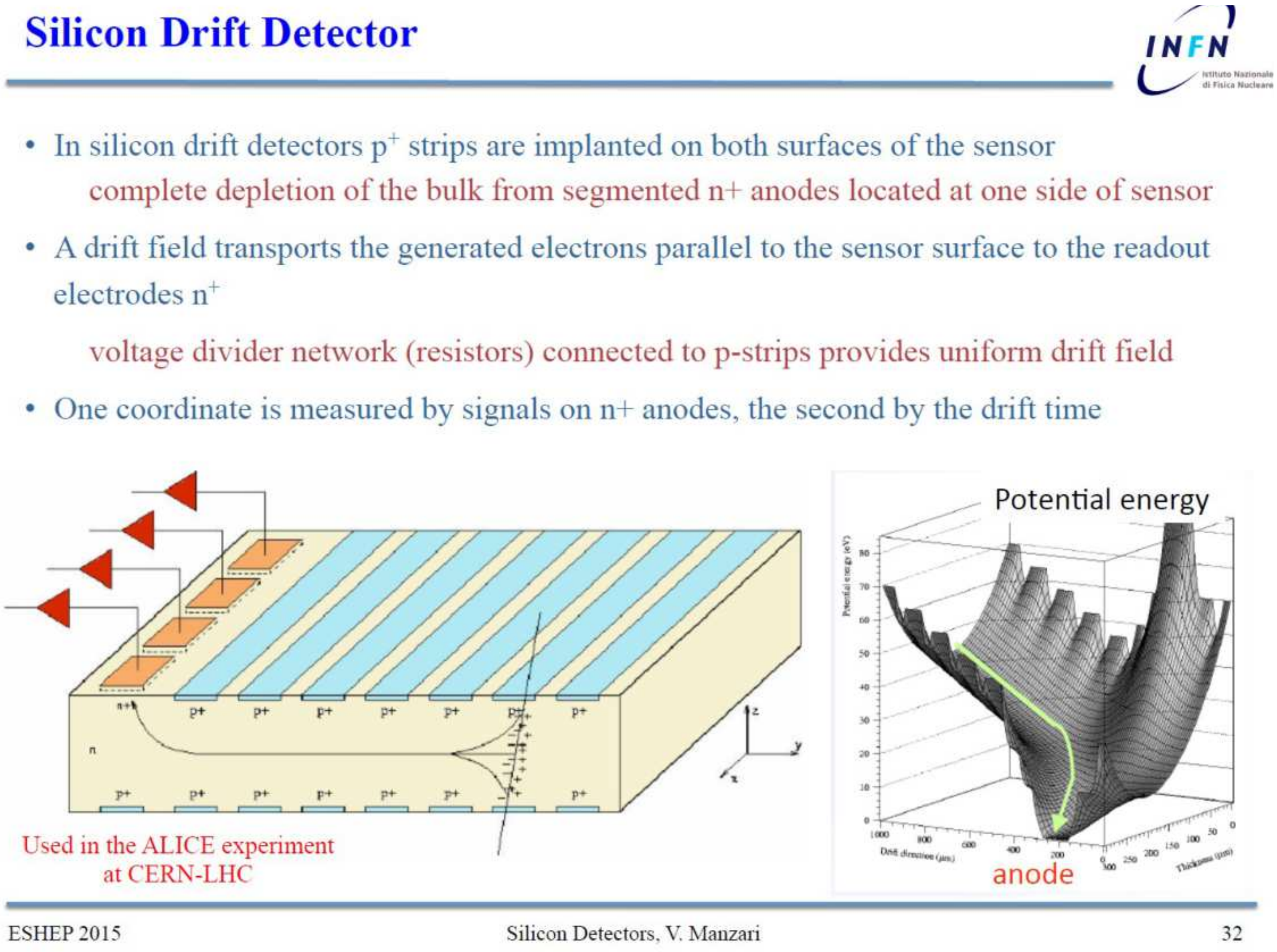
(low full depletion voltage and high CCE even at very high fluences)

Drawbacks:

- electrodes are (partially) dead regions
- feasibility of large scale production still to be assessed

3D Detector


3D P-TYPE Detector
Bump
Passiv
Metal
SiO2
Si-P
Poly-N+
P-stop
10 µm
N-diffusion
P-diffusion
250µm
holes
285µm
Silicon
SiO2
Poly-P+
Metal
X-ray photon



Silicon Drift Detector

- In silicon drift detectors p^+ strips are implanted on both surfaces of the sensor
  complete depletion of the bulk from segmented n+ anodes located at one side of sensor
- A drift field transports the generated electrons parallel to the sensor surface to the readout electrodes n^+
  voltage divider network (resistors) connected to p-strips provides uniform drift field
- One coordinate is measured by signals on n+ anodes, the second by the drift time

Used in the ALICE experiment at CERN-LHC

ESHEP 2015 Silicon Detectors, V. Manzari 32

Used in
Alice ITS1 Layer 2

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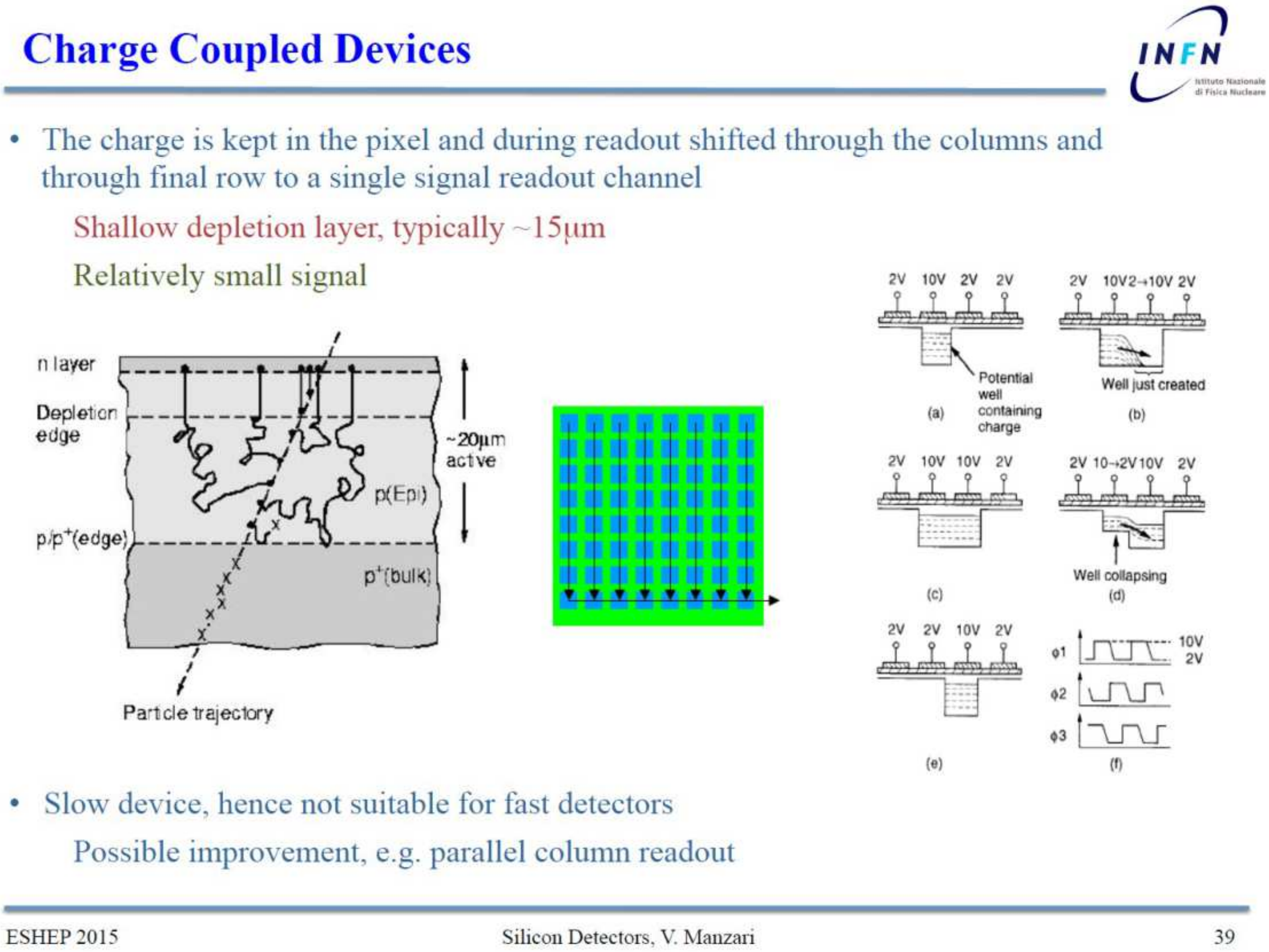

Charge Coupled Devices

- The charge is kept in the pixel and during readout shifted through the columns and through final row to a single signal readout channel
  - Shallow depletion layer, typically ~15µm
  - Relatively small signal

- Slow device, hence not suitable for fast detectors
  - Possible improvement, e.g. parallel column readout

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Nothing else?

The following slides are from **Gianluigi Casse** lectures at the
XXXII INTERNATIONAL SEMINAR
of NUCLEAR and SUBNUCLEAR PHYSICS "Francesco Romano"
7-11 June 2021

https://agenda.infn.it/event/21318/

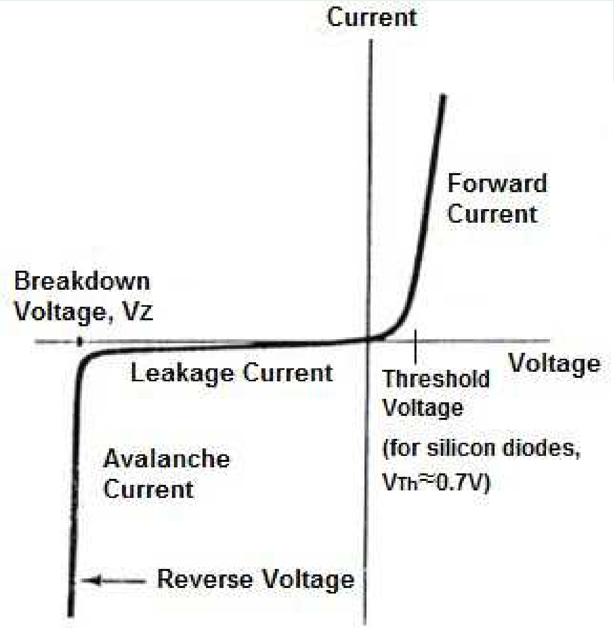
Detecting single photons

A mip in a 300μm thick Si-detector releases 24ke, and need low noise amplification. Here we talk about 1 electron.

Need a different mechanism:

Internal amplification multiplication

Remember the diode IV characteristic:

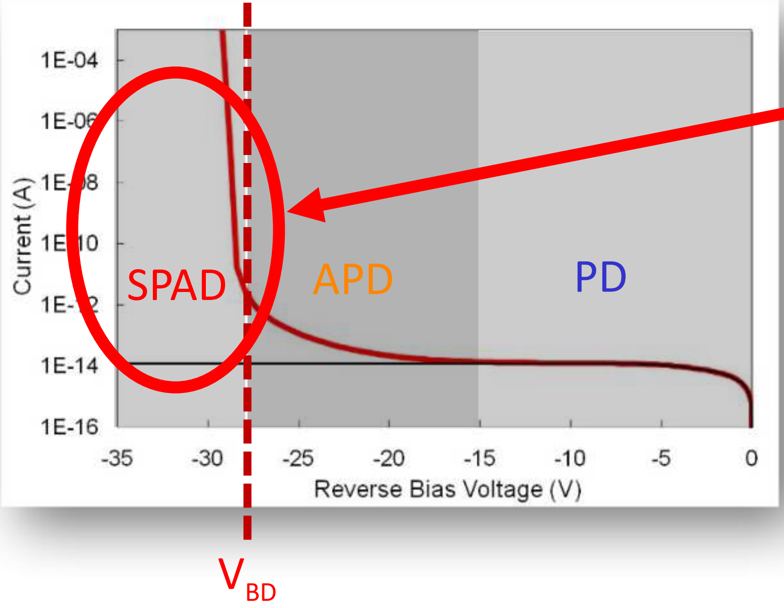


Solid-state low-light detectors

SOLID-STATE DETECTORS WITH INTERNAL GAIN

- process: multiplication of carriers via **impact ionization**

- **Advantages**: low-bias, compact, rugged, insensitive to magnetic field.

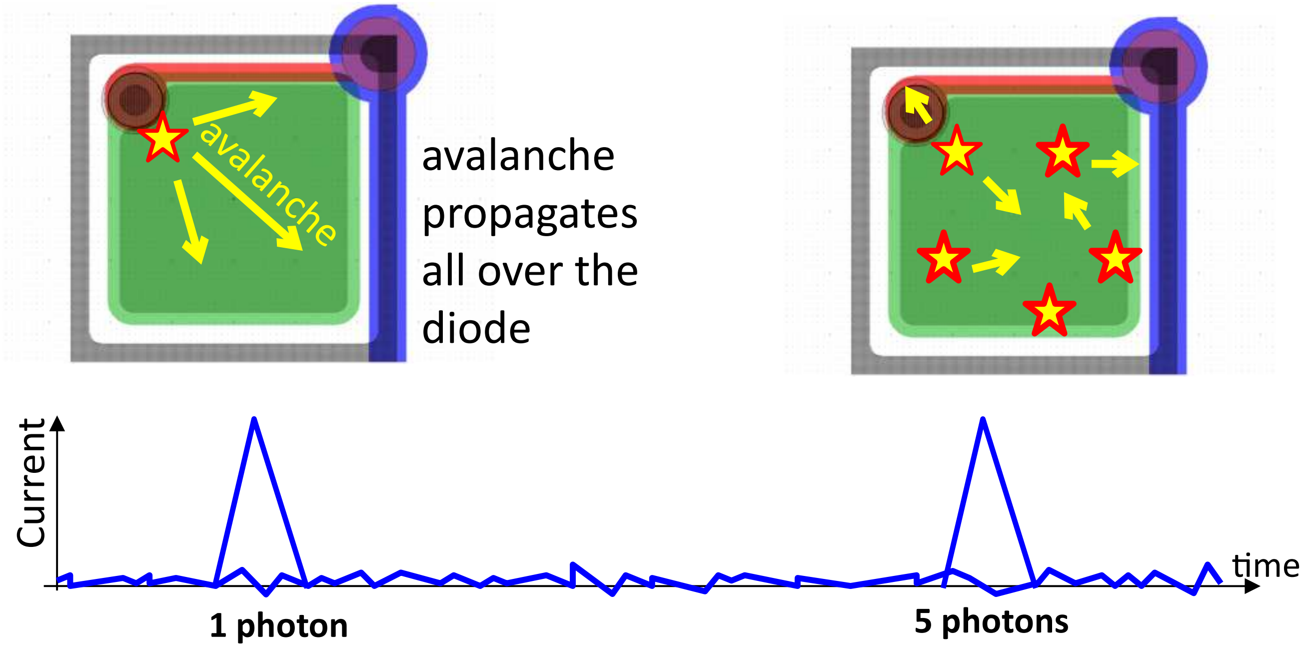


SPAD **(Single-photon avalanche diode)**
(GEIGER-MODE APD)

- Gain ~10^6 or more
- Timing ~ 20÷50 ps.
- Bias voltage <100V
- Sensitivity ~1 ph. e.

SPAD: drawbacks

- **Limited active area: 20µm ÷ 200µm**
- **Cannot count the number of photons**

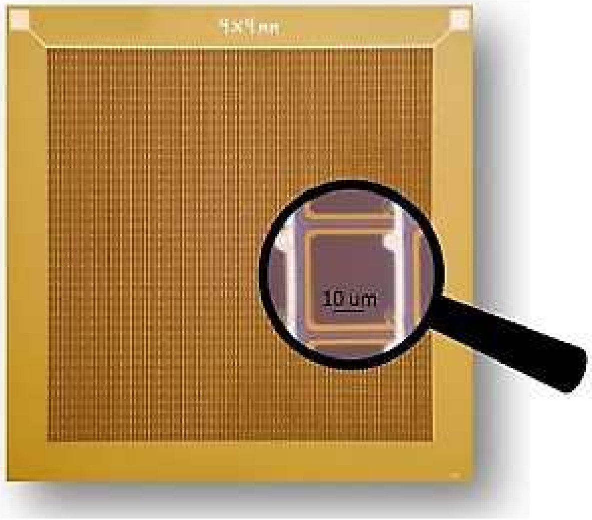


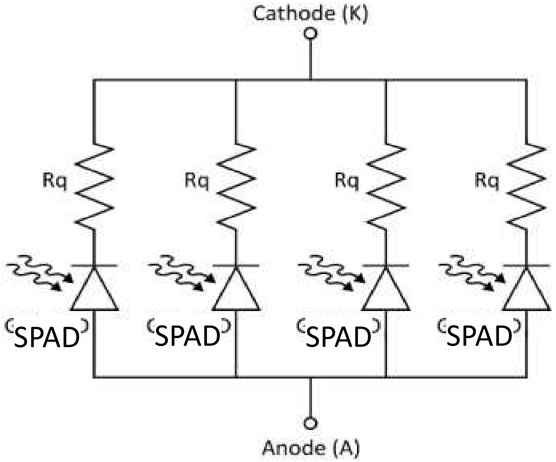
avalanche propagates all over the diode

The Silicon Photomultiplier (SiPM)

SiPMs are arrays of small SPADs connected in parallel.

Each SPAD employs a passive quenching mechanism.





SiPM size:

1x1 mm^2 to 10x10 mm^2

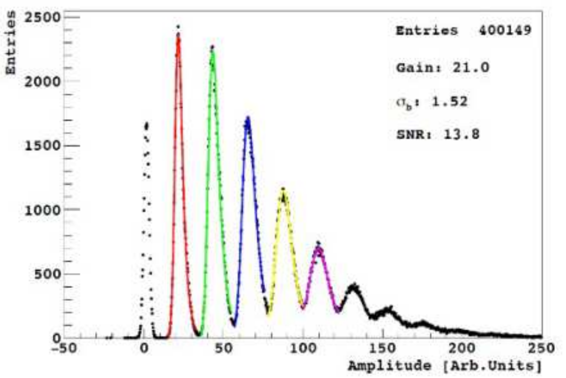
Microcell (SPAD) pitch:
12 um to 40 um
(typical)

The Silicon Photomultiplier

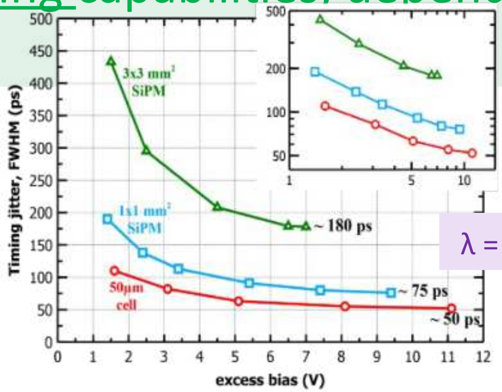
A SiPM is a single-photon detector, with internal signal amplification, fabricated on CMOS-compatible silicon wafers.

Capabilities of SiPMs:

- Detection of single photons in the visible / NIR range with simple (low power) readout electronics.
- Excellent timing performance: down to 50 ps FWHM.
- Few-photon or many-photon counting capabilities, depending on



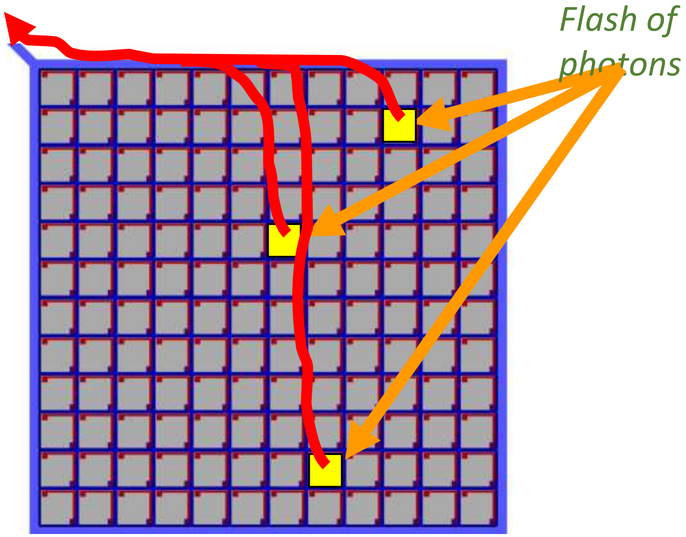
Example of few-photon counting

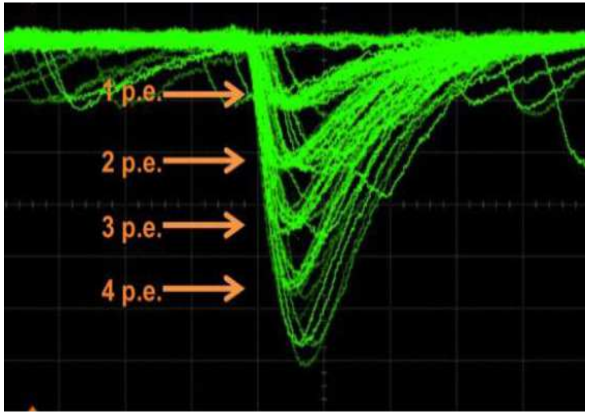


λ = 425 nm

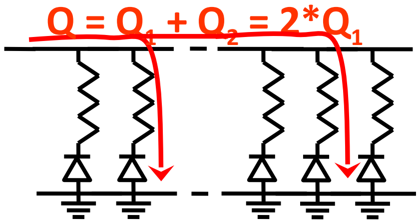
Single photon time resolution (SPTR)

The Silicon Photomultiplier (SiPM)





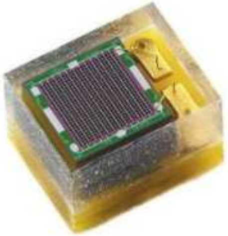
- Each element is independent and gives the same signal when fired.

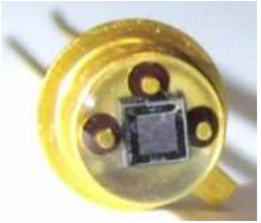


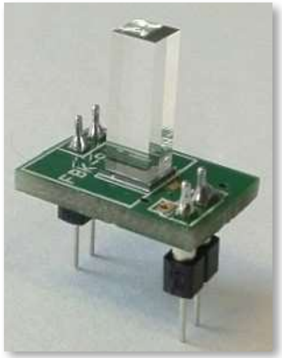
$Q = Q_1 + Q_2 = 2*Q_1$

⇒ Output amplitude (and charge) → proportional to the number of triggered cells → proportional to the number of photons.

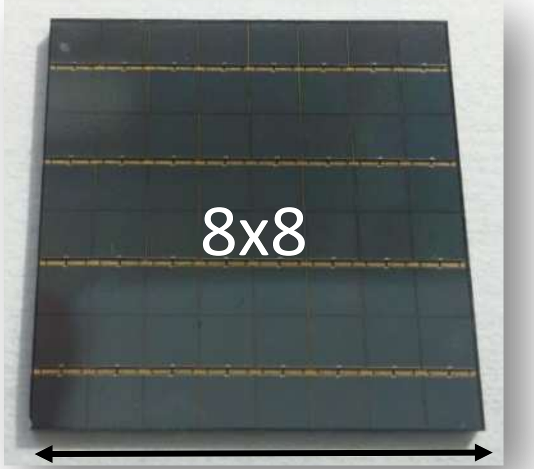
Silicon Photomultiplier (SiPM)


http://
www.ketek.net/


http://advansid.com/



- composed of square SPAD e.g. 40x40 μm^2
- Active area of 1x1mm^2 up to 10x10mm^2
- Different package and connections.
- **TILE of SiPMs** to cover big areas.
- Typically **coupled to scintillators** for gamma-ray detection *(e.g. medical imaging, physics experiments)*



3.23 cm

More?

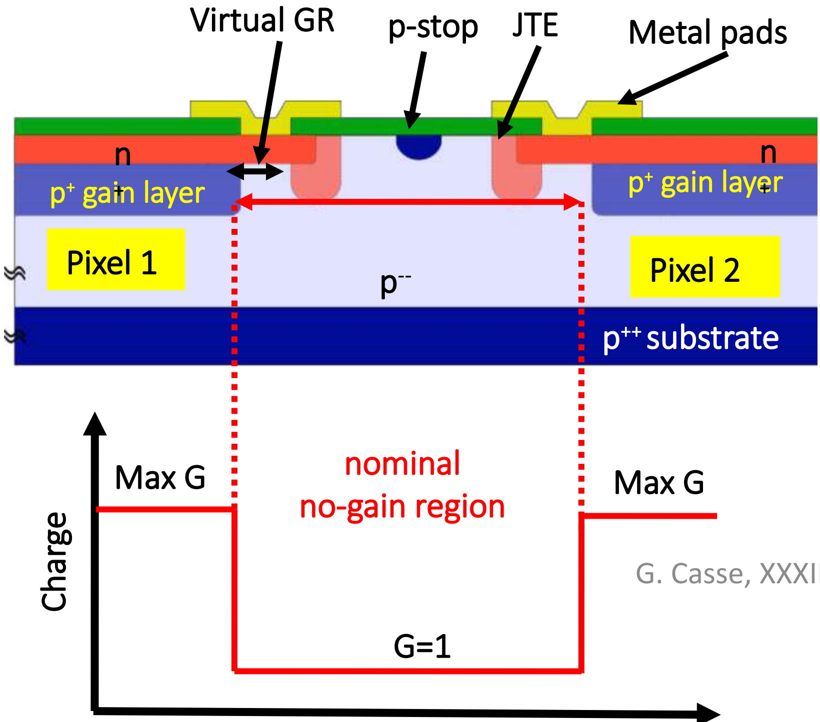
LGAD Technology

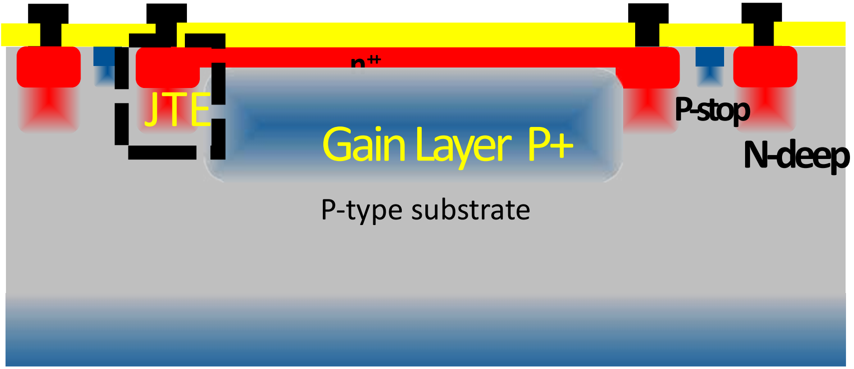
Inspiration from the multiplying irradiated detectors. Development in CERN/RD50. A "gain layer" is included in the structure (local doping enrichment with to activate the impact ionization). Termination structure JTE for stability.

- Silicon detectors that look like a normal pixel or strip sensor, but with a **much larger signal** (internal Gain in the range ~ 10 – 20)
- High signals also with thin silicon substrates
- **Better timing performance**
- Easy to be segmented
- Low gain -> **low excess noise**

Two major challenges:

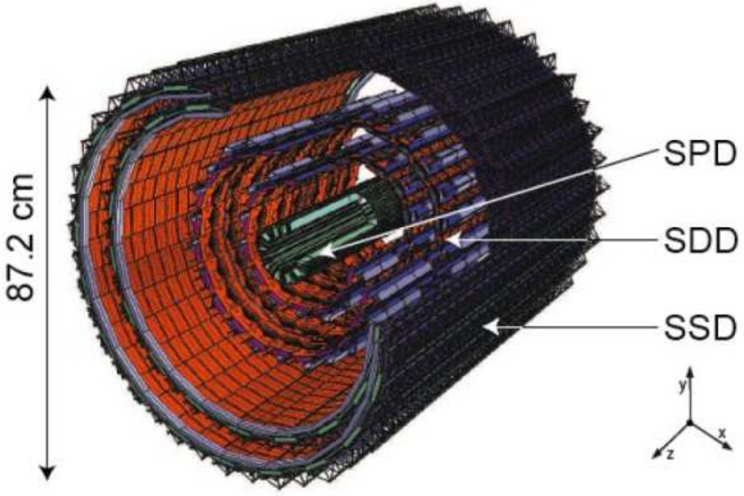
- Radiation tolerance
- Fill factor

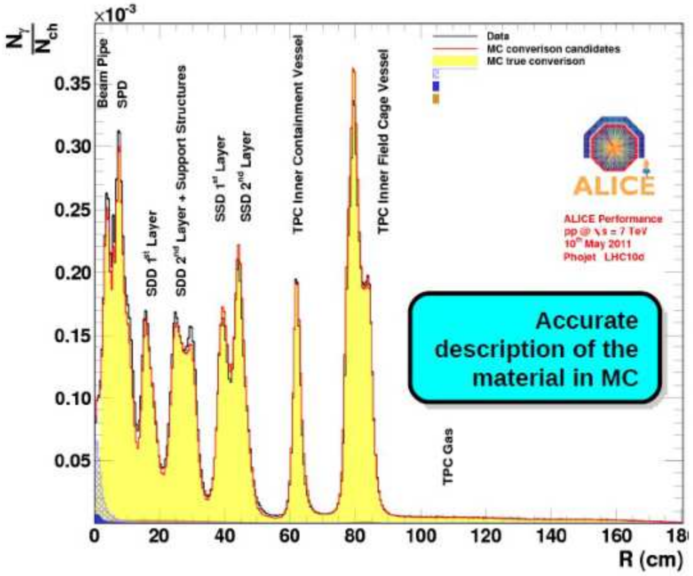




The ALICE Detector:
from ITS1 to ITS2

Inner Tracking System (ITS)

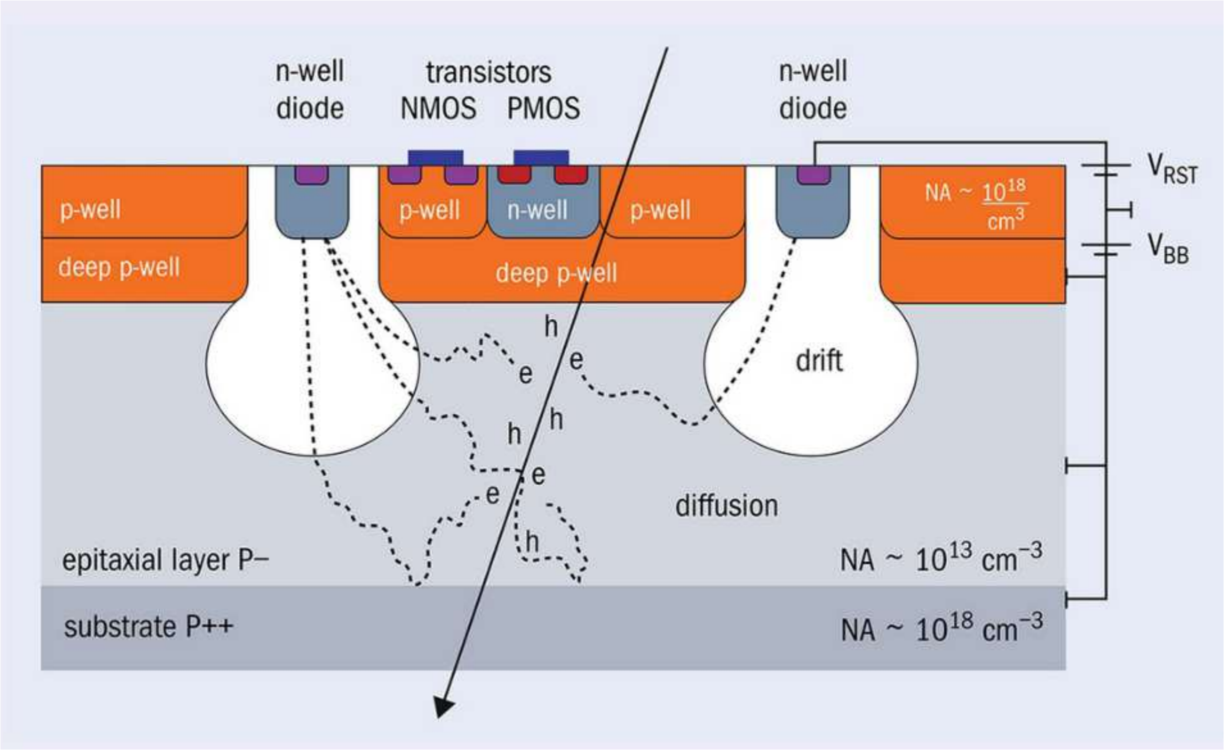




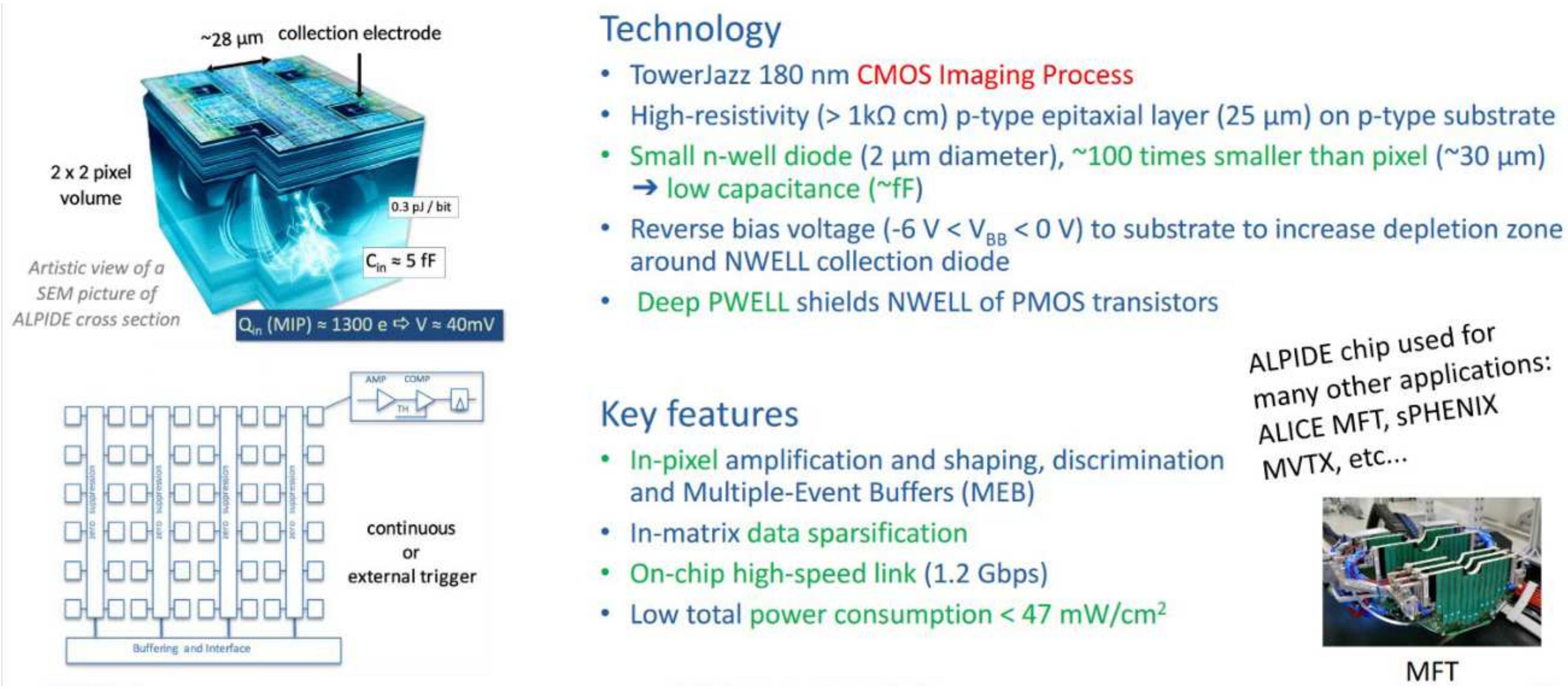
Accurate description of the material in MC

Layer	Det.	Radius (cm)	Length (cm)	Surface (m2)	Chan.	Spatial precision (mm)		Cell (μm2)	Max occupancy central PbPb (%)	Material Budget (% X/X_0)	Power dissipation (W)	
						rφ	z				barrel	end-cap
1	SPD	3.9	28.2	0.21	9.8M	12	100	50x425	2.1	1.14	1.35k	30
2		7.6	28.2						0.6	1.14		
3	SDD	15.0	44.4	1.31	133 K	35	25	202x294	2.5	1.13	1.06k	1.75k
4		23.9	59.4						1.0	1.26		
5	SSD	38.0	86.2	5.0	2.6M	20	830	95x40000	4.0	0.83	850	1.15k
6		43.0	97.8						3.3	0.86		

Monolithic Active Pixel Silicon sensor (MAPS)



ALPIDE chip: a MAPS sensor for ALICE ITS2 and MFT upgrade



Artistic view of a SEM picture of ALPIDE cross section

Technology

- TowerJazz 180 nm CMOS Imaging Process
- High-resistivity (> 1kΩ cm) p-type epitaxial layer (25 µm) on p-type substrate
- Small n-well diode (2 µm diameter), ~100 times smaller than pixel (~30 µm) ➔ low capacitance (~fF)
- Reverse bias voltage (-6 V < V_{BB} < 0 V) to substrate to increase depletion zone around NWELL collection diode
- Deep PWELL shields NWELL of PMOS transistors

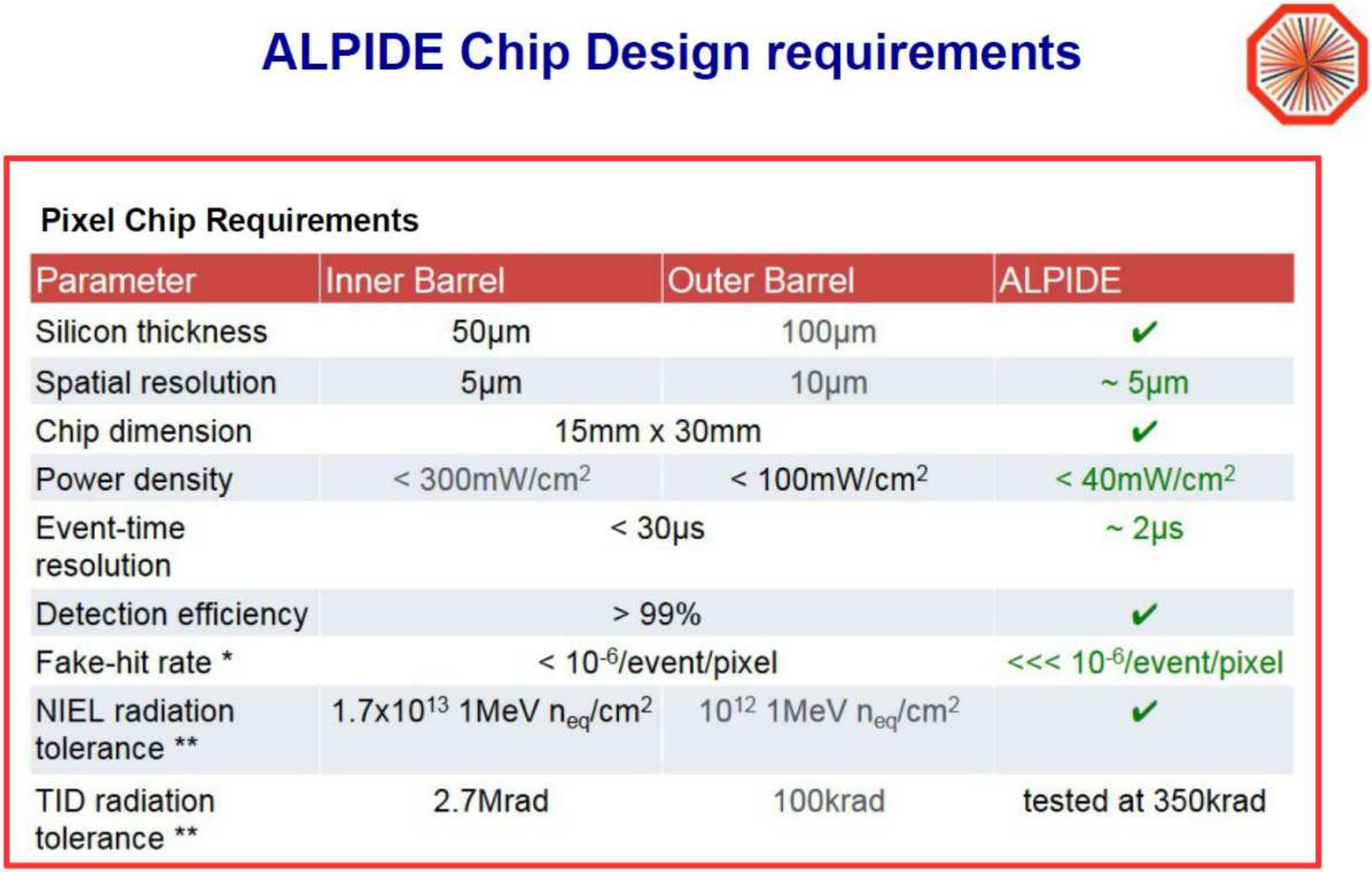
Key features

- In-pixel amplification and shaping, discrimination and Multiple-Event Buffers (MEB)
- In-matrix data sparsification
- On-chip high-speed link (1.2 Gbps)
- Low total power consumption < 47 mW/cm²

ALPIDE chip used for many other applications: ALICE MFT, sPHENIX MVTX, etc…

Slide from: CERN Detector Seminar - S. Beolé, 15/09/2023

The ALPIDE chip and the Alice ITS Upgrade project



ALPIDE Chip Design requirements

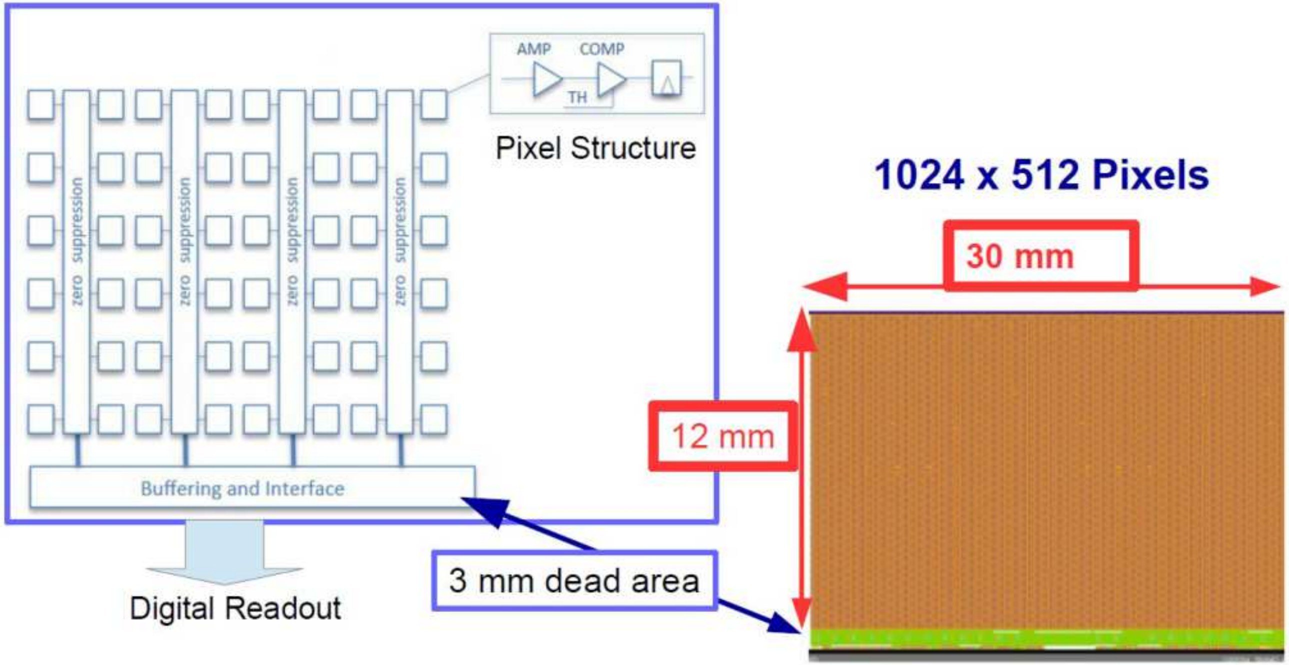
Pixel Chip Requirements

Parameter	Inner Barrel	Outer Barrel	ALPIDE
Silicon thickness	50µm	100µm	✔
Spatial resolution	5µm	10µm	~ 5µm
Chip dimension	15mm x 30mm		✔
Power density	< 300mW/cm^2	< 100mW/cm^2	< 40mW/cm^2
Event-time resolution	< 30µs		~ 2µs
Detection efficiency	> 99%		✔
Fake-hit rate *	< 10^{-6}/event/pixel		<<< 10^{-6}/event/pixel
NIEL radiation tolerance **	1.7x10^{13} 1MeV n$_{eq}$/cm^2	10^{12} 1MeV n$_{eq}$/cm^2	✔
TID radiation tolerance **	2.7Mrad	100krad	tested at 350krad

The ALPIDE chip and the Alice ITS Upgrade project

The ALPIDE Chip

Chip realized with MAPS Technologies:



Pixel Structure

Digital Readout

3 mm dead area

1024 x 512 Pixels

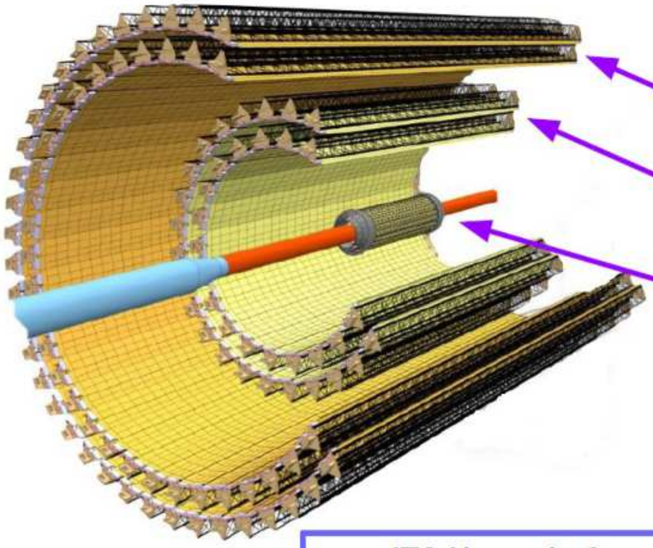
30 mm

12 mm

The ALPIDE chip and the Alice ITS Upgrade project

ITS Upgrade Overview:

12.5 Gigapixels
~ 10 m^2 active surface



7 layers:

- 2 Outer Barrel Layers
- 2 Middle Barrel Layers
- 3 Inner Barrel Layers

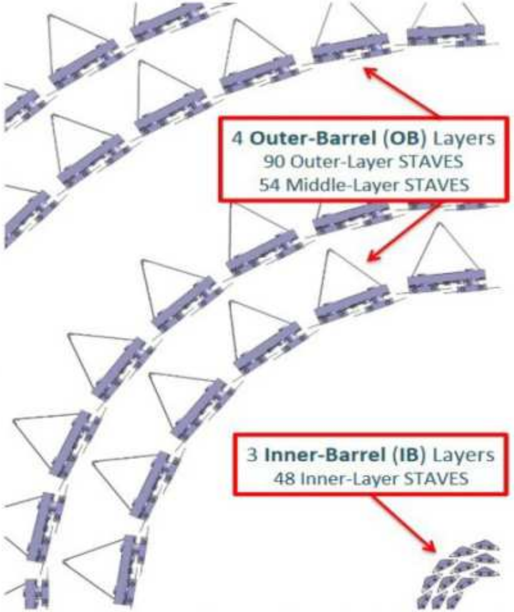
ITS Upgrade Coverage Requirements

η coverage: $|\eta| \leq 1.22$
r coverage: 22 – 400 mm
z coverage: Inner Layers L = 290 mm
Middle Layers L = 900 mm
Outer Layers L = 1500 mm

The ALPIDE chip and the Alice ITS Upgrade project

ITS Upgrade Overview:

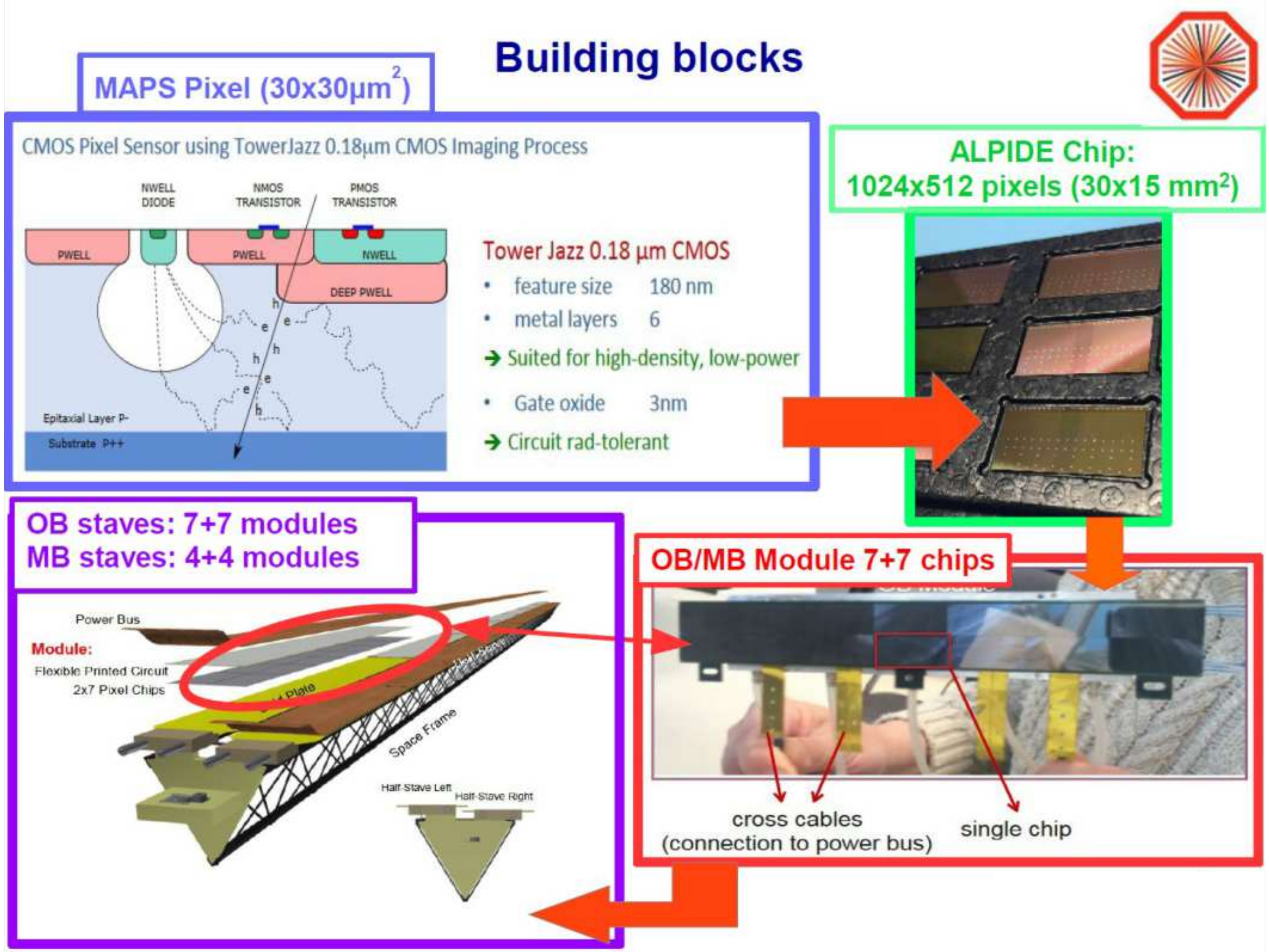
Layer #	6	5	4	3	2	1	0
n. of Chip	9408	8232	3360	2688	180	144	108
n. of Modules	672	588	240	192	20	16	12
n. of Staves	48	42	30	24	20	16	12



192 staves: 90 (OL) 54 (ML), 48 (IL)

Staves are composed by two type of modules:
- Inner Barrel:
  modules of 9 Chips
- Outer Barrel (Outer Layers and Middle Layers):
  Modules of 14 Chips

The ALPIDE chip and the Alice ITS Upgrade project



Building blocks

MAPS Pixel (30x30µm^2)

CMOS Pixel Sensor using TowerJazz 0.18µm CMOS Imaging Process

Tower Jazz 0.18 µm CMOS

- feature size 180 nm
- metal layers 6

→ Suited for high-density, low-power

- Gate oxide 3nm

→ Circuit rad-tolerant

ALPIDE Chip:
1024x512 pixels (30x15 mm^2)

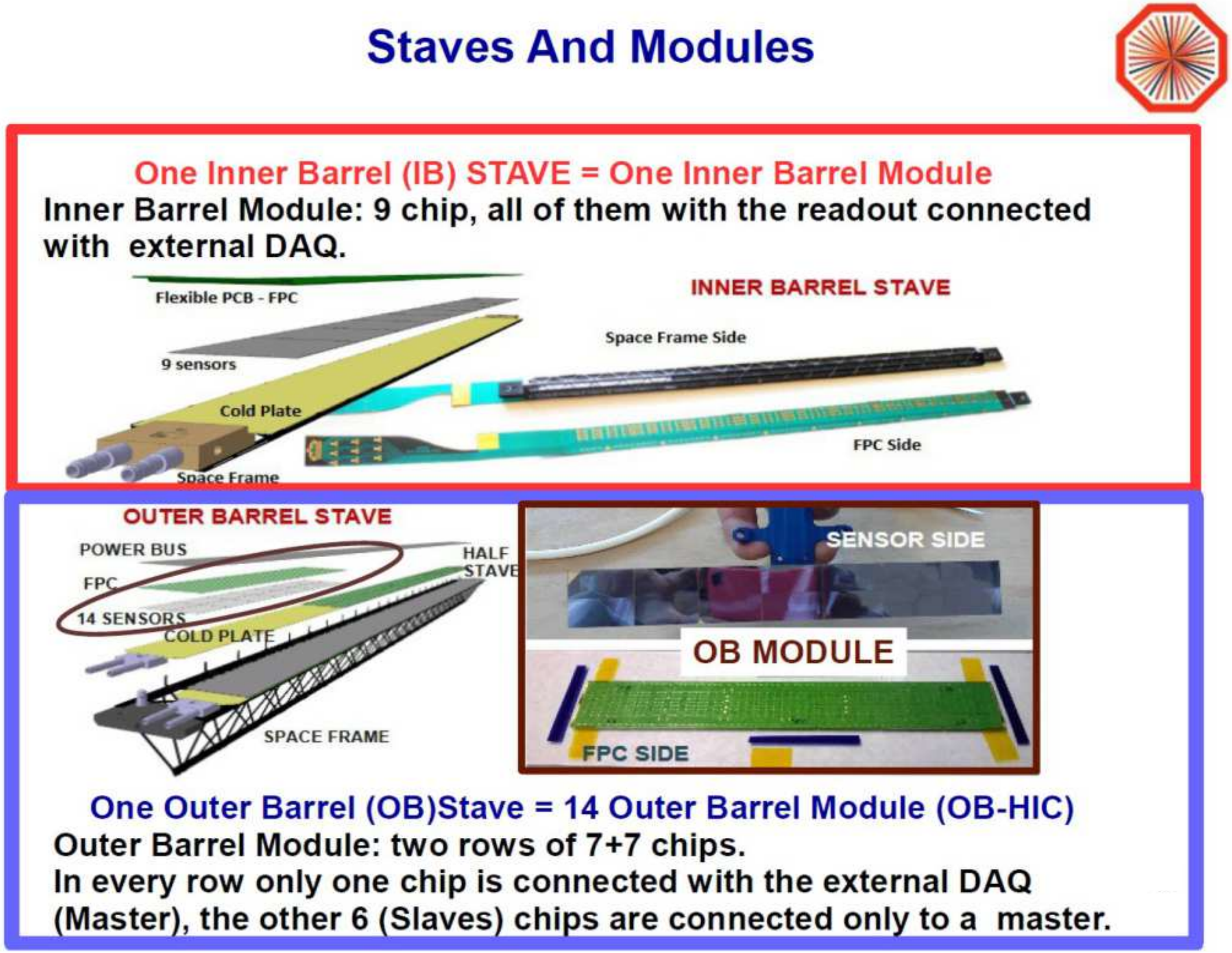
OB staves: 7+7 modules
MB staves: 4+4 modules

OB/MB Module 7+7 chips

cross cables
(connection to power bus)

single chip

The ALPIDE chip and the Alice ITS Upgrade project



Staves And Modules

One Inner Barrel (IB) STAVE = One Inner Barrel Module

Inner Barrel Module: 9 chip, all of them with the readout connected with external DAQ.

One Outer Barrel (OB)Stave = 14 Outer Barrel Module (OB-HIC)

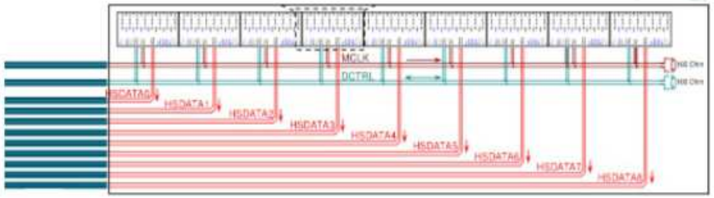
Outer Barrel Module: two rows of 7+7 chips.
In every row only one chip is connected with the external DAQ (Master), the other 6 (Slaves) chips are connected only to a master.

The ALPIDE chip and the Alice ITS Upgrade project

Chip Connections inside Modules

Inner Barrel Module
External Lines:

One Control Line
One Clock Line
Nine Serial Data lines

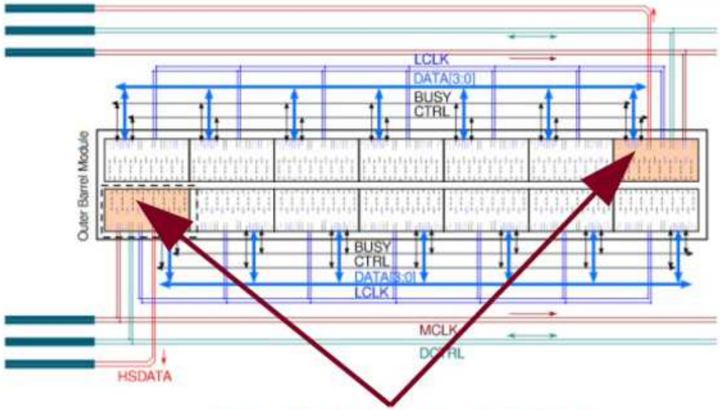


Hit Density ~ 150 hit/cm^2

Outer Barrel Module External Lines:

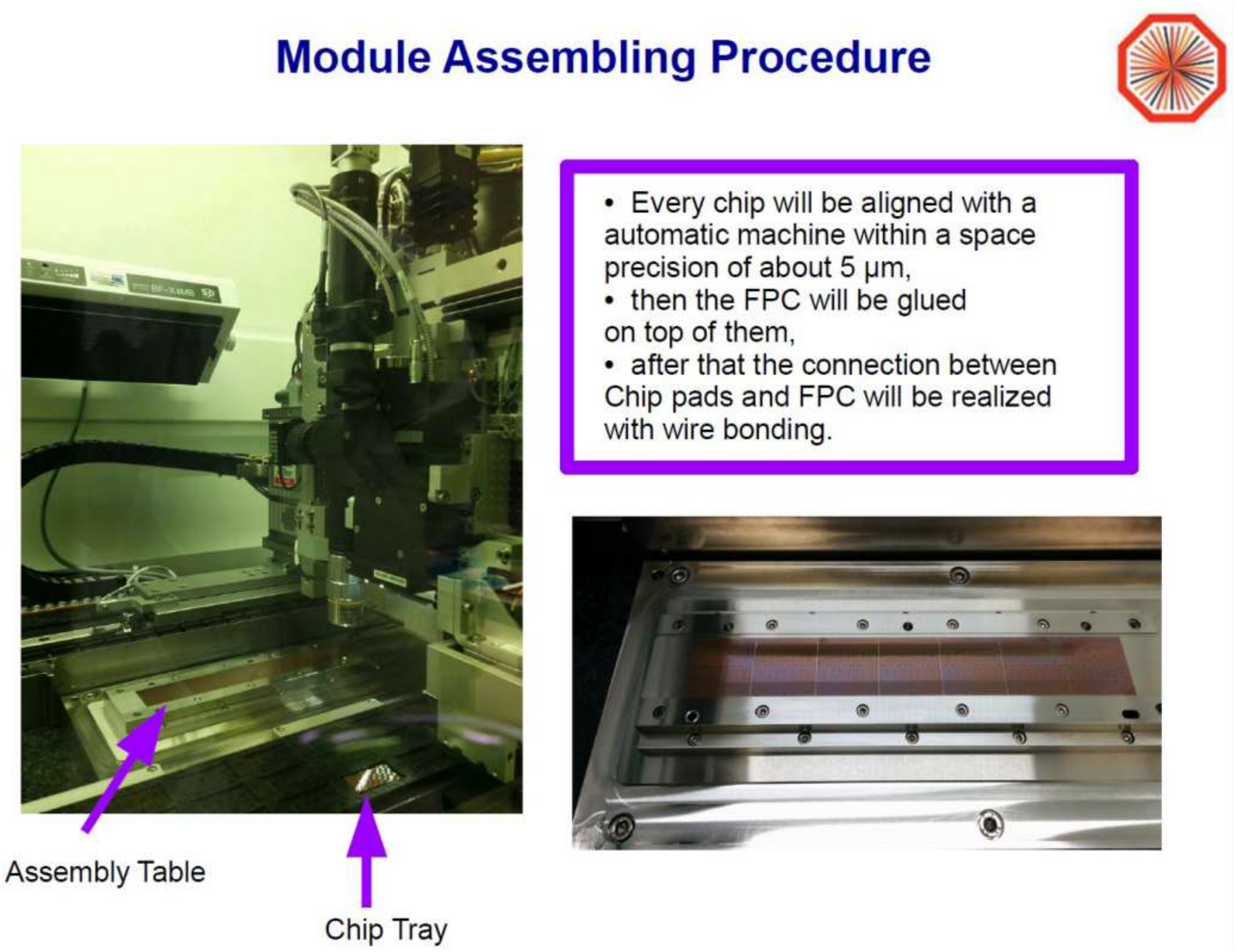
One + One Control Line
One + One Clock Line
One + One Serial Data lines

Hit Density ~ 1 hit/cm^2



Two Masters every module

The ALPIDE chip and the Alice ITS Upgrade project



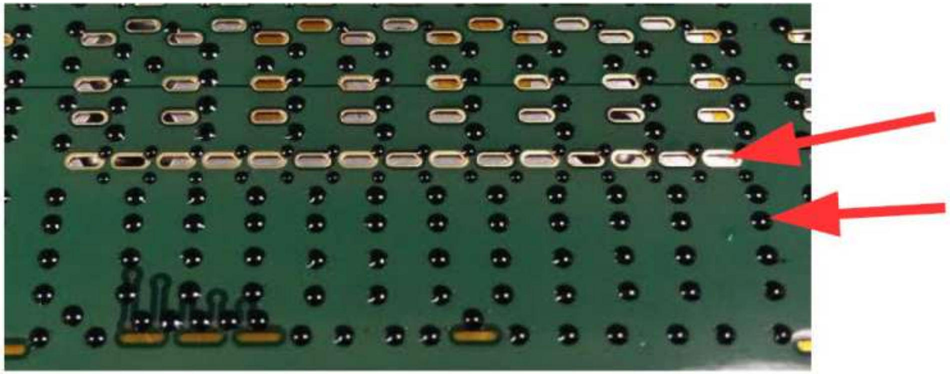
Module Assembling Procedure

- Every chip will be aligned with a automatic machine within a space precision of about 5 µm,
- then the FPC will be glued on top of them,
- after that the connection between Chip pads and FPC will be realized with wire bonding.

The ALPIDE chip and the Alice ITS Upgrade project

Module wire bonding procedure

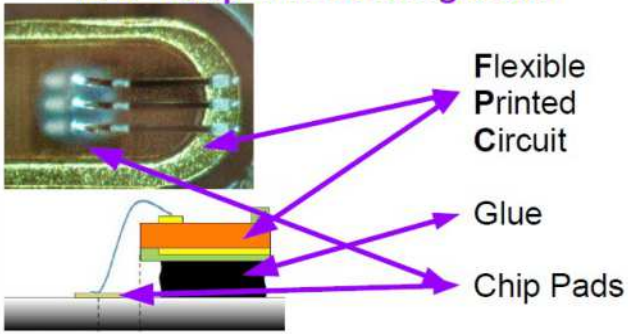
Flexible Printed Circuit (FPC)

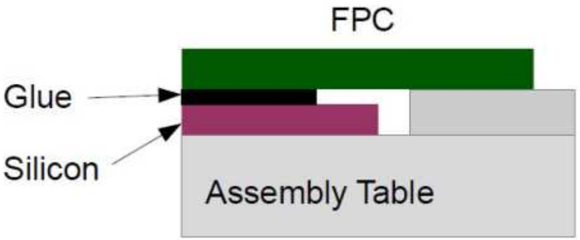


Holes for wire bonding

Glue (Ecobond 45)

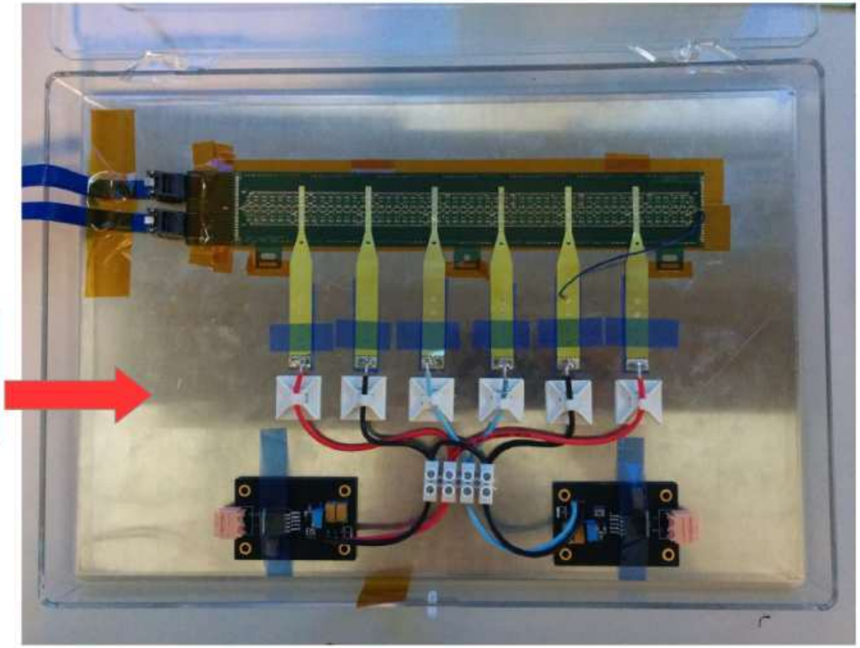
FPC - Chip wire bonding detail





The ALPIDE chip and the Alice ITS Upgrade project

Module ready for characterization



Control, Clock and
Serial Data Lines

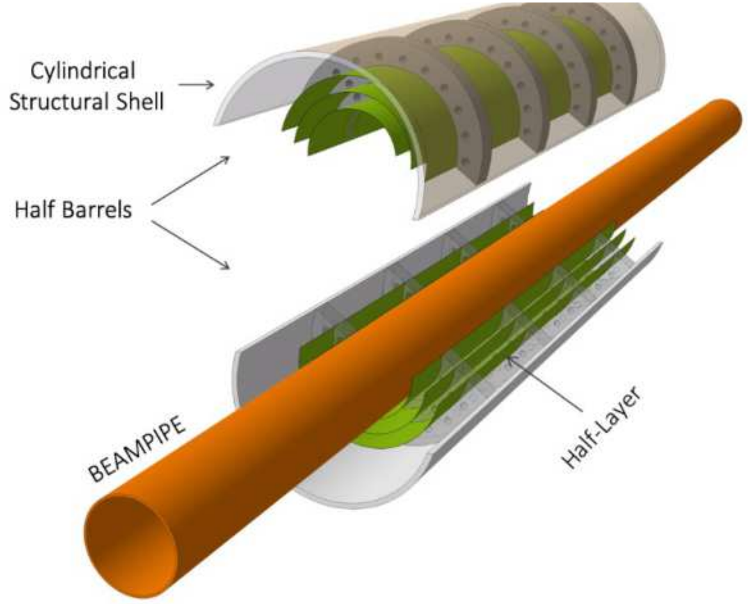
POWER Lines:
Analog, Digital and Ground

Studies for Large area bent sensors

The ALICE ITS3 tracker

Report number: CERN-LHCC-2019-018 ; LHCC-I-034
Title: Letter of Intent for an ALICE ITS Upgrade in LS3
Author(s): Musa, Luciano
DOI 10.17181/CERN-LHCC-2019-018
Web: https://cds.cern.ch/record/2703140

Stitching is a technology that allows the fabrication of an image sensor that is larger than the field of view of the lithographic equipment. In this technology, the reticles which fit into the field of view of that equipment are placed on the wafer with high precision, achieving a tiny but well defined overlap. In this way, wafer-scale sensors can be manufactured

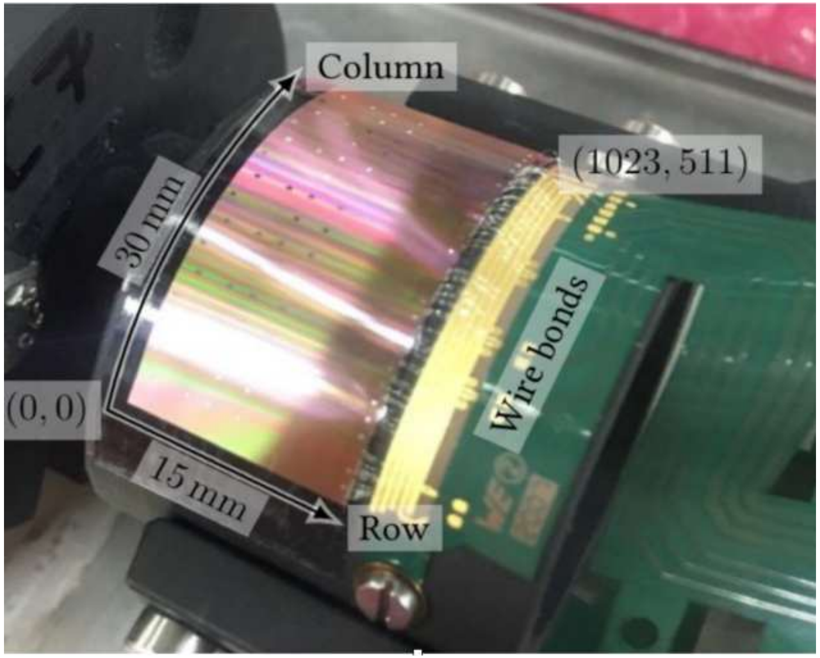


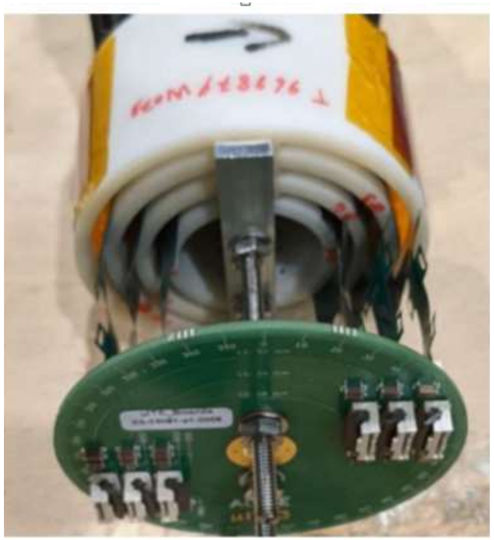
Stitching technology and sensor tinning can allow
The realization of large area bent detectors

The half-layers are arranged inside the half-barrel. They have a truly (half-) cylindrical shape, with each half-layer consisting of a single large pixel chip, which is curved to a cylindrical shape.

Studies for Large area bent sensors

See: https://ep-news.web.cern.ch/content/alice-its3-clears-major-milestone





The “µITS3” assembly, based on 6 ALPIDE chips that are bent to the target radii of ITS3 (2 chips each at 18, 24, and 30 mm).

This sensor is also candidate as vertex silicon detector for the ePIC detector at the future EIC Collider in BNL (https://wiki.bnl.gov/EPIC/index.php?title=Si_Vertex_Tracker)

End part 1

Thanks for you attention!

comments, questions ... suggestions ?

benedetto.diruzza@unifg.it

Back-up slides

ICHEP 2020 Conference: Benedetto Di Ruzza
Proton and x-ray irradiation of silicon devices at the TIFPA-INFN facilities in Trento (Italy)
slides: https://indico.cern.ch/event/868940/contributions/3815732
proceeding: DOI: 10.22323/1.390.0685; https://pos.sissa.it/390/685

16th "Trento" Workshop on Advanced Silicon Radiation Detectors 2021: Benedetto Di Ruzza
Ionizing and Non-Ionizing Energy Loss irradiation studies with 70-230 MeV protons at the Trento Proton Therapy Center
slides: https://indico.cern.ch/event/983068/contributions/4223200

WEBLINKS

- Trento Institute for Fundamental Physics and Applications (**TIFPA**):
  https://www.tifpa.infn.it/about-tifpa

- TIFPA Activity Reports:
  https://www.tifpa.infn.it/contacts/downloads

- Bruno Kessler Foundation (**FBK**):
  https://www.fbk.eu/en

WEB References

TIFPA-INFN: www.tifpa.infn.it
APSS: https://protonterapia.provincia.tn.it/eng
Physics UniTN: https://www.physics.unitn.it/en
Biology UniTN: https://www.cibio.unitn.it
IBA: https://iba-worldwide.com

Trento Proton Therapy Center:
Experimental Area info and Beam Time applications:
http://www.tifpa.infn.it/sc-init/med-tech/p-beam-research

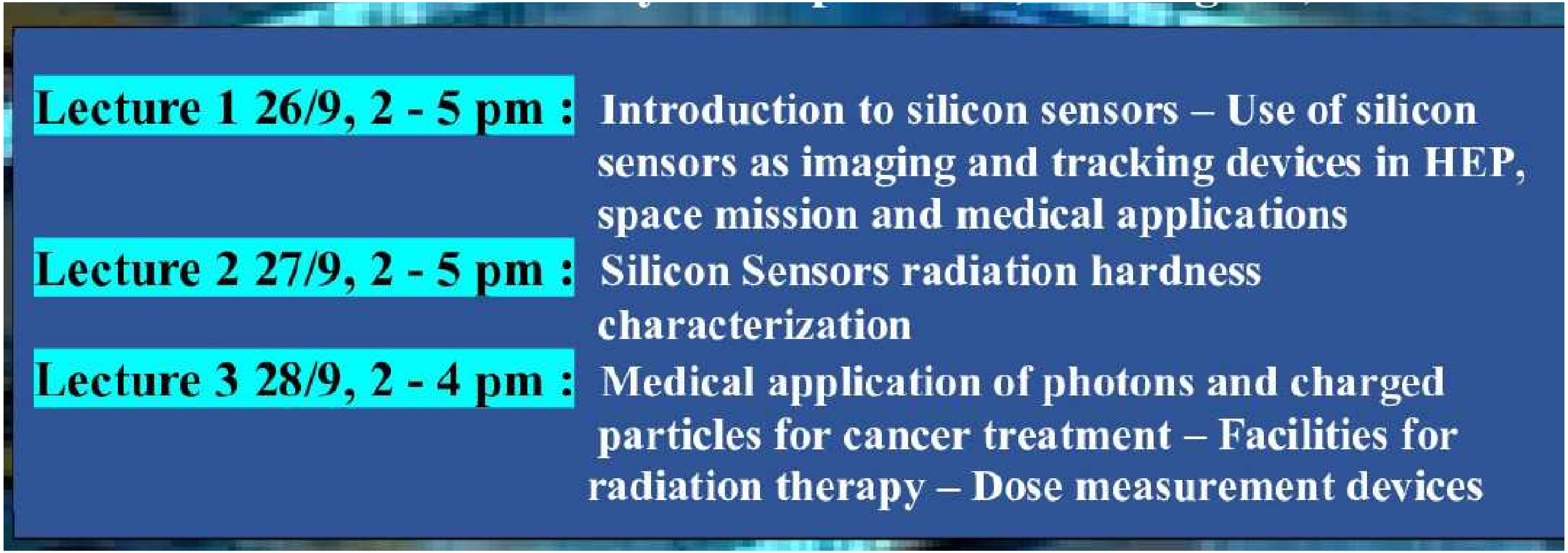
TIFPA Activity Reports:
https://www.tifpa.infn.it/contacts/downloads

Experimental area beam characterization:

REF1 – *Proton beam characterization in the experimental room of the Trento Proton Therapy facility*
F. Tommasino et al. NIM A 869 (2017) 15–20.
DOI: http://dx.doi.org/10.1016/j.nima.2017.06.017

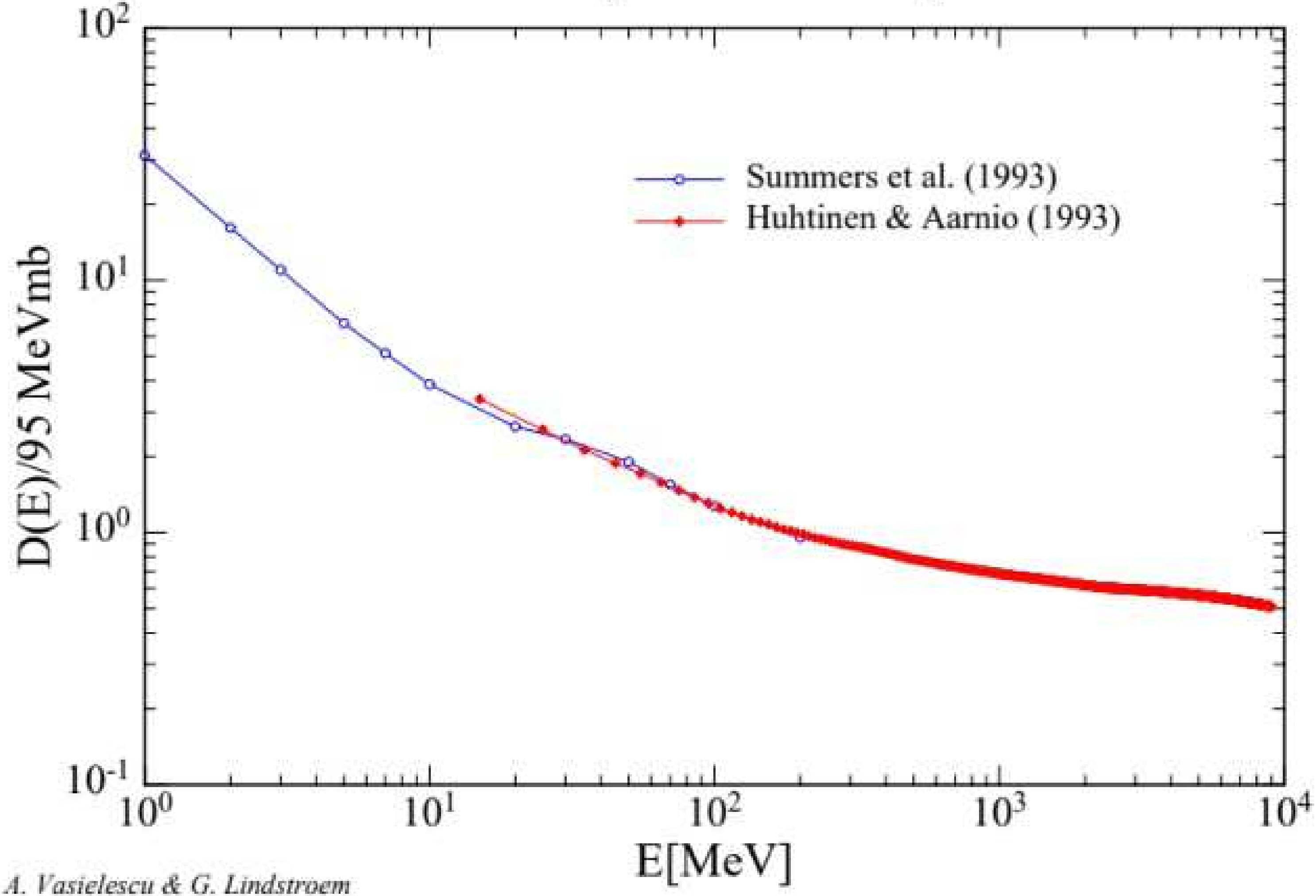
REF2 – *A new facility for proton radiobiology at the Trento proton therapy centre: Design and implementation*
F. Tommasino et al. Physica Medica 58 (2019) 99–106
DOI: https://doi.org/10.1016/j.ejmp.2019.02.001

INTRODUCTION



Lecture 1 26/9, 2 - 5 pm :	Introduction to silicon sensors – Use of silicon sensors as imaging and tracking devices in HEP, space mission and medical applications
Lecture 2 27/9, 2 - 5 pm :	Silicon Sensors radiation hardness characterization
Lecture 3 28/9, 2 - 4 pm :	Medical application of photons and charged particles for cancer treatment – Facilities for radiation therapy – Dose measurement devices

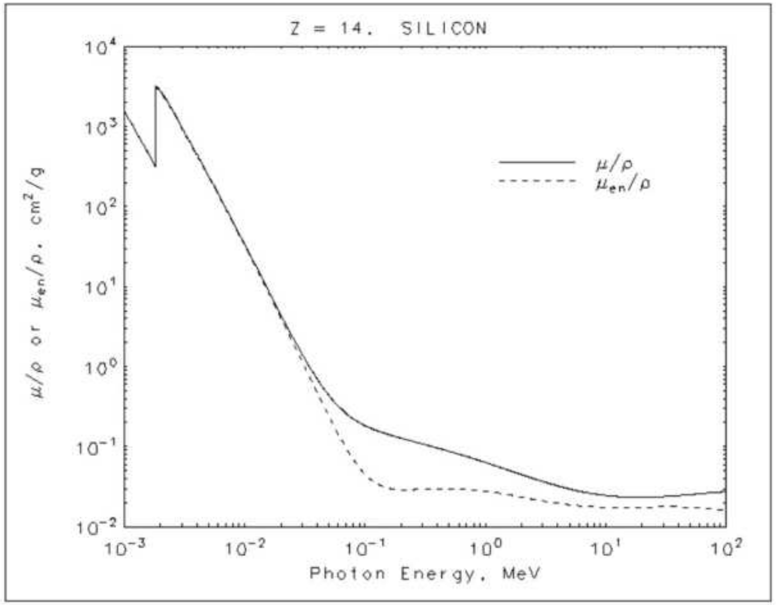
Proton induced displacement damage in Silicon

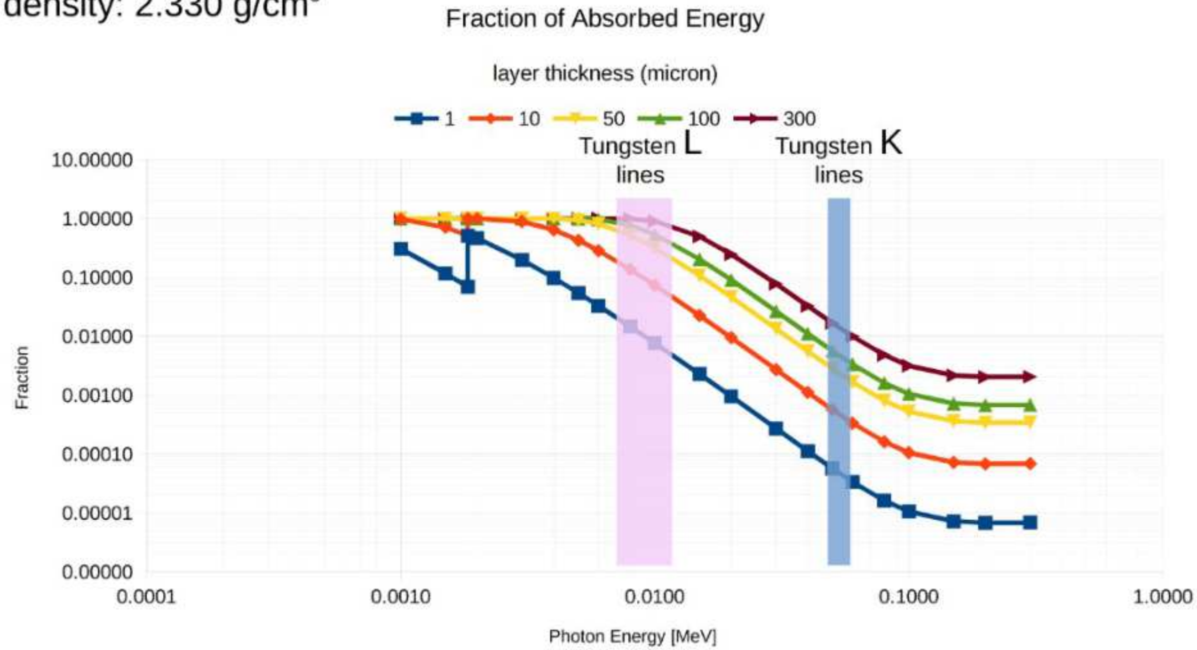


A. Vasielescu & G. Lindstroem

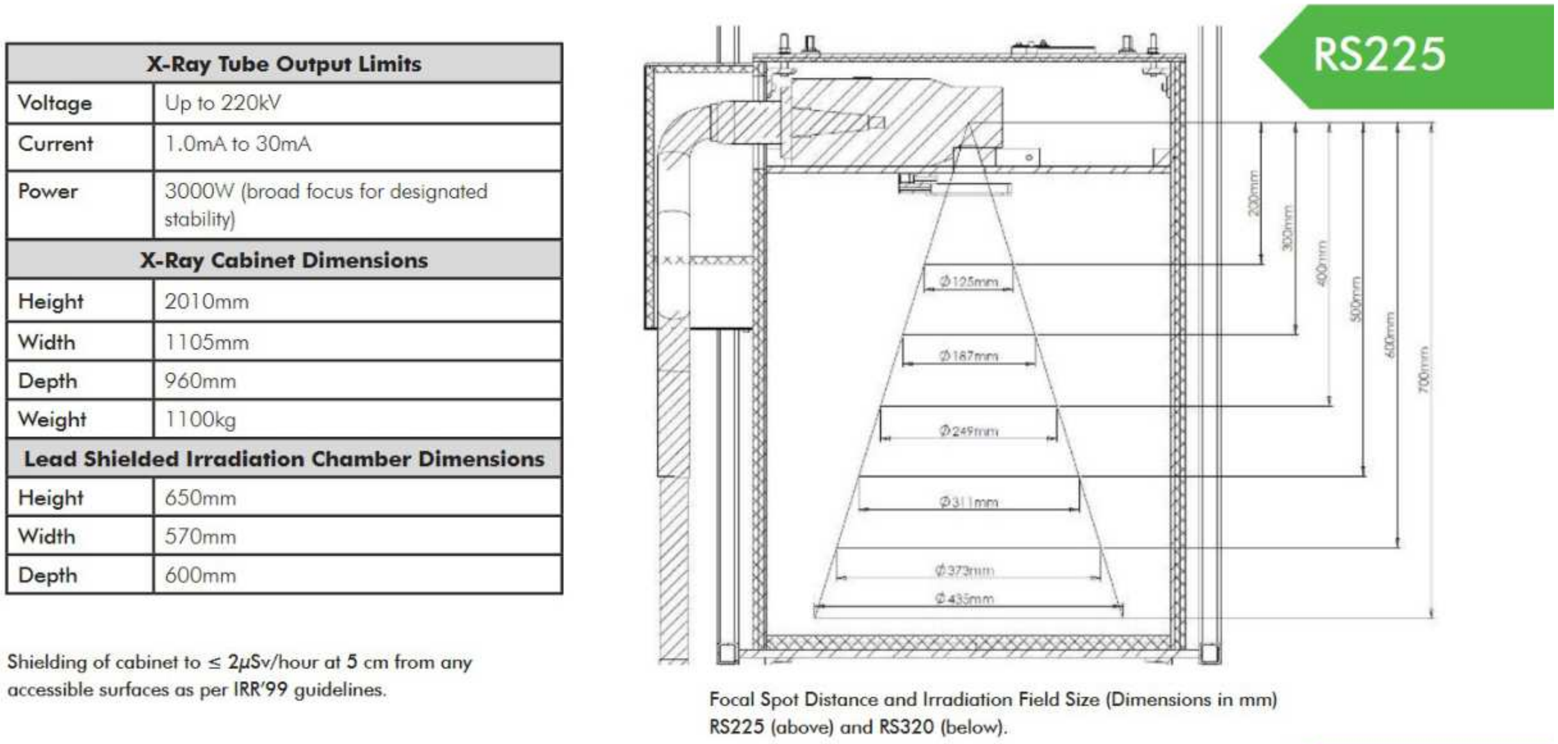
The TIFPA-INFN x-ray irradiation Laboratory

silicon density: 2.330 g/cm^3





Cabinet Xstrahl RS225



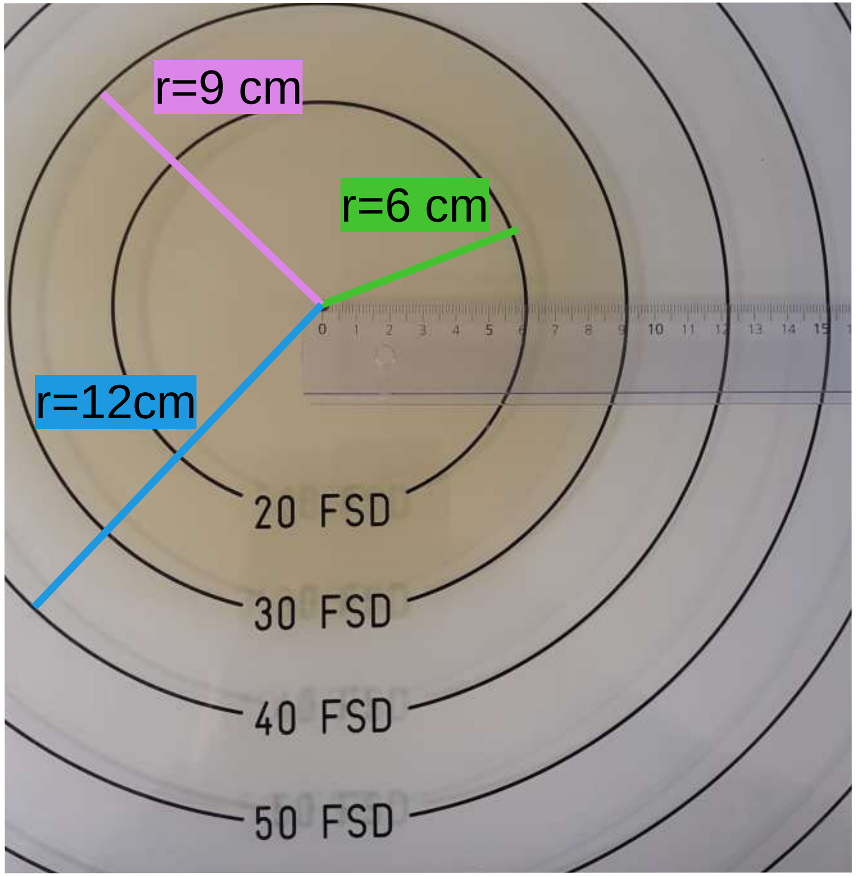
X-Ray Tube Output Limits	
Voltage	Up to 220kV
Current	1.0mA to 30mA
Power	3000W (broad focus for designated stability)
X-Ray Cabinet Dimensions	
Height	2010mm
Width	1105mm
Depth	960mm
Weight	1100kg
Lead Shielded Irradiation Chamber Dimensions	
Height	650mm
Width	570mm
Depth	600mm

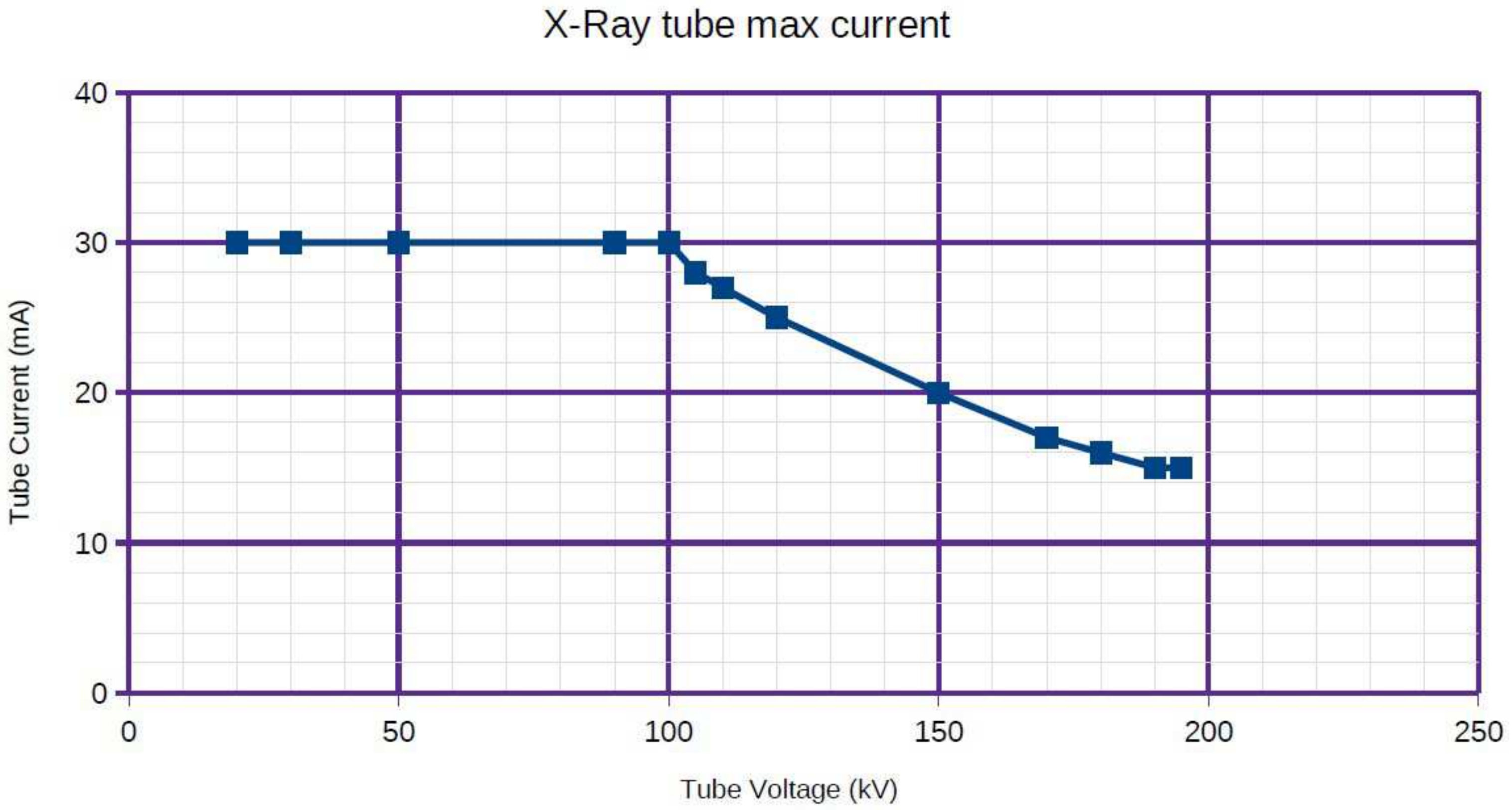
Shielding of cabinet to ≤ 2μSv/hour at 5 cm from any accessible surfaces as per IRR'99 guidelines.

Focal Spot Distance and Irradiation Field Size (Dimensions in mm) RS225 (above) and RS320 (below).

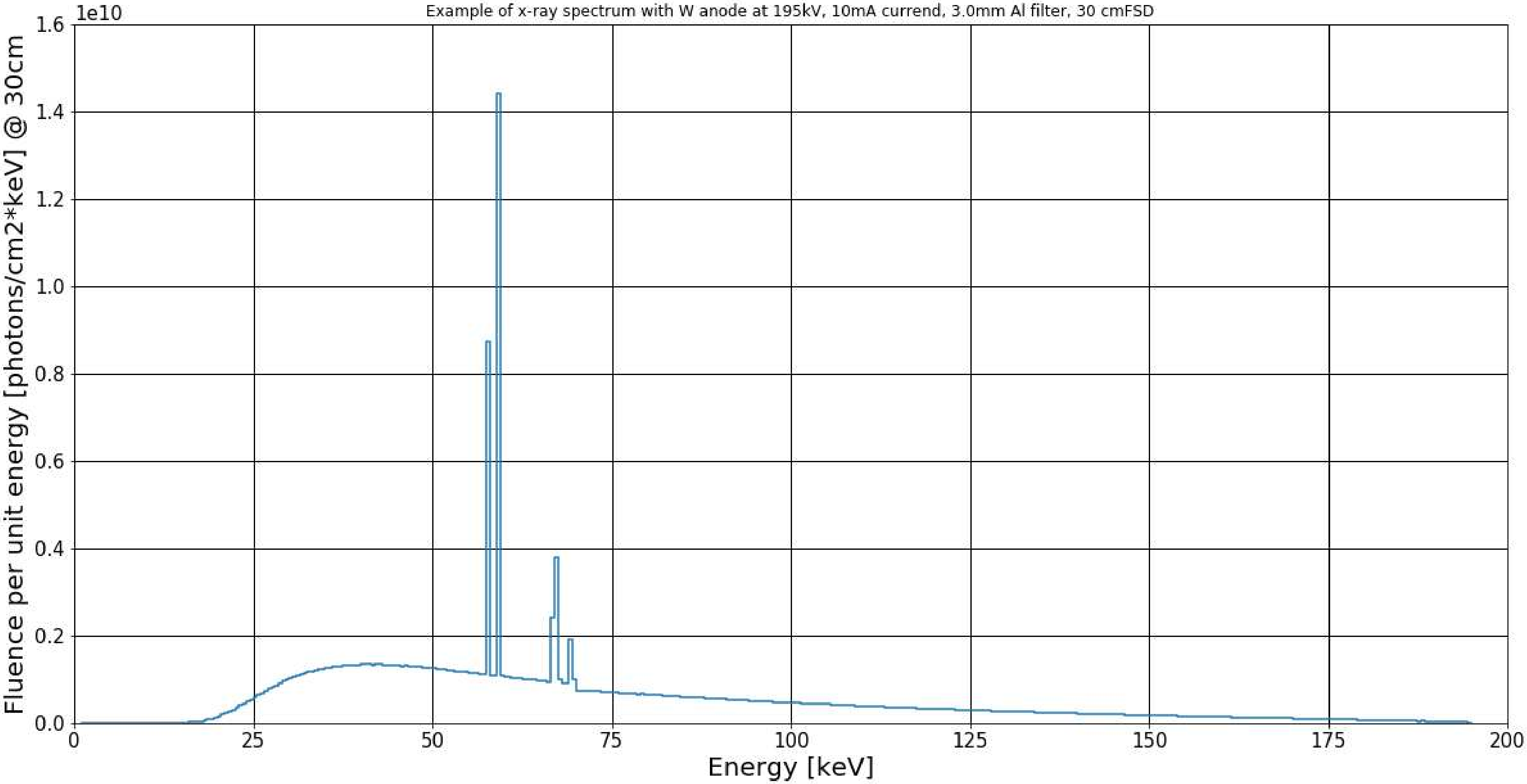
- In this set-up configuration the x-ray uniform spot is a circumference of 4.5 cm radius and can be used for sensors or electronic circuits TID
- characterization studies requiring total dose of the order of 1-50 Mrad.

R-X support plane



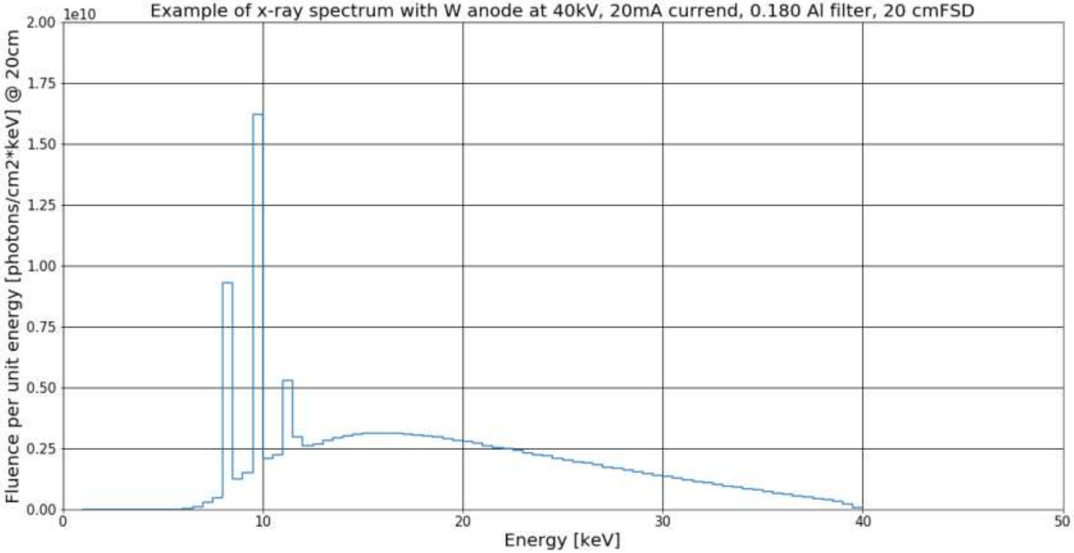

X-Ray tube max current
Tube Current (mA)
40
30
20
10
0
0
50
100
150
200
250
Tube Voltage (kV)

Tungsten emission spectrum



The TIFPA-INFN x-ray irradiation Laboratory

SiPM Radiation Field simulation with the the SpekPy* software toolkit:

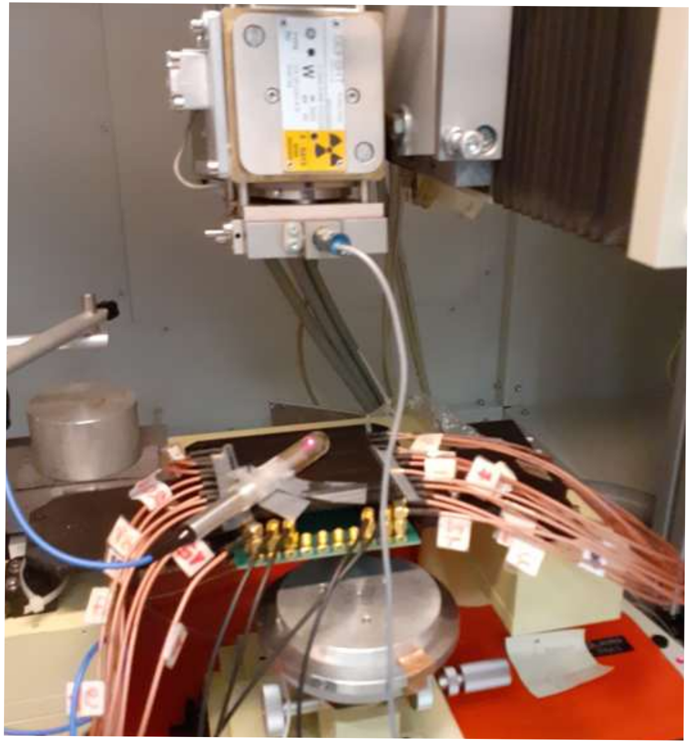


Considered tube configuration:

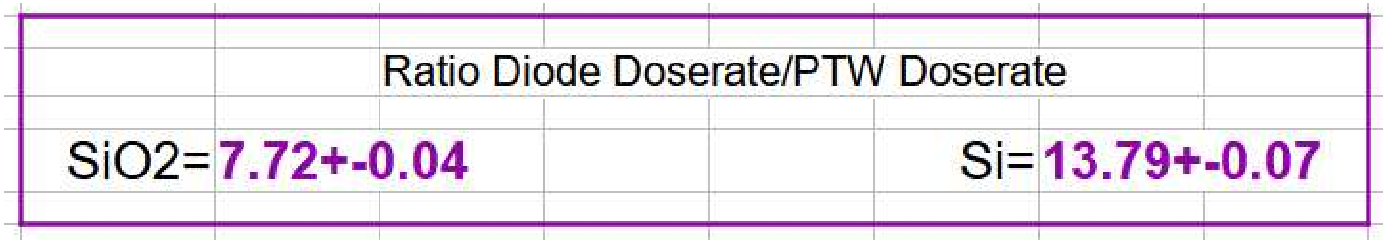
tungsten anode, 0.8mm Be window;
40kV anode tension, 20mA current, 0.180 mm Al filter,
20 cm FSD target position.

(*) https://doi.org/10.1016/j.ejmp.2020.04.026

In order to use the PTW Farmer Chamber dose measurement system, preliminary comparison framer chamber vs calibrated diode read-out were performed in the Padova INFN x-ray station using exactly the planed SiPM radiation field. In this way was evaluated the read-out ratio farmer chamber dose/Si dose .

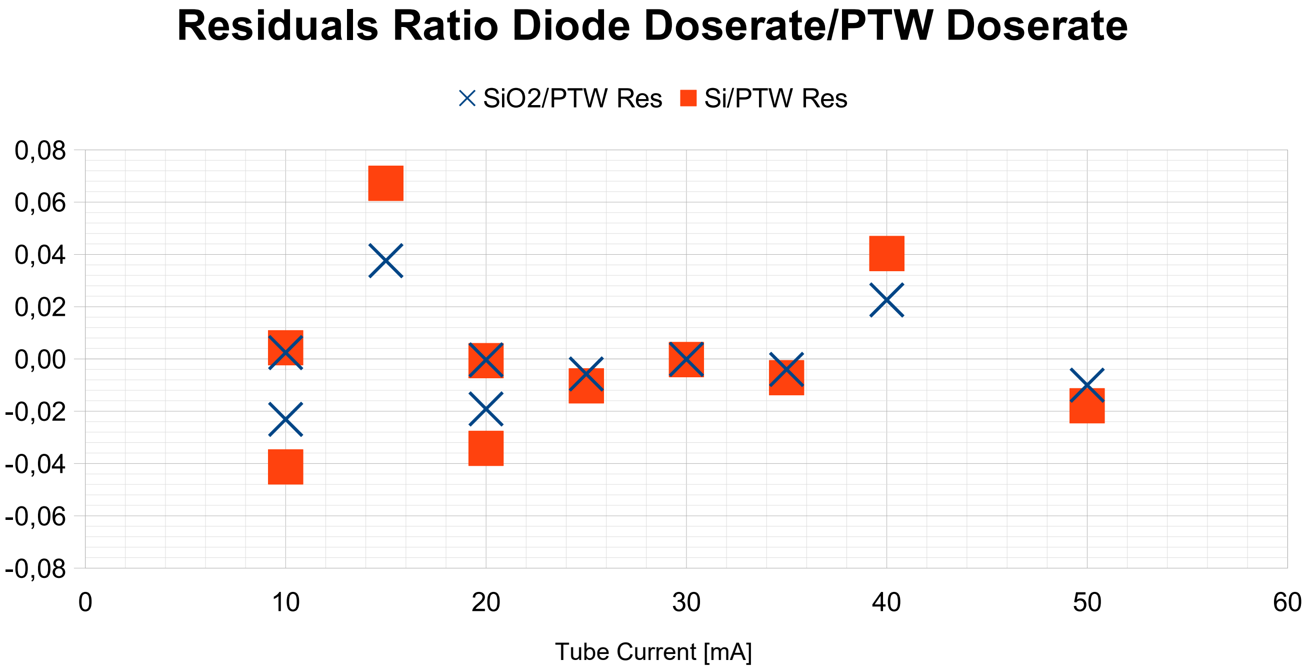


Diode - Farmer Chamber doserate comparison at the Padova x-ray irradiation laboratory



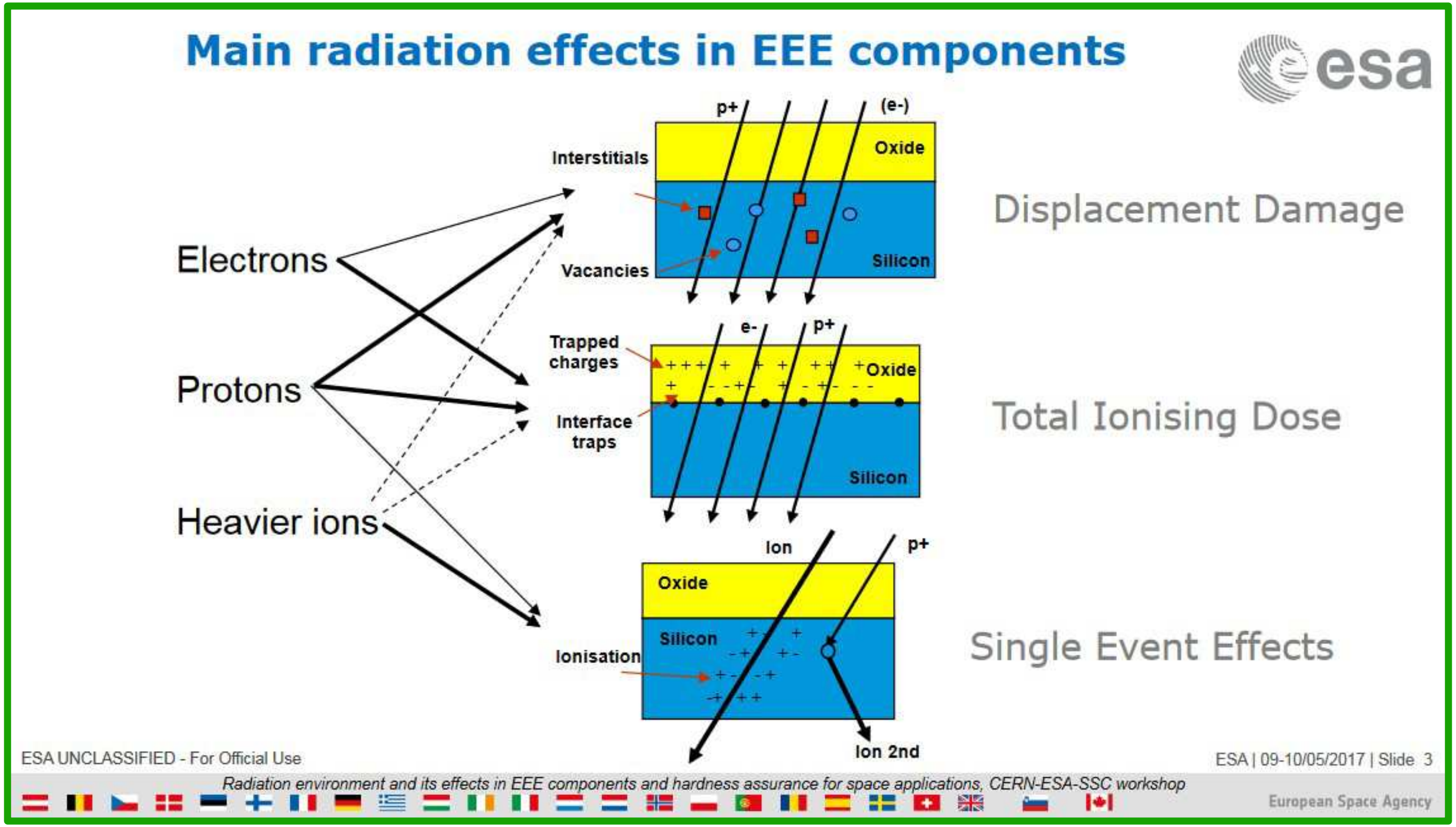
Ratio Diode Doserate/PTW Doserate

SiO2=**7.72+-0.04** Si=**13.79+-0.07**



Residuals Ratio Diode Doserate/PTW Doserate

Slide from Marc Poizat:
https://indico.cern.ch/event/635099/contributions/2570674/attachments/1456398/2248961/
Radiation_Effects_and_RHA_ESA_Course_9-10_May_2017_TID_MP_FINAL.pdf



Main radiation effects in EEE components

Electrons

Protons

Heavier ions

Displacement Damage

Total Ionising Dose

Single Event Effects

ESA UNCLASSIFIED - For Official Use

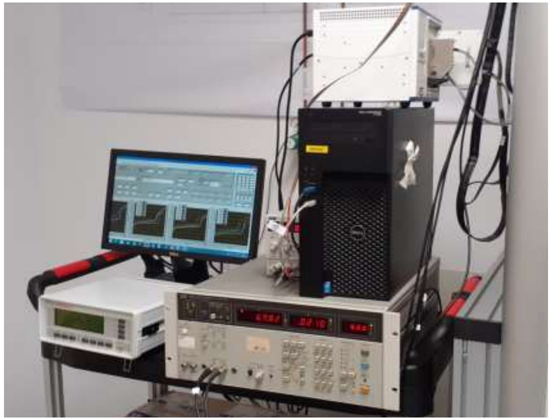
ESA | 09-10/05/2017 | Slide 3

Radiation environment and its effects in EEE components and hardness assurance for space applications, CERN-ESA-SSC workshop

European Space Agency

Case application: FBK SiPM Irradiations

Overview of the irradiation set-up

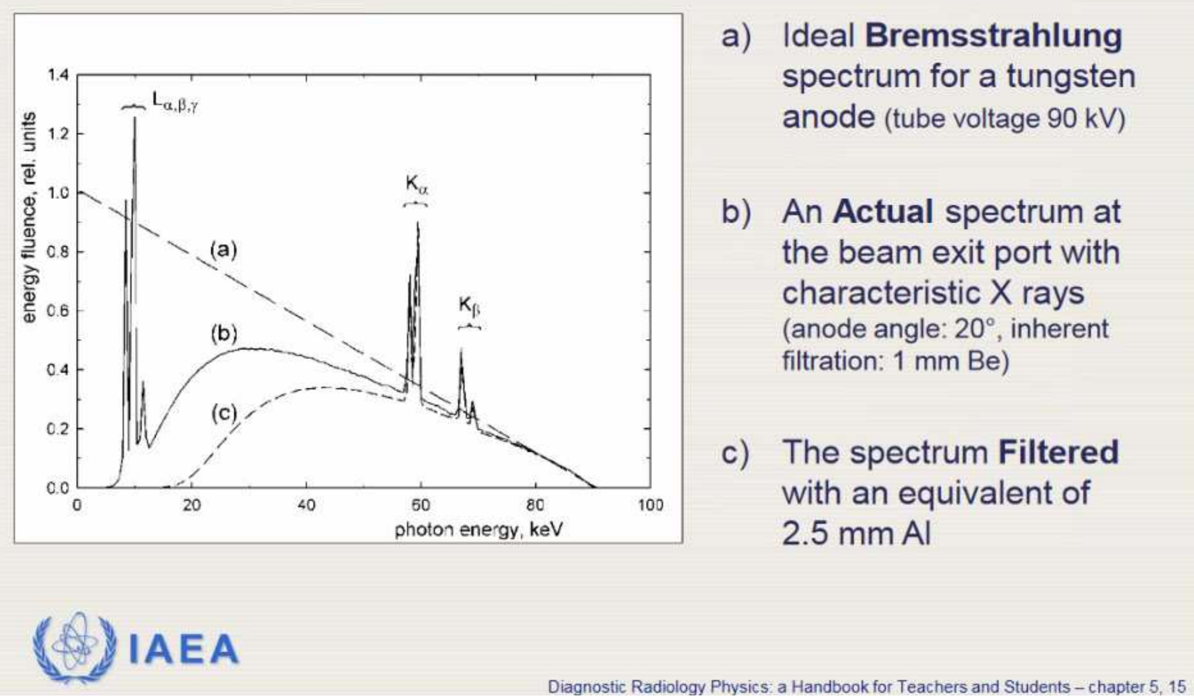


SiPM online characterization system (FBK)

Farmer chamber and SiPM support (FBK)

For results see:
DOI: 10.1016/j.nima.2022.167502

IAEA documents



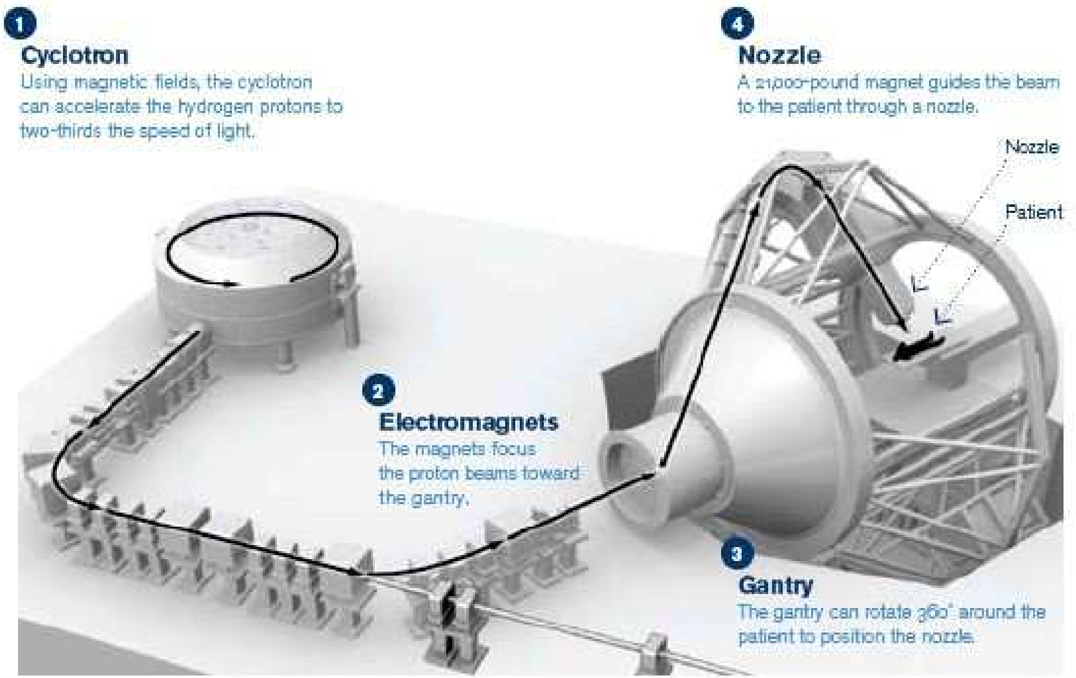
a) Ideal **Bremsstrahlung** spectrum for a tungsten anode (tube voltage 90 kV)

b) An **Actual** spectrum at the beam exit port with characteristic X rays (anode angle: 20°, inherent filtration: 1 mm Be)

c) The spectrum **Filtered** with an equivalent of 2.5 mm Al

IAEA

Diagnostic Radiology Physics: a Handbook for Teachers and Students – chapter 5, 15 https://www.oncolink.org/cancer-treatment/radiation/types-of-radiation-therapy/proton-therapy/overviews-of-proton-therapy/proton-therapy-behind-the-scenes



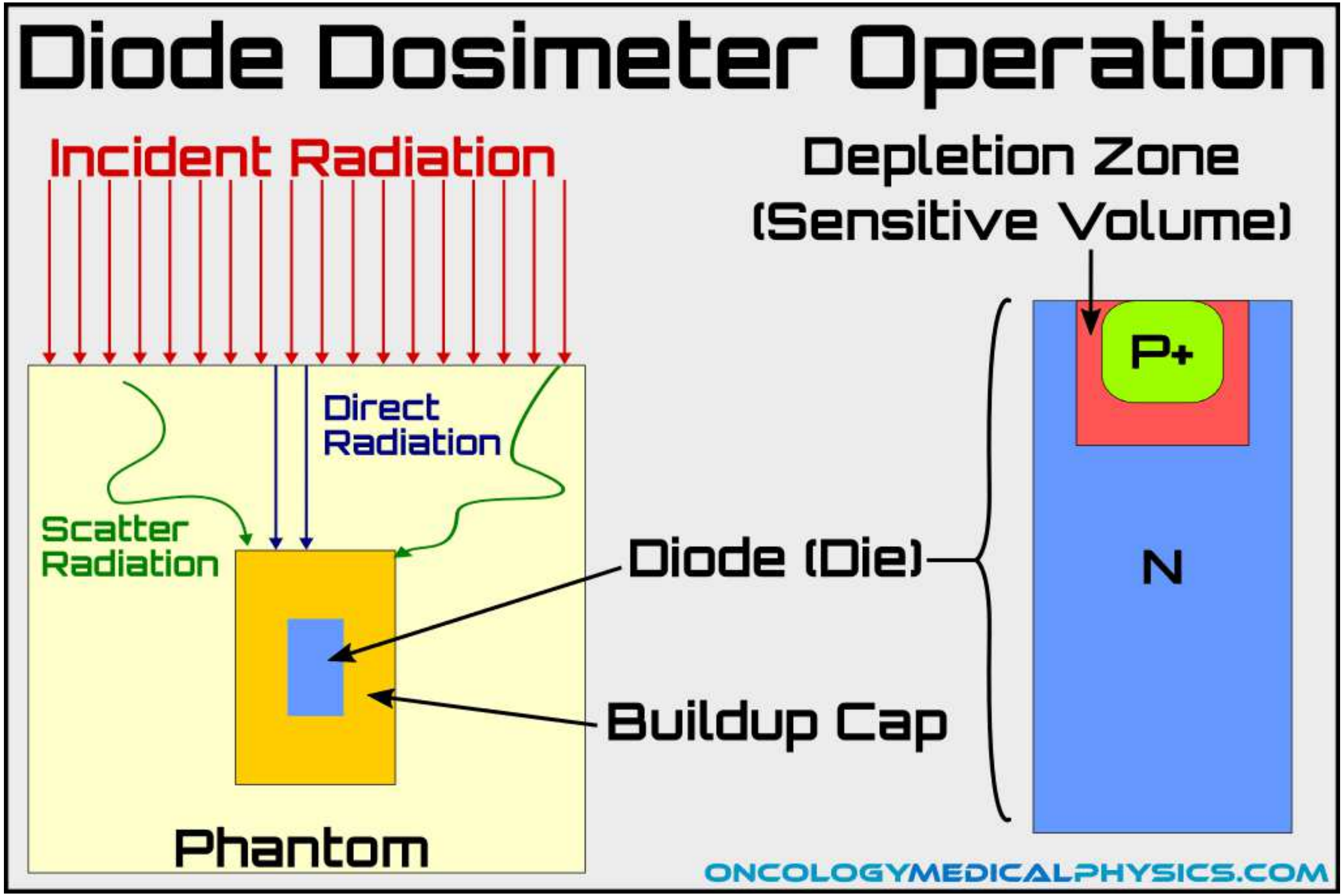
Cyclotron
Using magnetic fields, the cyclotron can accelerate the hydrogen protons to two-thirds the speed of light.

Electromagnets
The magnets focus the proton beams toward the gantry.

Gantry
The gantry can rotate 360° around the patient to position the nozzle.

Nozzle
A 21,000-pound magnet guides the beam to the patient through a nozzle.

https://www.drmanojsharmaoncology.com/proton-therapy



https://oncologymedicalphysics.com/diode-detectors/

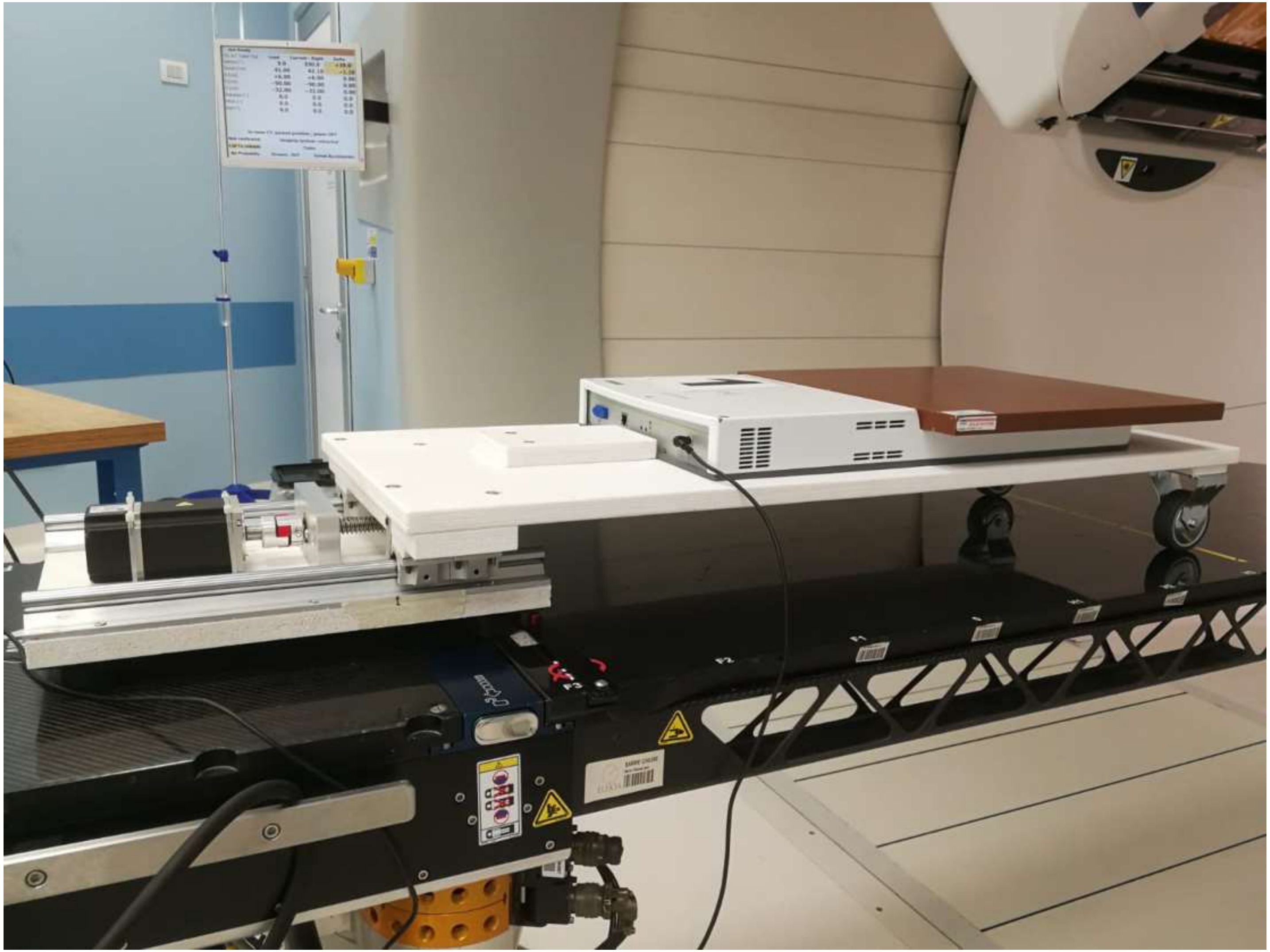
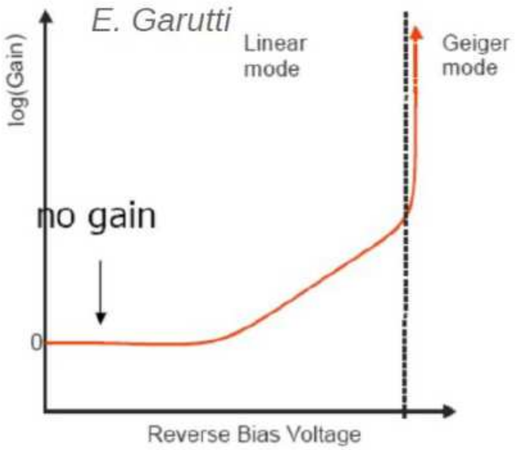


Image Credit: NASA/SOHO

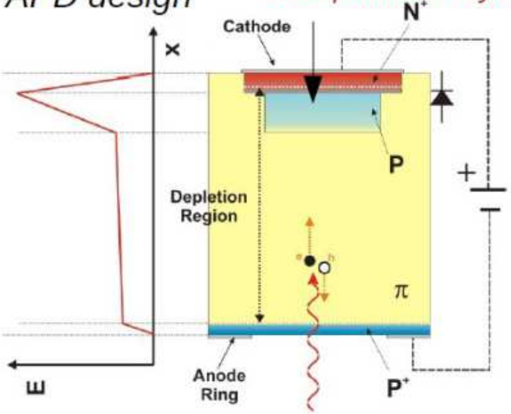
- But devices with charge multiplication were already there:
  - Avalanche Photodiodes (APDs)
    - Photodiodes *Gain=1*
    - APD *Gain=100-1000*
    - Geiger mode (SPAD/SiPM) *Gain~1E7*



E. Garutti

APD design

Key feature: multiplication layer



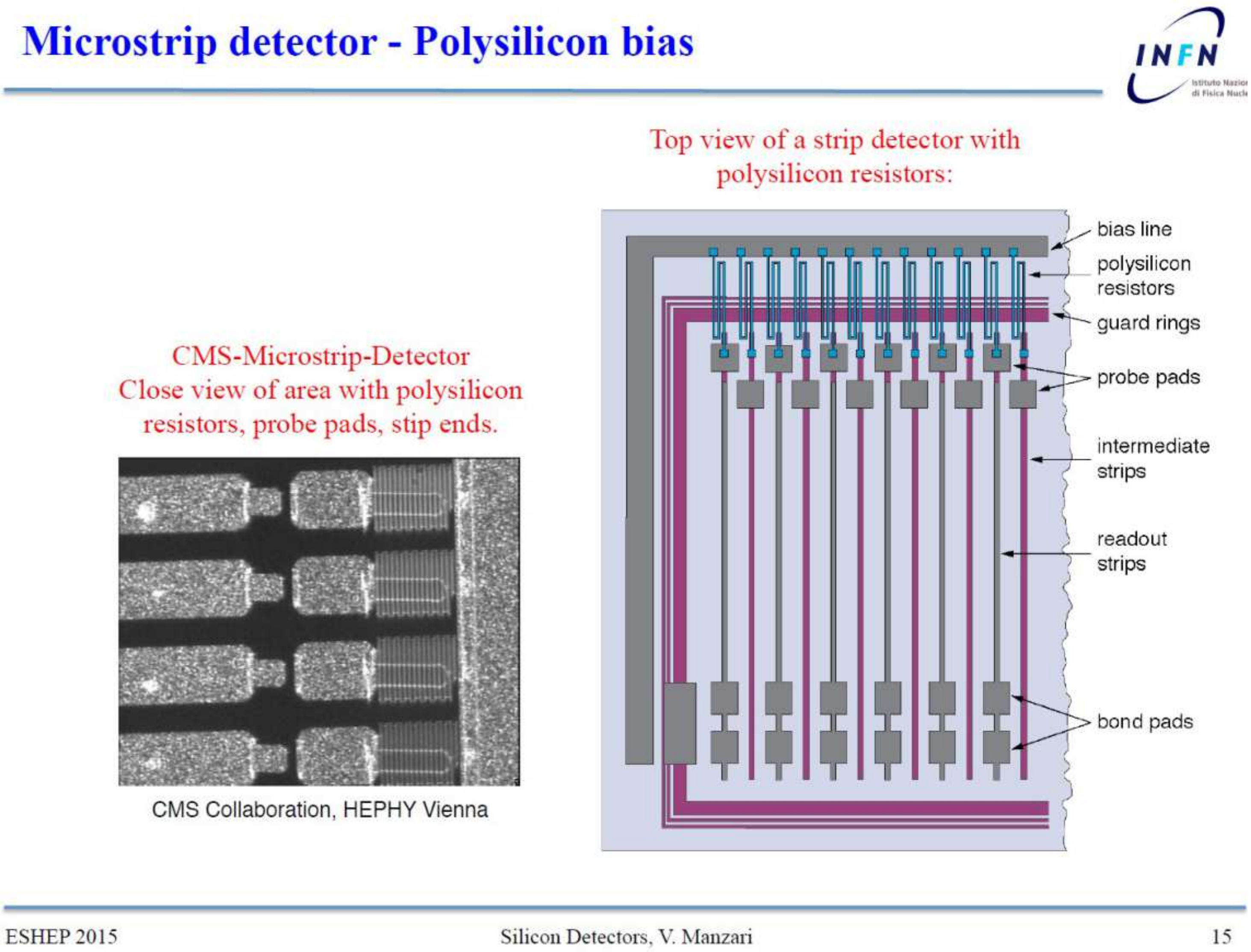
For HEP (particle detection, not photons)

- Keep charge information (linearity, not Geiger mode)
- But APDs are too noisy due to gain

Initial idea was APD with "low Gain" (~10-20) to compensate charge loss after irradiation

P. Fernandez (PhD thesis, 2014)

S. Grinstein, IAS 2021



Microstrip detector - Polysilicon bias

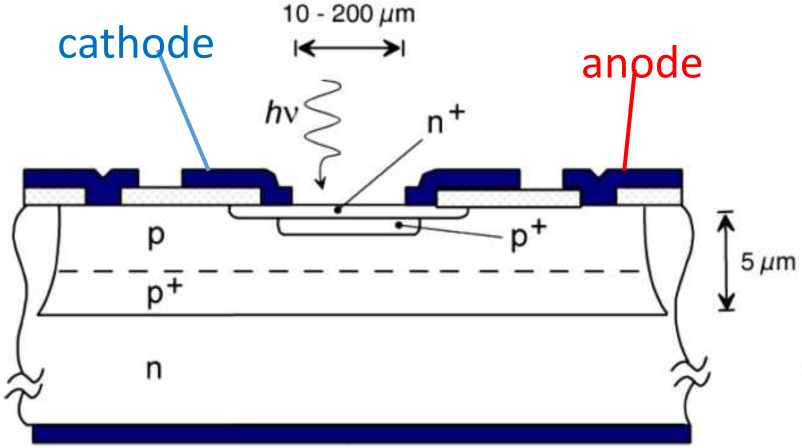
CMS-Microstrip-Detector
Close view of area with polysilicon resistors, probe pads, stip ends.

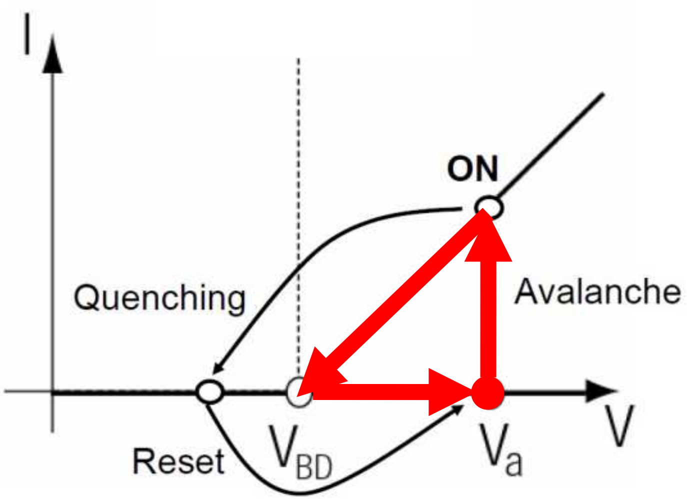
CMS Collaboration, HEPHY Vienna

Top view of a strip detector with polysilicon resistors:

Vito Manzari
ESHEP School 2015

SPAD: working principle





1. Biased (V_a) ABOVE breakdown voltage (with excess bias Vex)
2. Single photon or thermally generated carrier switches on avalanche process (with a certain probability) → macroscopic current
3. Avalanche has to be quenched by external circuit → quenching circuit:

   Passive quenching in SiPMs (large resistance: usually > 300 kOhm)
4. Bias reset above breakdown voltage → dead time.