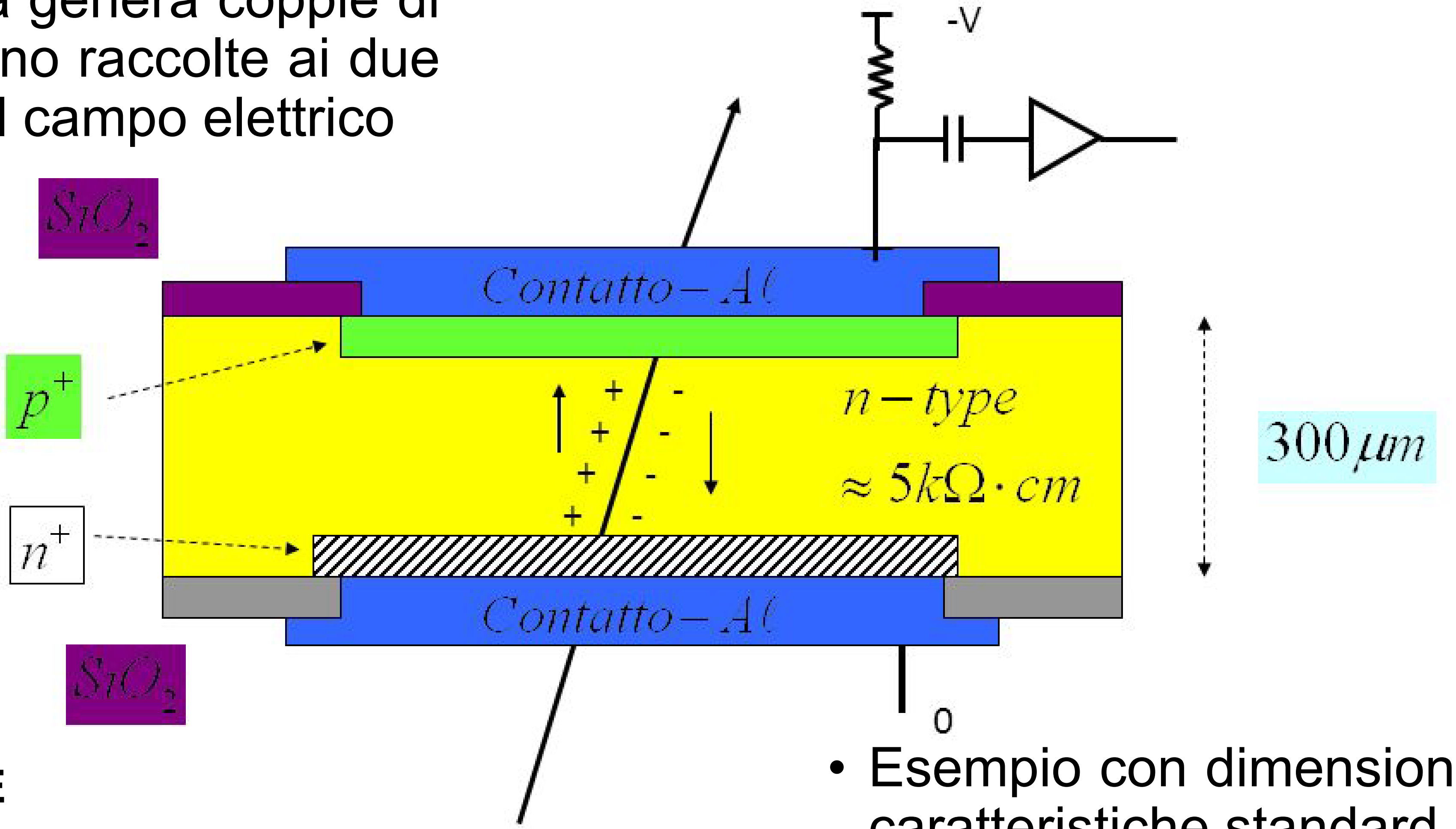
Rivelatori e Apparati

1

Per cosa li usiamo: **rivelare il passaggio**

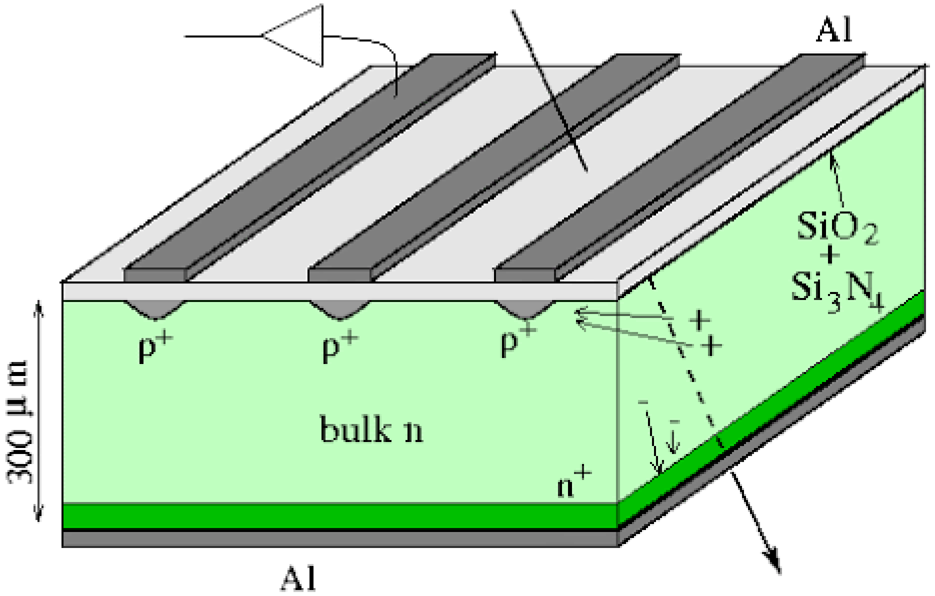
- La particella carica genera coppie di cariche che vengono raccolte ai due capi per ***deriva*** nel campo elettrico



GIUNZIONE SEMPLICE

- Esempio con dimensioni e caratteristiche standard

Per cosa li usiamo: **misurare la posizione (1D)**

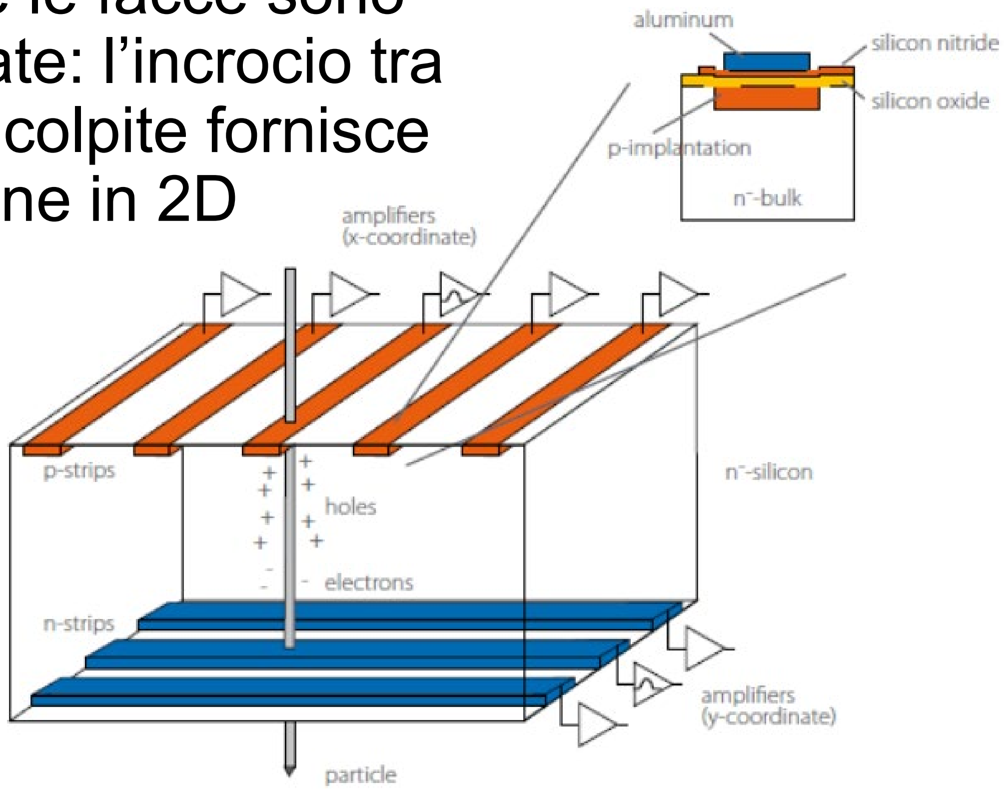


- La superficie del sensore e’ segmentata in striscie parallele lungo una direzione: la posizione dei contatti che raccolgono e trasmettono le cariche corrisponde alla coordinata della particella
- La risoluzione spaziale e’ data dal passo tra striscie, e puo’ essere migliorata misurando l’ampiezza dei segnali

MICROSTRISCE MONOFACCIA

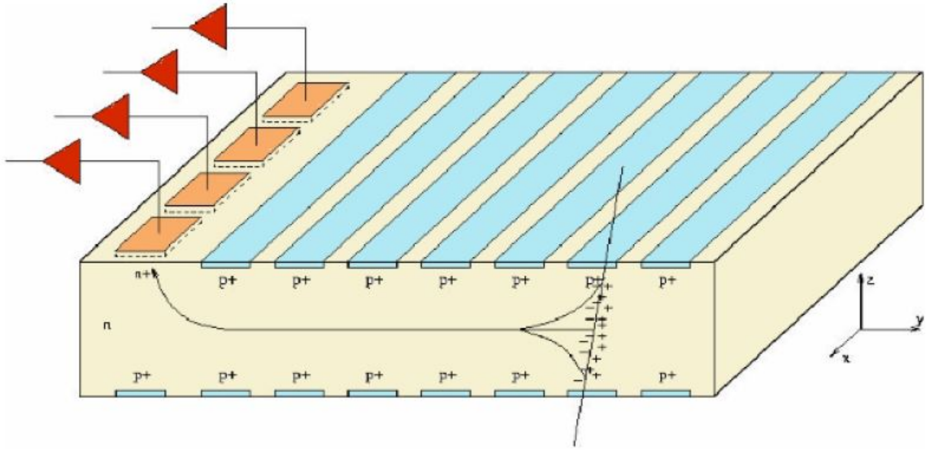
Per cosa li usiamo: **misurare la posizione (2D)**

- Entrambe le facce sono segmentate: l’incrocio tra le strisce colpite fornisce la posizione in 2D



MICROSTRISCE A DOPPIA FACCIA

- La seconda coordinata puo’ essere ricavata dal tempo di deriva delle cariche fino al secondo elettrodo

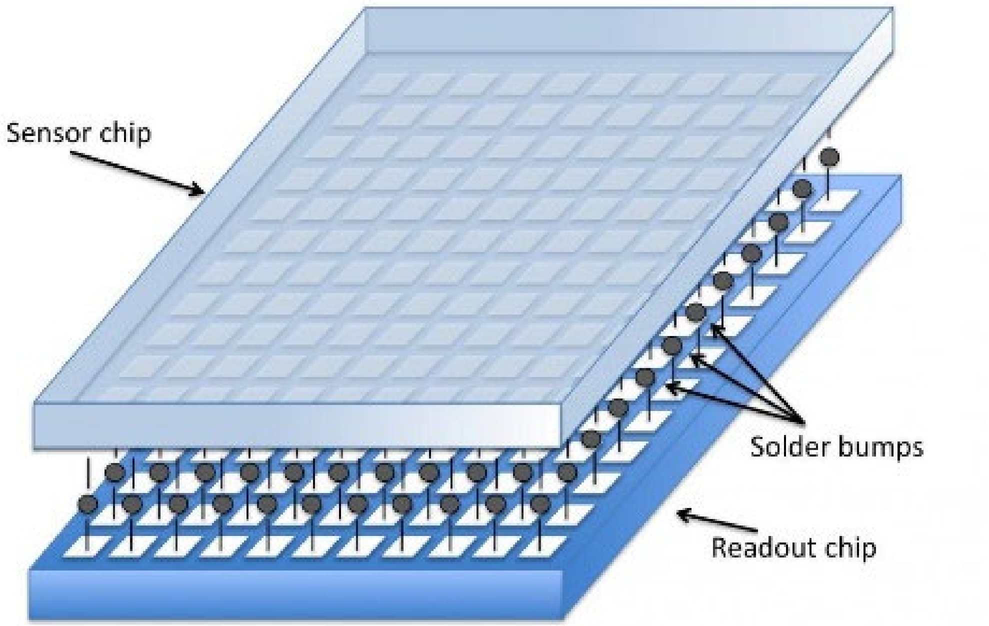


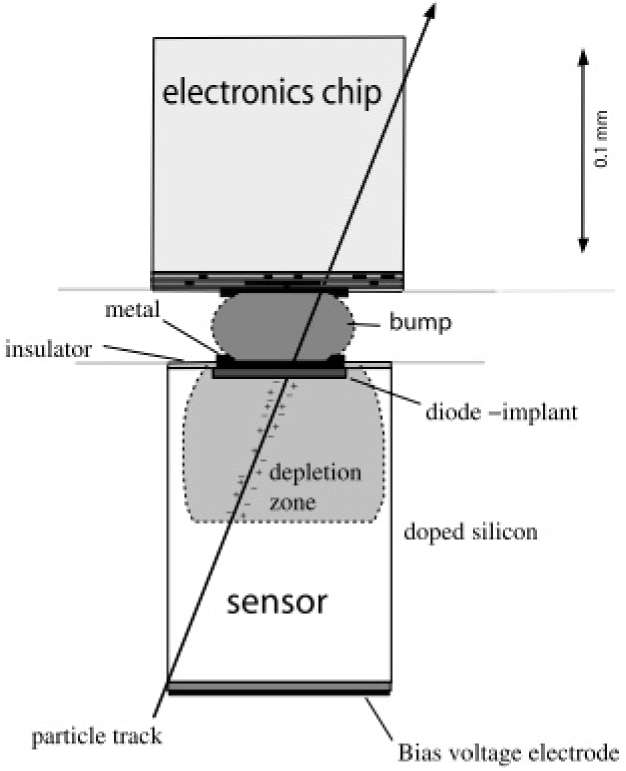
CAMERA A DERIVA DI SILICIO

Per cosa li usiamo: **misurare la posizione (2D)**

- Posso segmentare la superficie del sensore nelle due direzioni formando una matrice di pixel

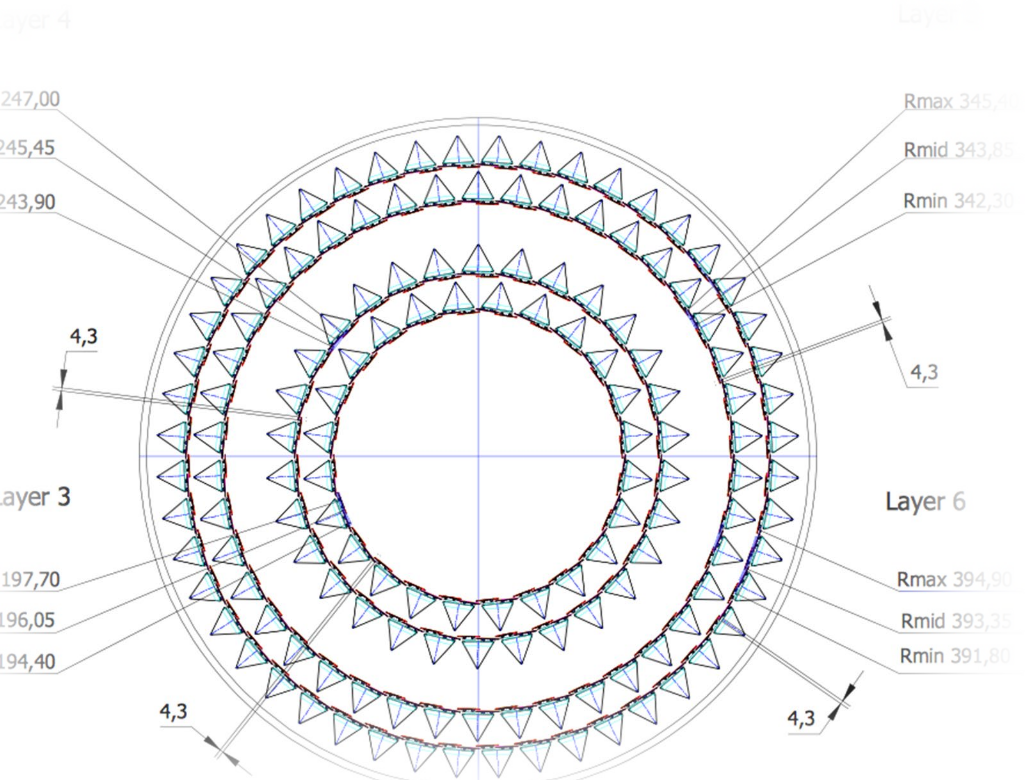
- L'elettronica deve essere connessa direttamente sopra ogni pixel: serve un secondo chip, accoppiato

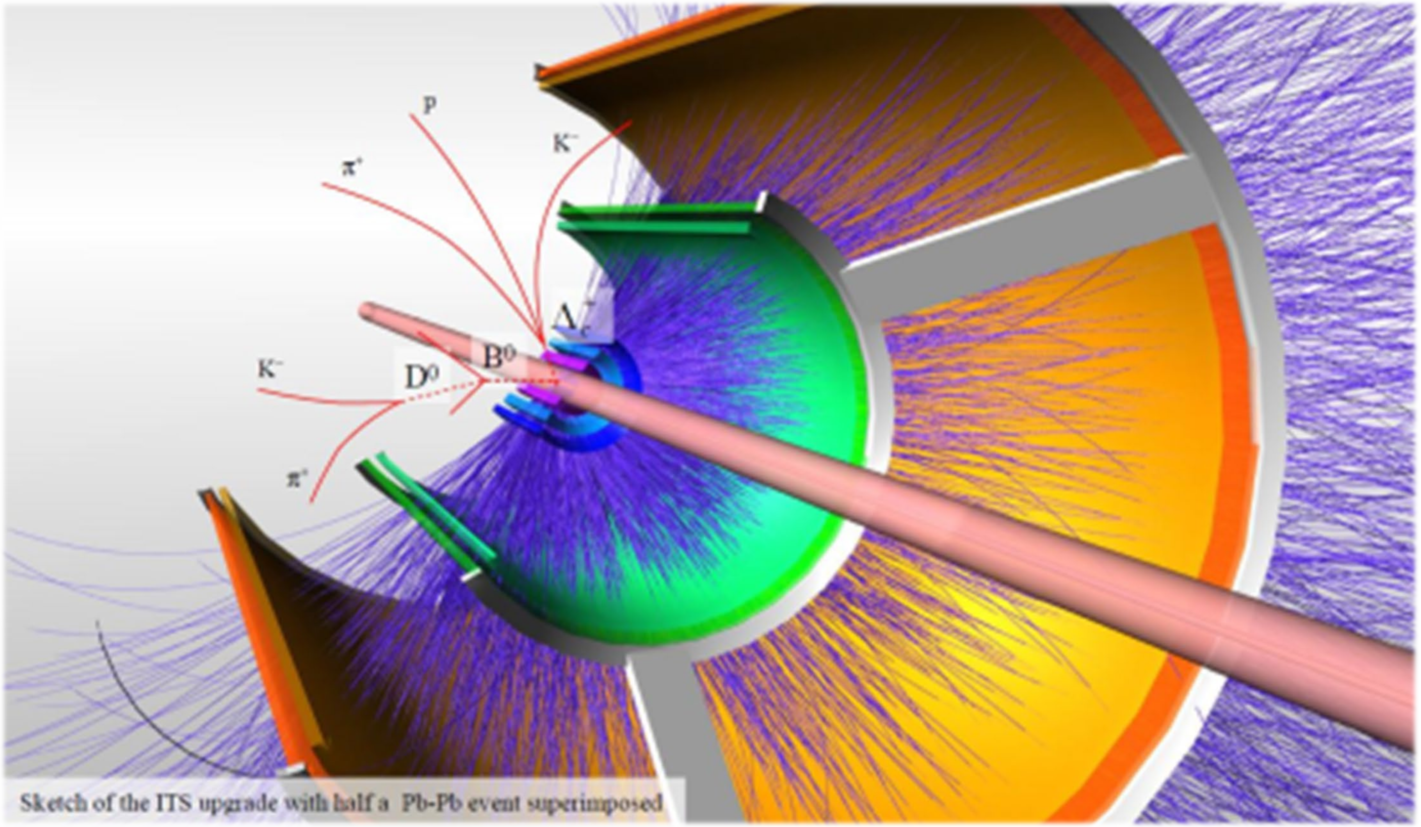




PIXEL IBRIDI

Per cosa li usiamo: **seguire la traiettoria**…



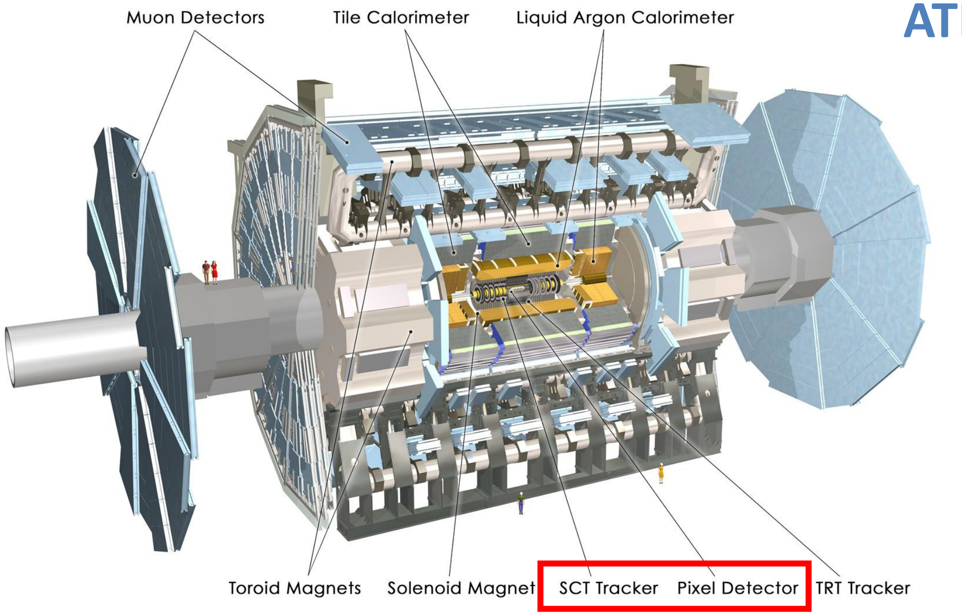


Sketch of the ITS upgrade with half a Pb-Pb event superimposed

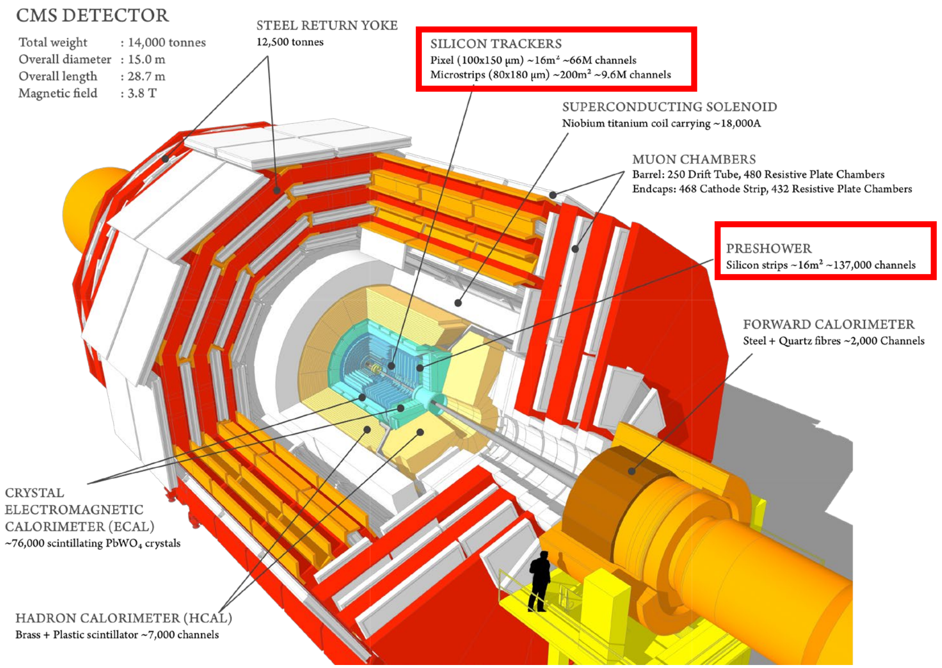
- Disponendo i rivelatori in modo da formare cilindri concentrici attorno alla linea del fascio possiamo “seguire” la traccia mentre si allontana

I rivelatori degli esperimenti di LHC – Ruolo dei rivelatori al silicio e’ fondamentale

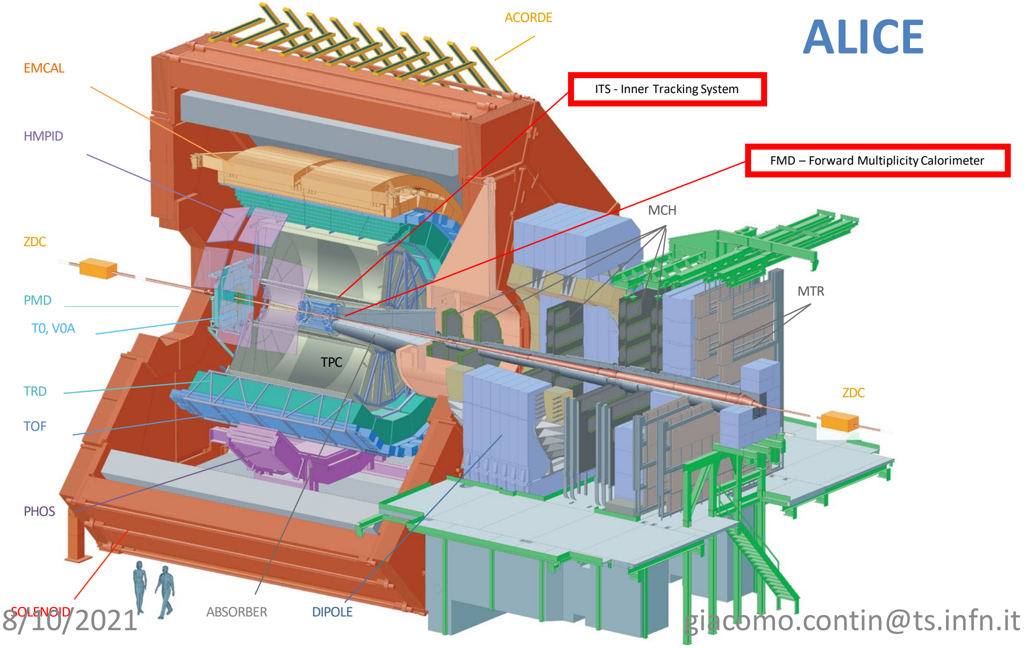
ATLAS



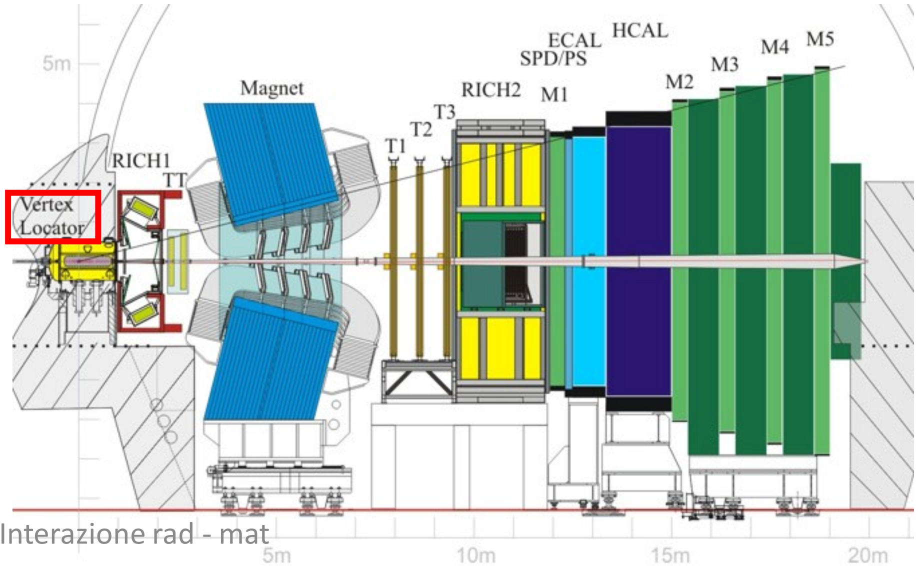
CMS



ALICE



LHCb



Esempi di rivelatori al silicio: canali e superficie

Esperimento	Tecnologia usata	Canali [M]	Superficie [m^2]	m^2/Mch
ATLAS	Pixel ibridi	80	1.7	0.021
	+ Pixel ibridi (Insertable B-Layer)	12	2	0.170
	Micro-strip	6	60	10.000
CMS	Pixel ibridi	66	1	0.015
	Micro-strip	10	200	20.000
ALICE	Pixel ibridi	10	0.3	0.030
	Silicon Drift	0.1	1.3	13.000
	Micro-strip	2.6	5.2	2.000
	→ Rimpiazzati da Pixel Monolitici (ITS)	1260	10	0.008
LHCb	Micro-strip	0.2	0.22	1.100
	→ Rimpiazzate da Pixel Ibridi (VELO Upgrade)	41	0.12	0.003

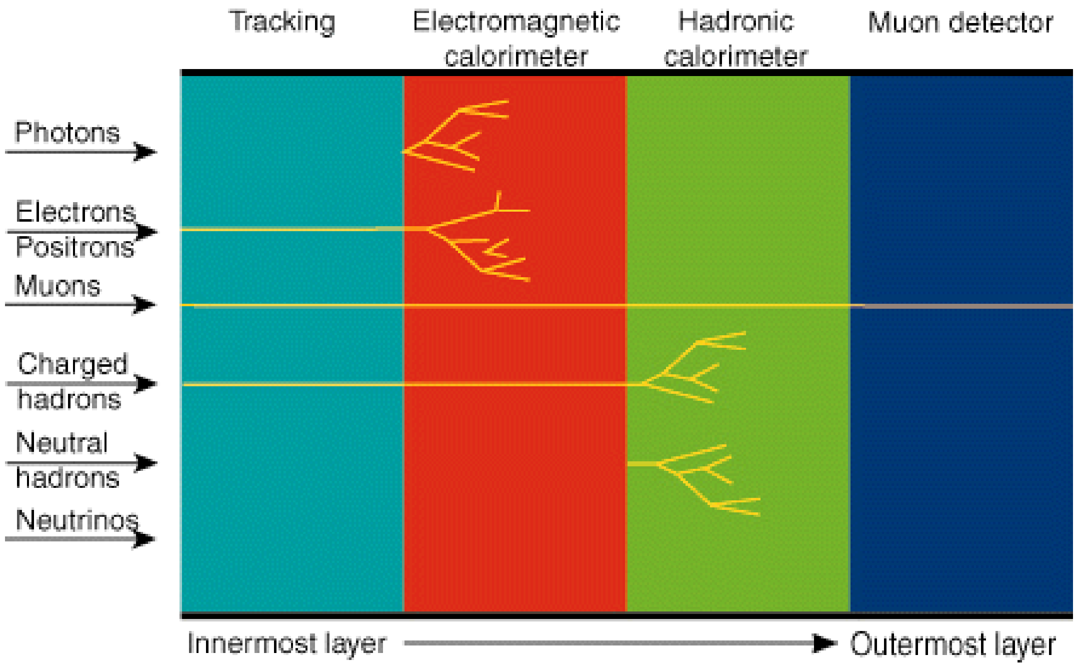
Rivelatori di tracciamento al silicio a LHC per Run1, Run2, Run3

Notare il rapporto canali/superficie per le diverse tecnologie usate

Tutti i pixel elencati sono ibridi, eccetto per il caso dell'ALICE ITS Upgrade (monolitici)

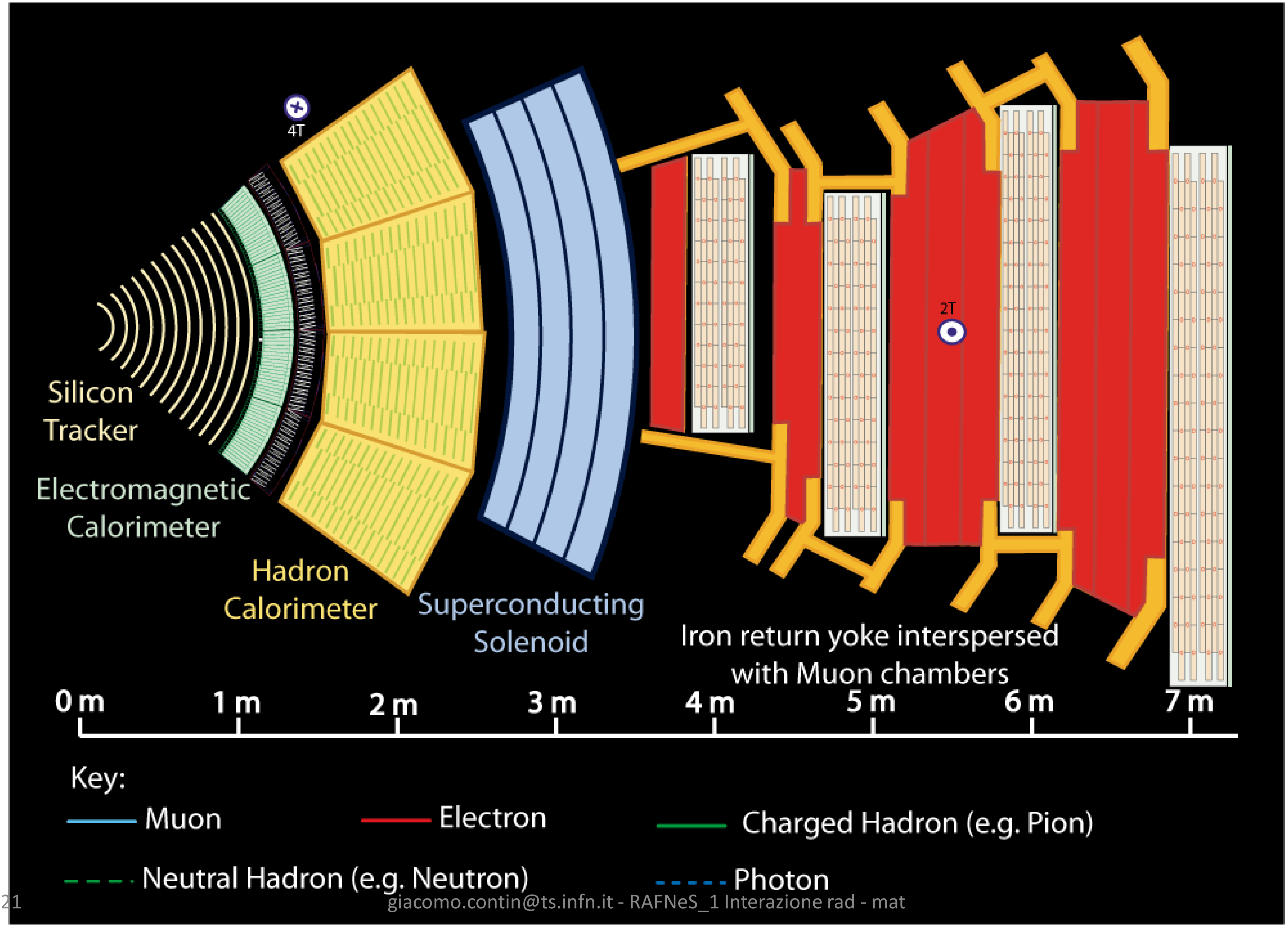
Interazione di particelle diverse con rivelatori diversi

- Particelle cariche sono visibili nei tracciatori
- Fotoni, elettroni, positroni vengono fermati nel calorimetro elettromagnetico, permettendone la misura di energia
- Gli adroni carichi vengono solo visti dal calorimetro elettromagnetico
- Gli adroni (carichi e neutri) vengono fermati nel calorimetro adronico, permettendone la misura di energia
- Solo i muoni sono visibili in tutti i 4 tipi di rivelatori

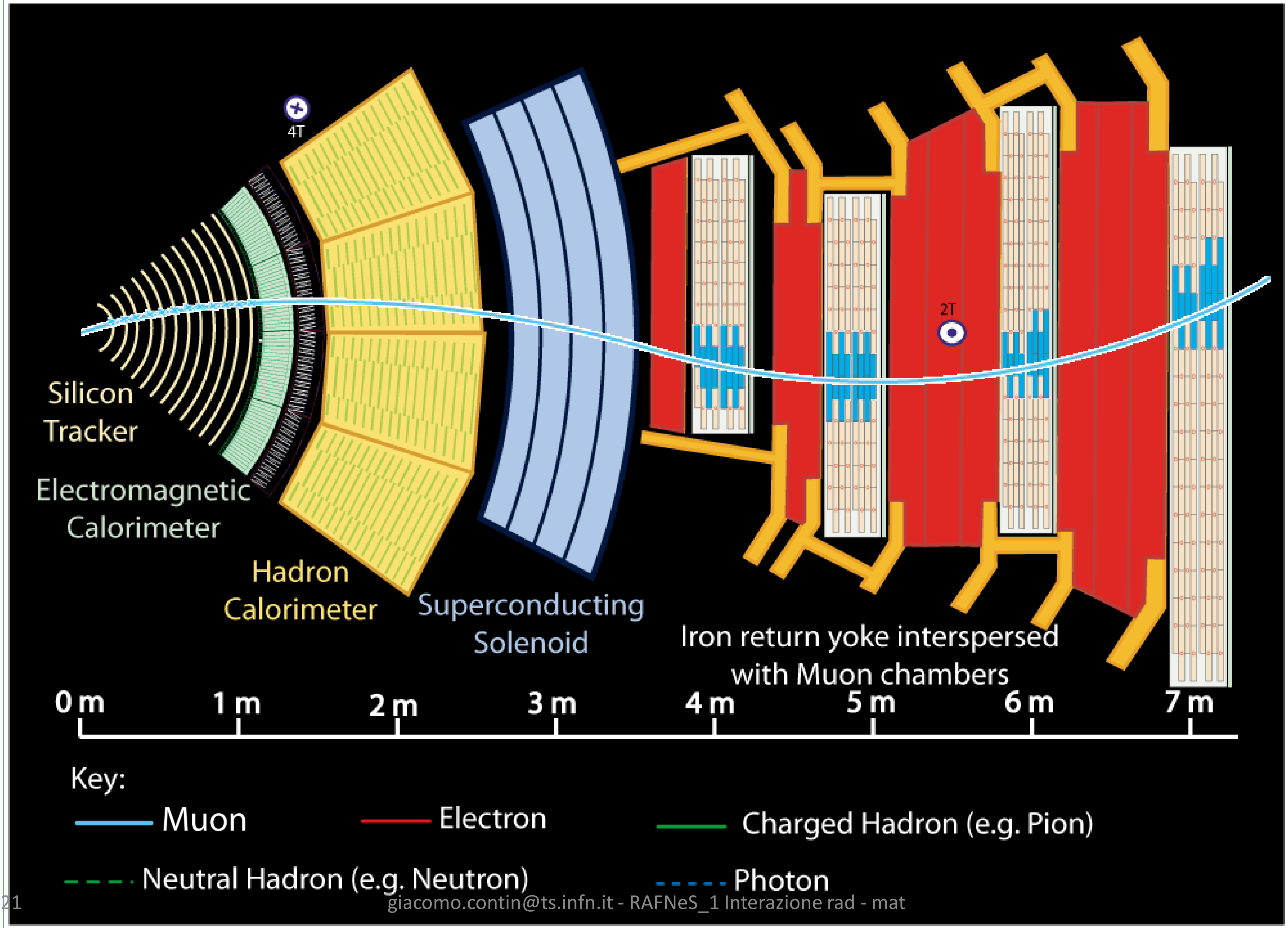


Per queste ragione viene rispettato questo ordine nella sequenza dei diversi sistemi di rivelazione

CMS slice


4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
0 m
1 m
2 m
3 m
4 m
5 m
6 m
7 m
Key:
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon

CMS slice


4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
0 m
1 m
2 m
3 m
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Key:
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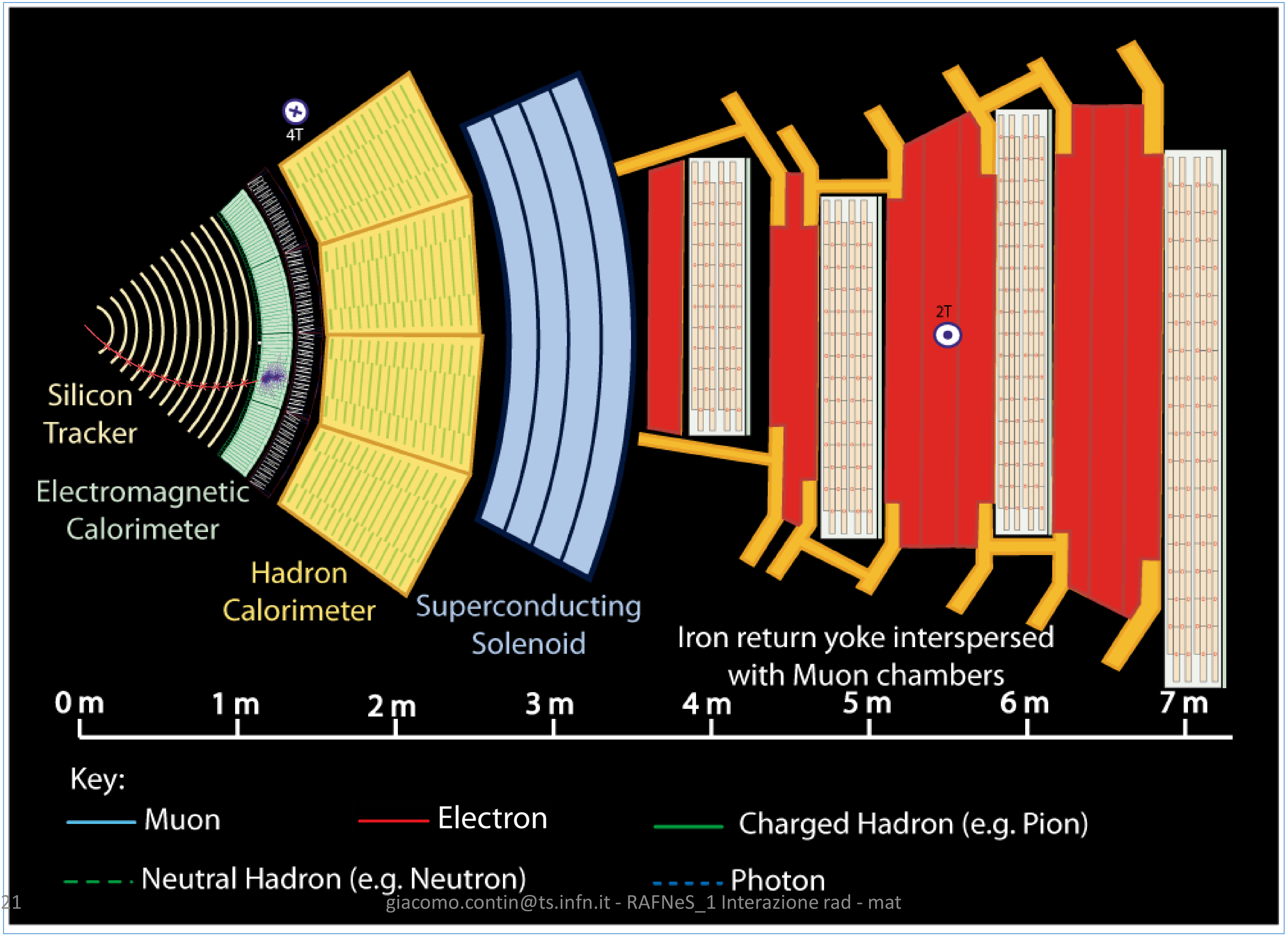
Photon

CMS slice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Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
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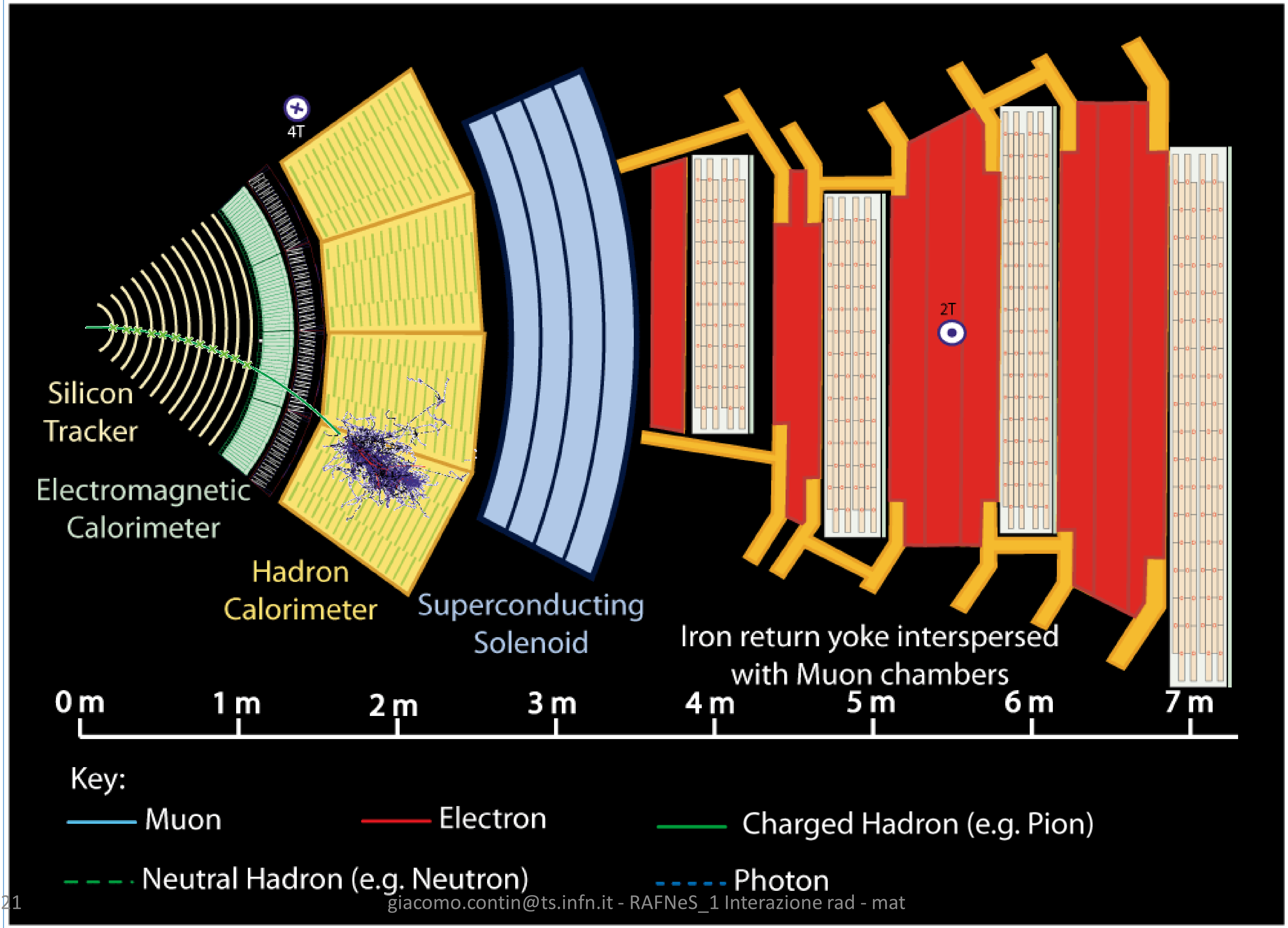
CMS slice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Superconducting Solenoid
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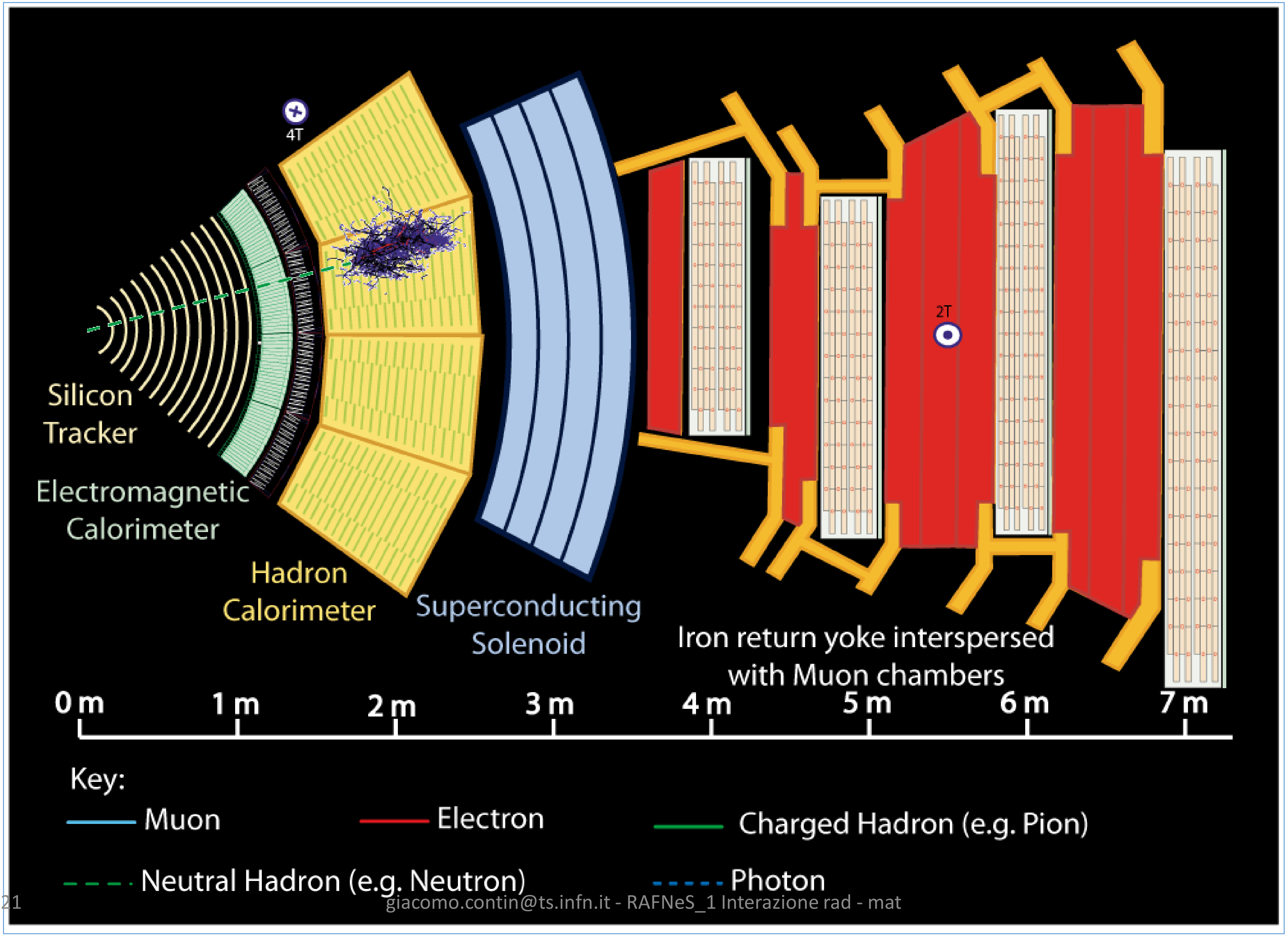
Photon

CMS slice


4T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
2T
0 m
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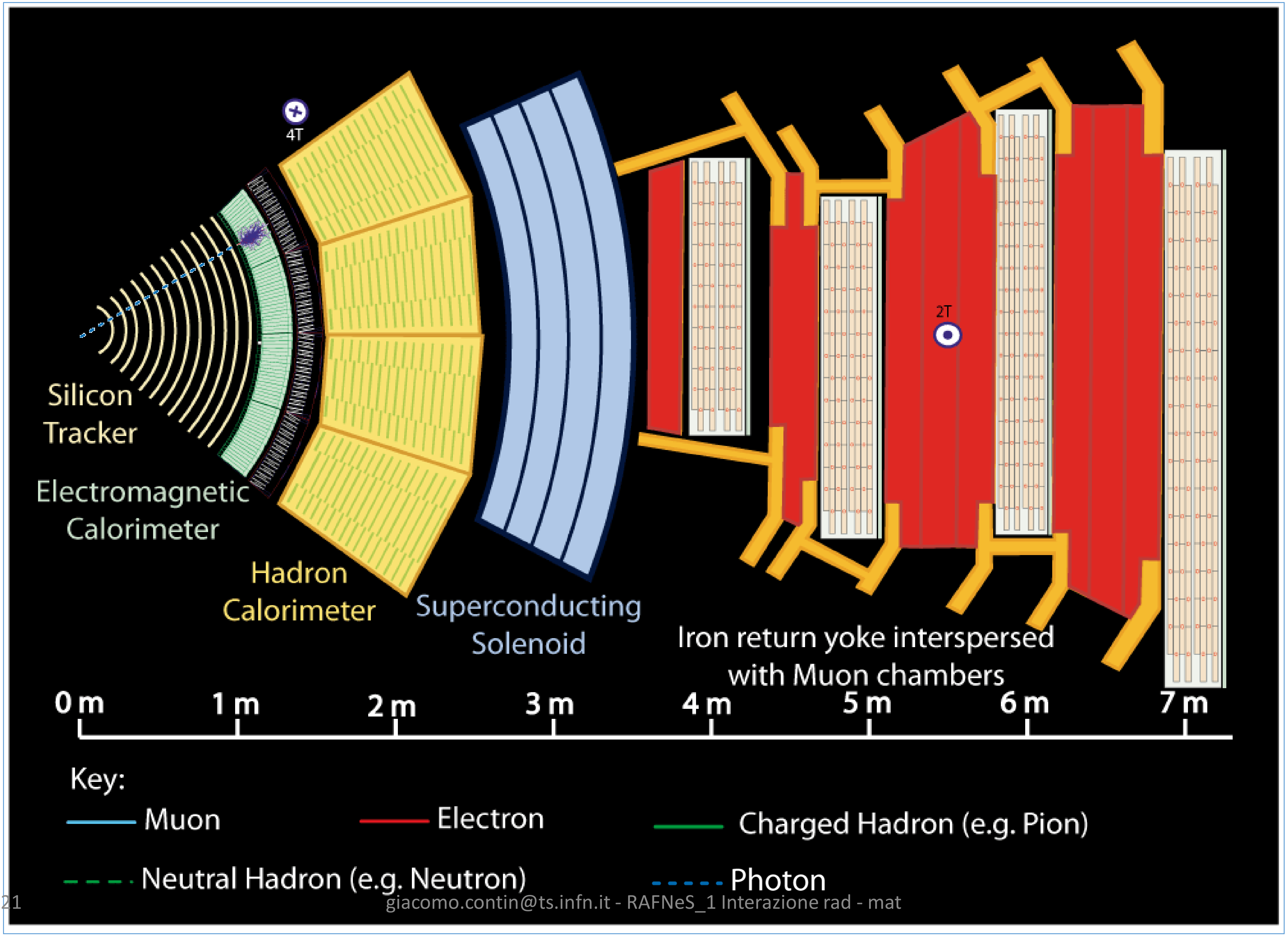
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon

CMS slice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Silicon Tracker
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Hadron Calorimeter
Superconducting Solenoid
2T
Iron return yoke interspersed with Muon chambers
0 m
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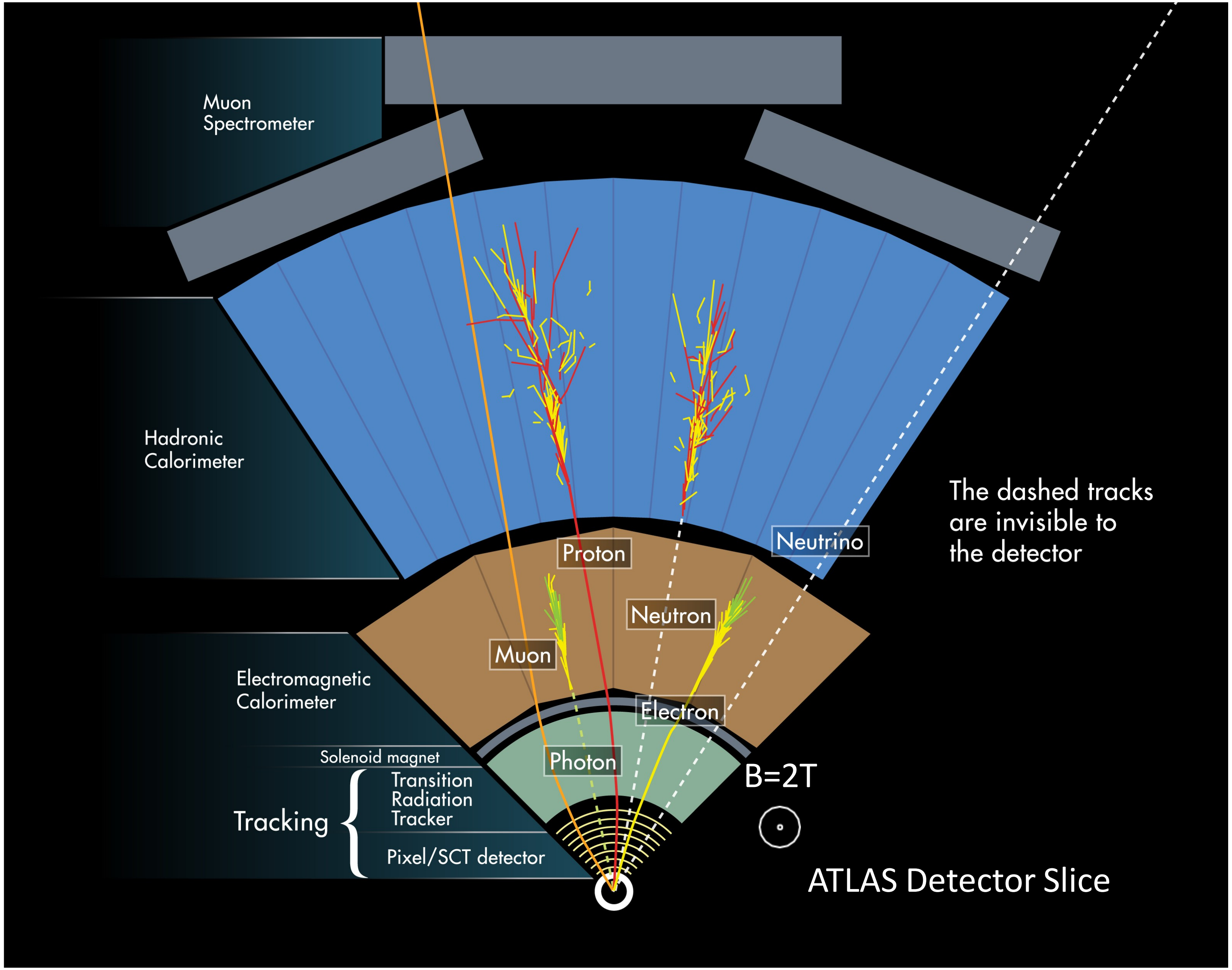
2 m
3 m
4 m
5 m
6 m
7 m
Key:
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon

ATLAS slice



The dashed tracks are invisible to the detector

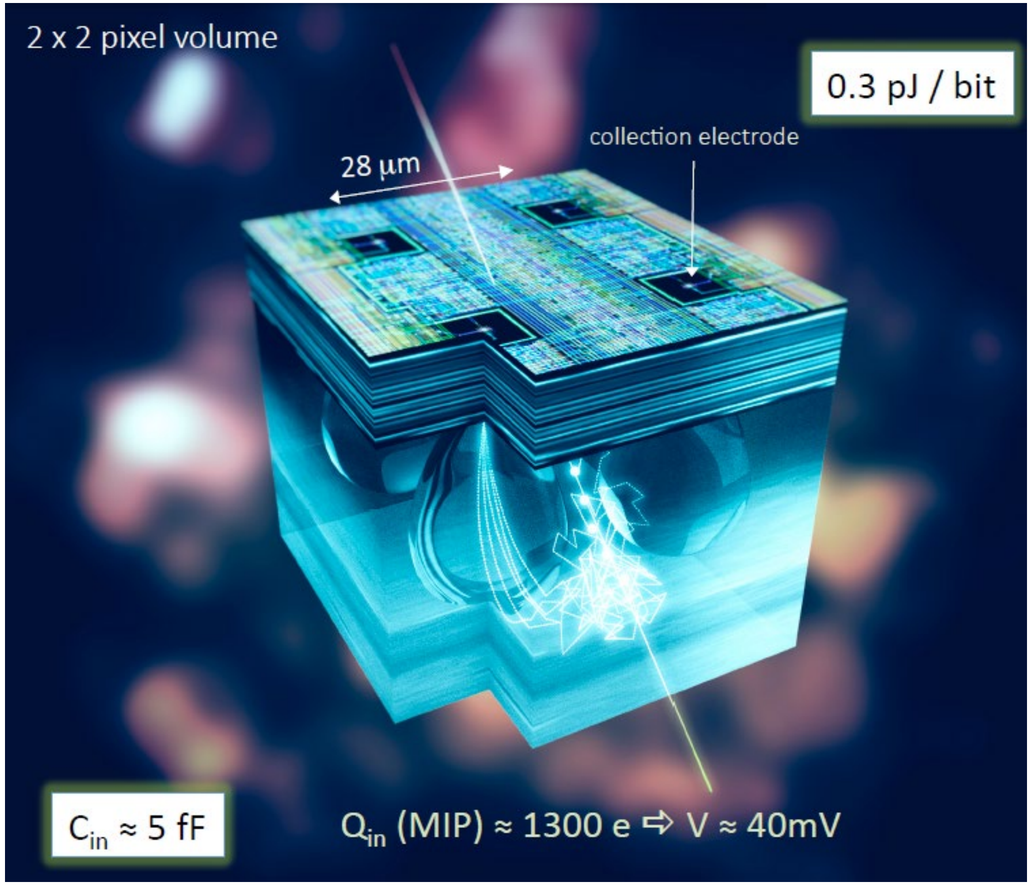
ATLAS Detector Slice

Caso esemplare: Sensore a Pixel Monolitici di Silicio

- Nello stesso blocco di silicio:

Volume sensibile per la raccolta del segnale
+
Logica di trattamento del segnale

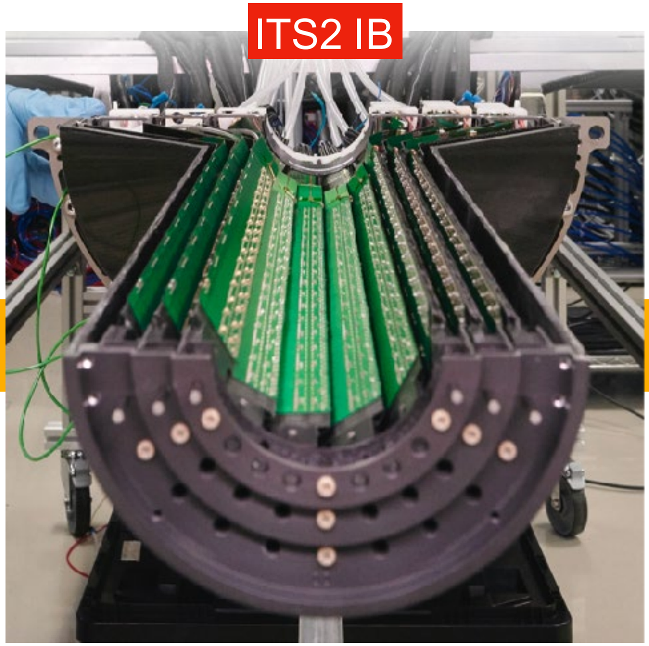
- Rivela il passaggio di particelle cariche
- Puo' essere realizzato in uno spessore minimo, dell'ordine di 50 μm
- Sviluppato per soddisfare la necessita' di ridurre la quantita' di materiale attraversata dalla particella:
  - Non perturbare la traiettoria della particella
  - Misurare la traiettoria delle particelle con bassa quantita' di moto
  - Mantenere una quantita' di segnale necessaria per misurare il passaggio
- Inizialmente sviluppato per applicazioni alle alte energie, ora in fase di test per applicazioni in campo medico e spaziale



Apparati del futuro: ALICE-ITS3 @ LHC (2027)

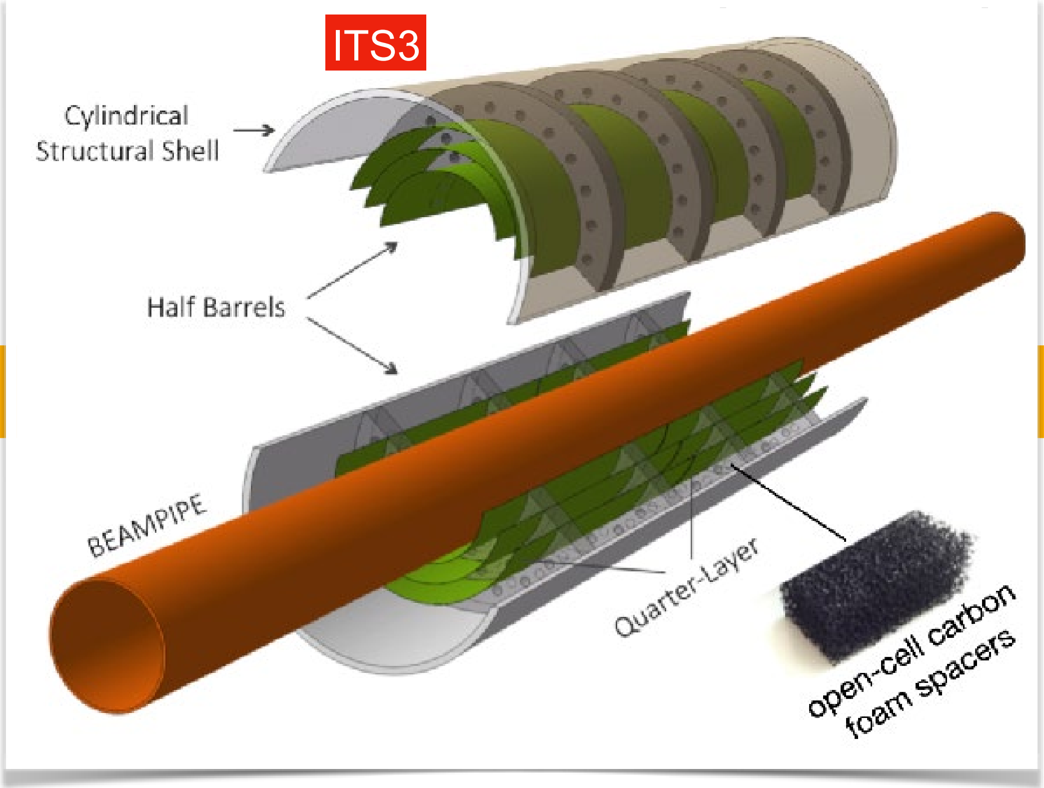
replace

ITS2 IB



by

ITS3



in LS3

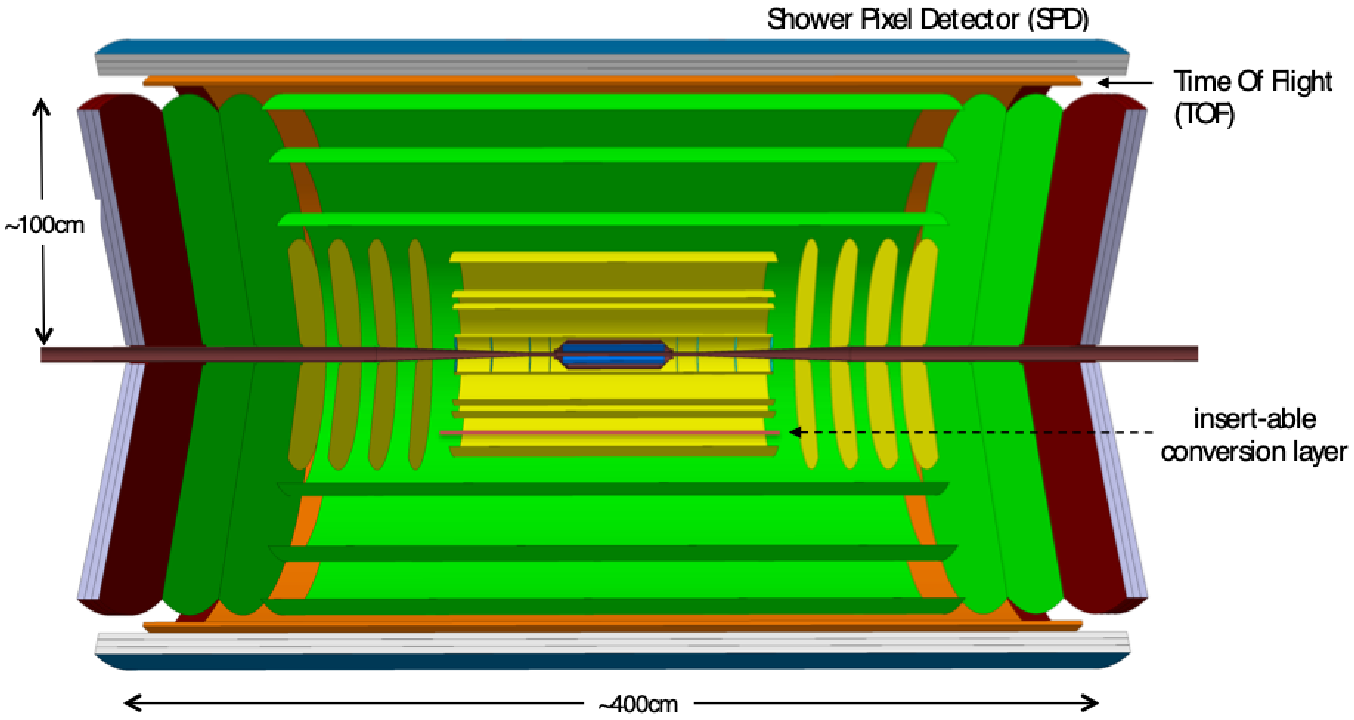
key improvements:
- closer to beam pipe: 23→18 mm
- less material: 0.3 → ~0.03 %X_0

main benefit:
- better tracking performance
- especially at low p_T

based on:
- wafer-scale (up to ~28x10 cm),
- ultra-thin (20-40 μm),
- bent (R=18, 24, 30 mm)

Si sensors (MAPS)

Apparati del futuro: ALICE 3 @ LHC (2032)



- **tracking**
  - ~10 layers (blue, yellow, green) based on MAPS
- **particle identification**
  - time-of-flight layers (orange) in central barrel based on silicon timing sensors
  - Pre-Shower Detector (outermost blue) based on dense material and MAPS

key requirements

- **ultra-low material budget** for low p_T tracking
  - $X/X_0 \sim 0.05$ % / layer
- **fast** to sample large luminosity
  - 50 - 100x Run 3/4
- **large acceptance**
  - $\eta| < 4 \Rightarrow \Delta\eta = 8$ (total)
  - $\eta| < \sim 1.4$ (central barrel)
- **excellent spatial resolution** for tracking and vertexing
  - innermost layers: $\sigma < 3$ µm
  - outer layers: $\sigma \sim 5$ µm
- **precise time measurement** for particle identification
  - $\sigma \sim 20$ ps

outperforming ALICE in Run 3+4

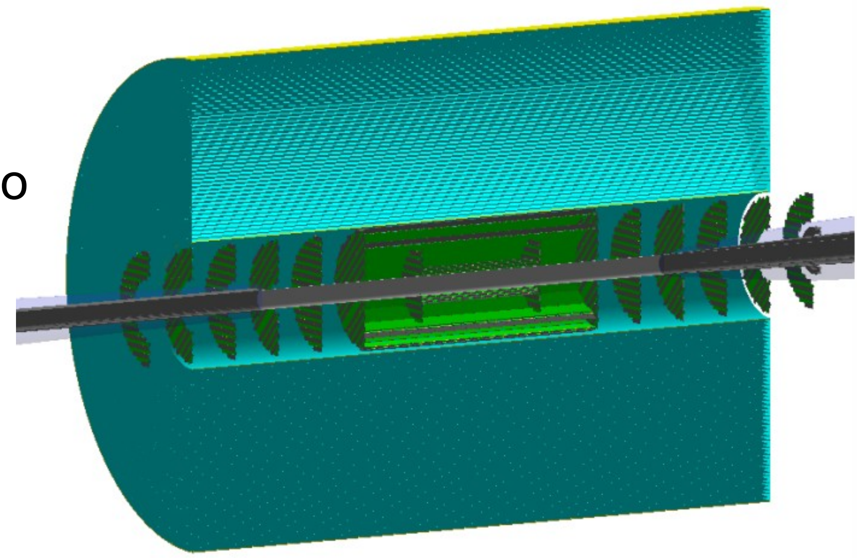
Marco van Leeuwen (Nikhef), Jochen Klein (CERN) @ALICE Week, July 2020

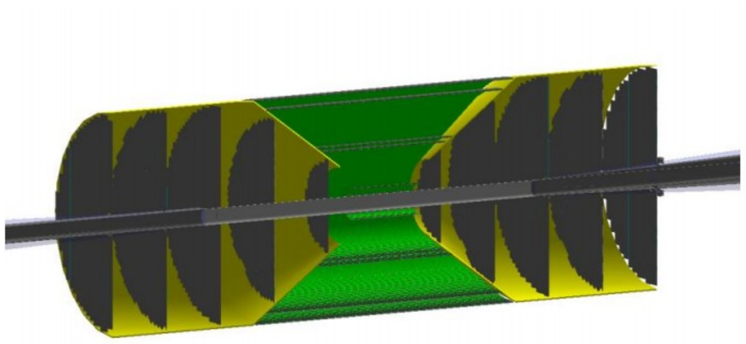
Apparati del futuro: Electron Ion Collider (2030 - 2035)

Requirements for an EIC tracker according to the EIC detector handbook:

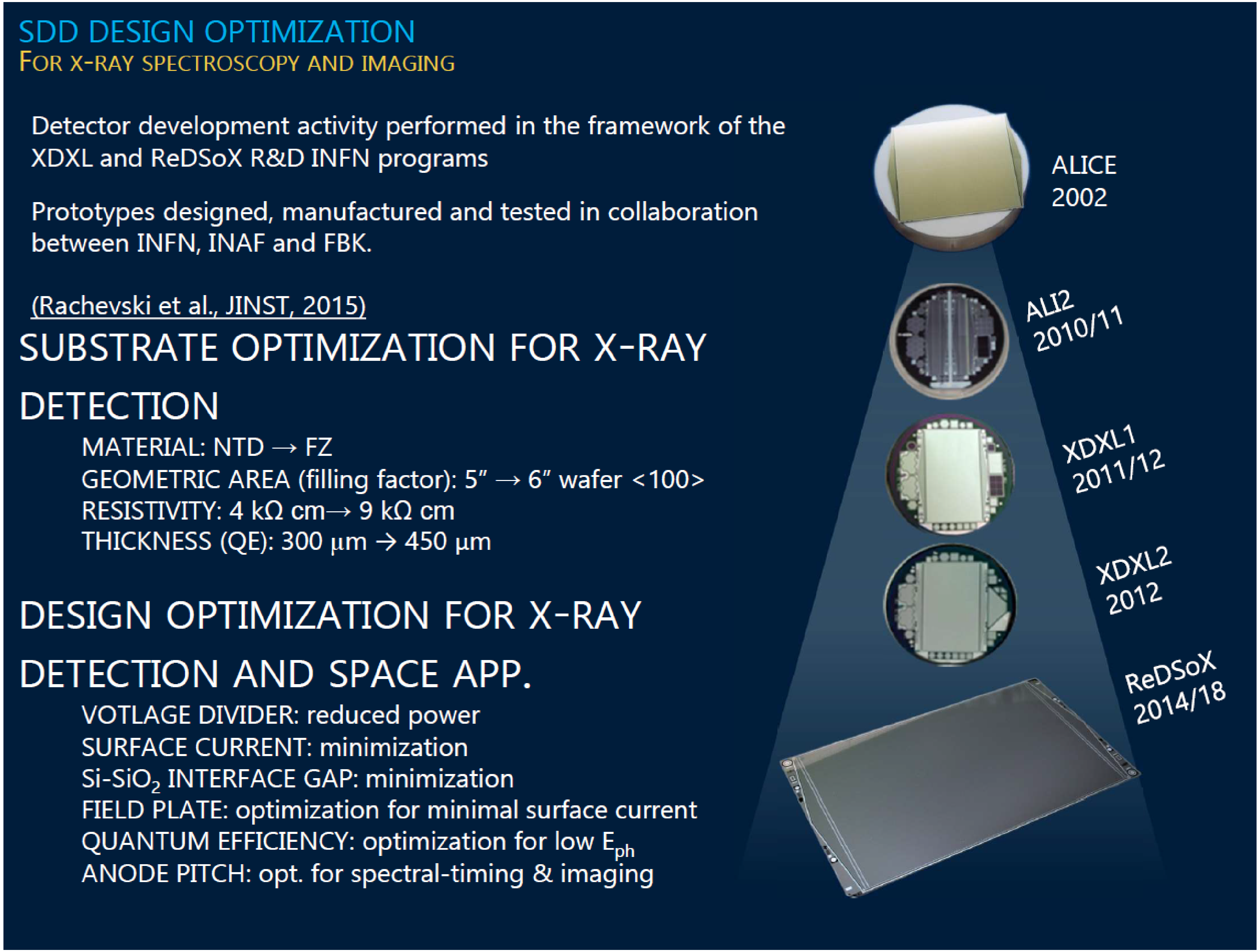
- Hermetic
  * (11 < 4, 0 :s ¢ < 2n coverage)
- Compact
- Low-material-budget tracker
  * (3-5% of X_0)
- Excellent momentum, angular, and vertex resolutions
  * (dp/p ~ few %)
- Aid in particle identification (PID).

Hybrid tracker





All-Si tracker



SDD DESIGN OPTIMIZATION
FOR X-RAY SPECTROSCOPY AND IMAGING

Detector development activity performed in the framework of the XDXL and ReDSoX R&D INFN programs

Prototypes designed, manufactured and tested in collaboration between INFN, INAF and FBK.

(Rachevski et al., JINST, 2015)

SUBSTRATE OPTIMIZATION FOR X-RAY DETECTION

MATERIAL: NTD → FZ
GEOMETRIC AREA (filling factor): 5″ → 6″ wafer <100>
RESISTIVITY: 4 kΩ cm→ 9 kΩ cm
THICKNESS (QE): 300 μm → 450 μm

DESIGN OPTIMIZATION FOR X-RAY DETECTION AND SPACE APP.

VOTLAGE DIVIDER: reduced power
SURFACE CURRENT: minimization
Si-SiO_2 INTERFACE GAP: minimization
FIELD PLATE: optimization for minimal surface current
QUANTUM EFFICIENCY: optimization for low E_{ph}
ANODE PITCH: opt. for spectral-timing & imaging

Altre applicazioni delle Silicon Drift Detector

- Spettroscopia + ricostruzione posizione 2D
  - Risoluzione all'anodo di decine di um per X-rays con 2 keV
  - Lunghezza di deriva piu' grossolana: non c'e' rivelazione di tempo zero (6 mm per E > 3.5 keV)

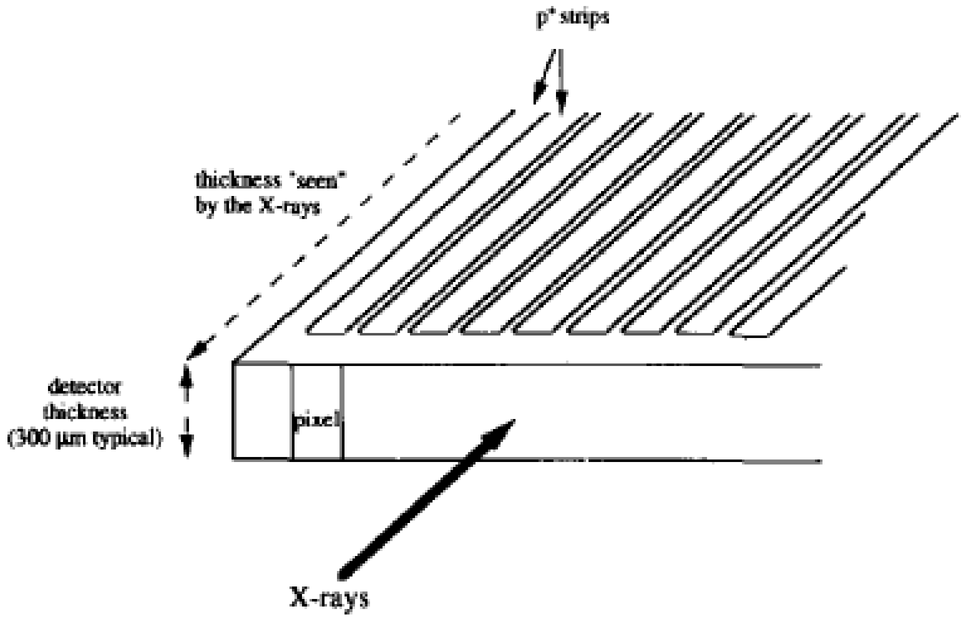
$\Rightarrow$ Medical field: Compton camera

$\Rightarrow$ Nuclear physics precision spectroscopy

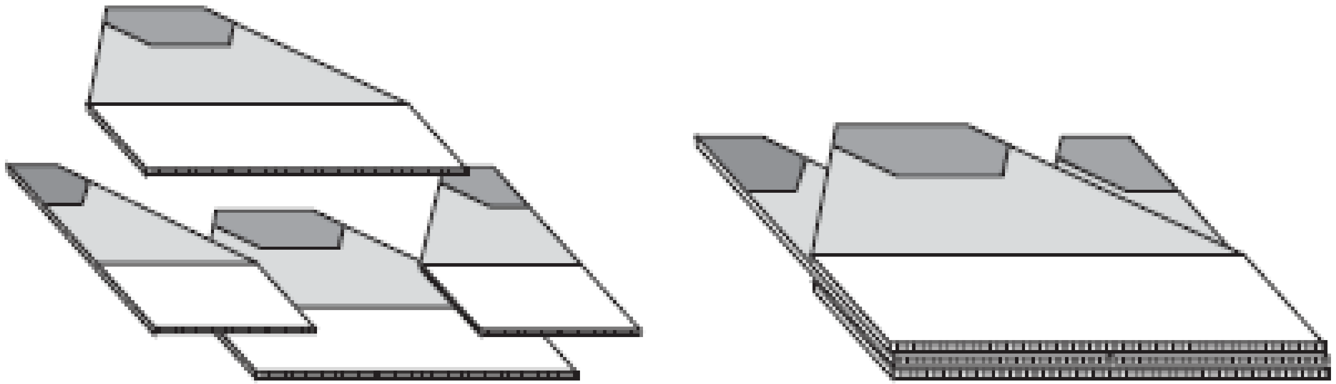
$\Rightarrow$ X-ray astronomy/astrophysics

$\Rightarrow$ X-ray imaging for Advanced Light Sources (SR and FEL)

Applicazione medica delle Silicon Strip Detector: **SYRMEP @ ELETTRA**: mammografia digitale



- Orientazione edge-on



- Struttura che ammetta connessione di tutti i canali in 3D, ma anche eviti una spaccatura al centro del volume sensibile

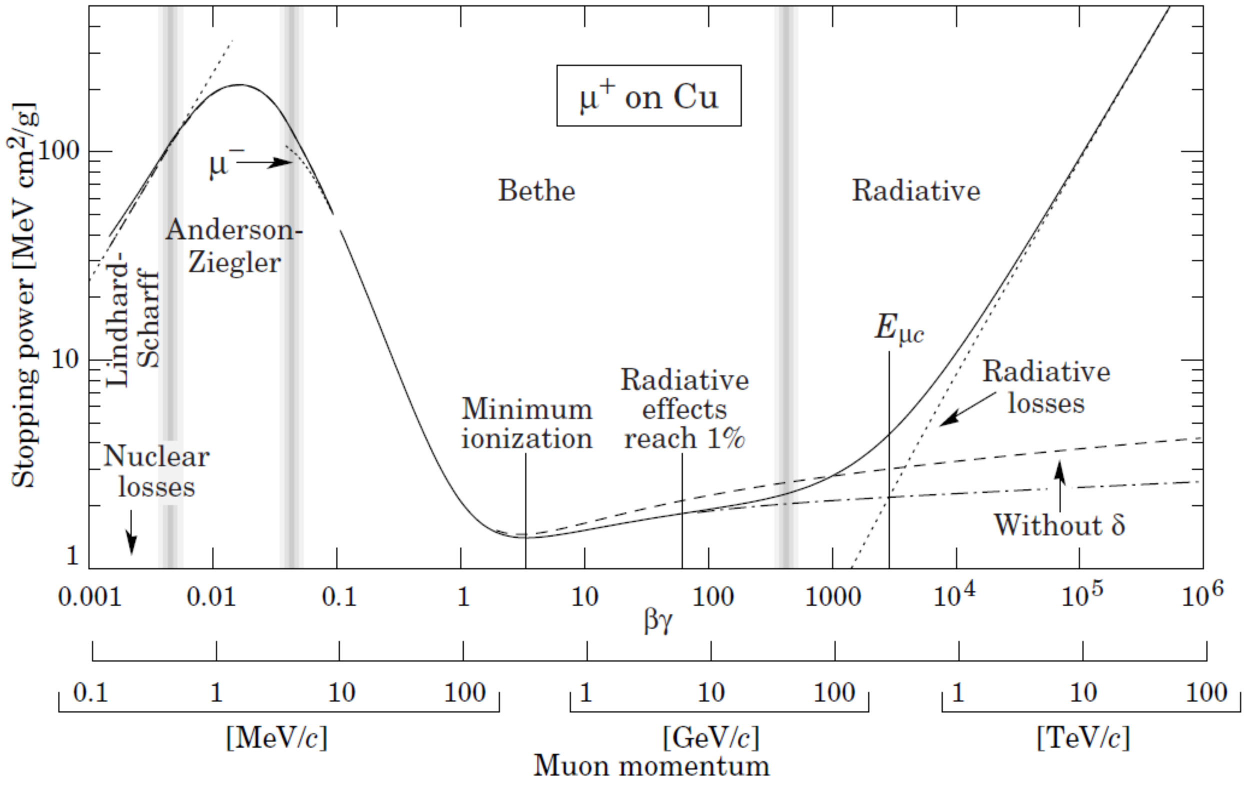


Fig. 27.1: Stopping power (= $\langle -dE/dx \rangle$) for positive muons in copper as a function of $\beta\gamma = p/Mc$ over nine orders of magnitude in momentum (12 orders of magnitude in kinetic energy). Solid curves indicate the total stopping power. Data below the break at $\beta\gamma \approx 0.1$ are taken from ICRU 49 [4], and data at higher energies are from Ref. 5. Vertical bands indicate boundaries between different approximations discussed in the text. The short dotted lines labeled "μ^-" illustrate the "Barkas effect," the dependence of stopping power on projectile charge at very low energies [6].

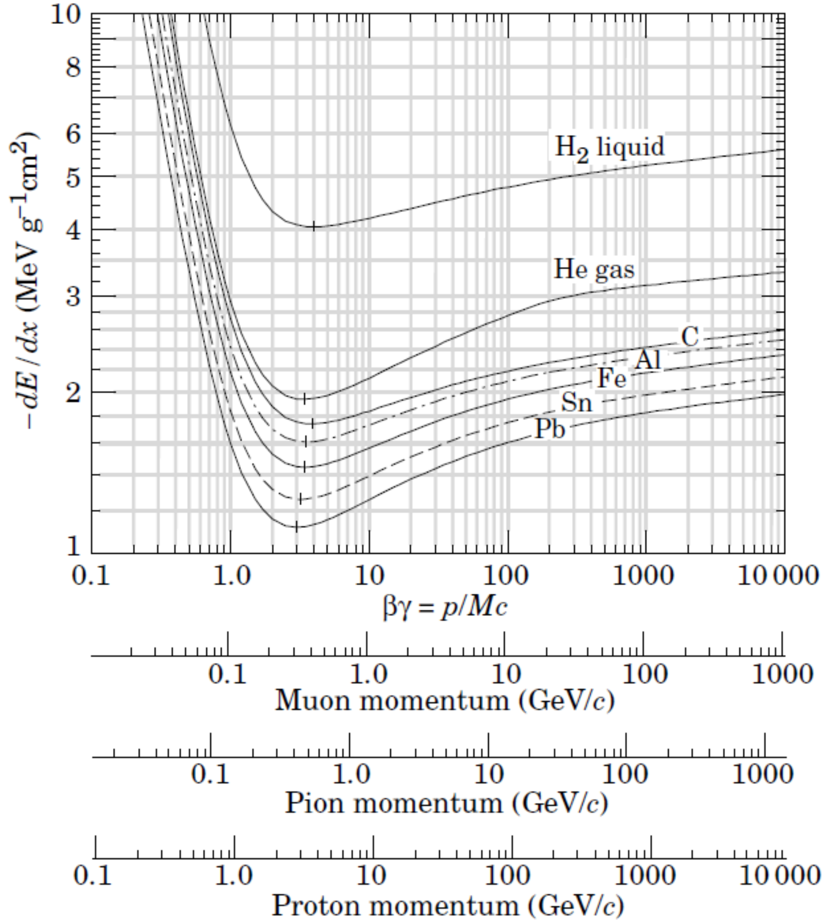


Figure 27.2: Mean energy loss rate in liquid (bubble chamber) hydrogen, gaseous helium, carbon, aluminum, iron, tin, and lead. Radiative effects, relevant for muons and pions, are not included. These become significant for muons in iron for $\beta\gamma \gtrsim 1000$, and at lower momenta for muons in higher-Z absorbers. See Fig. 27.23.

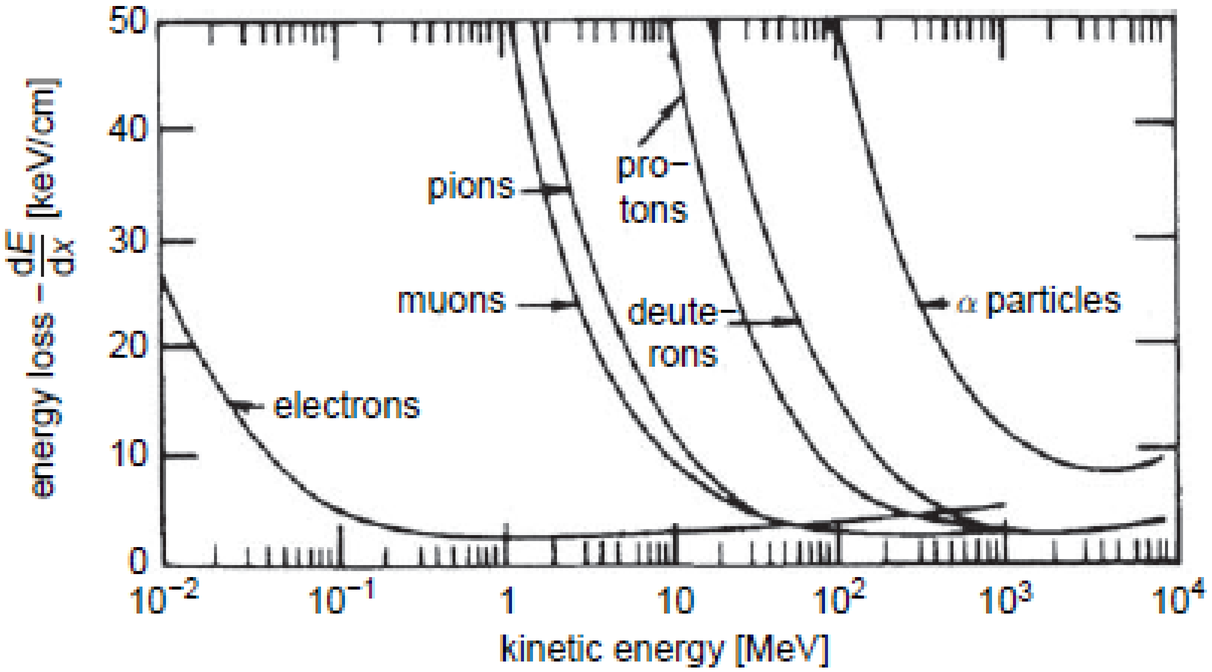
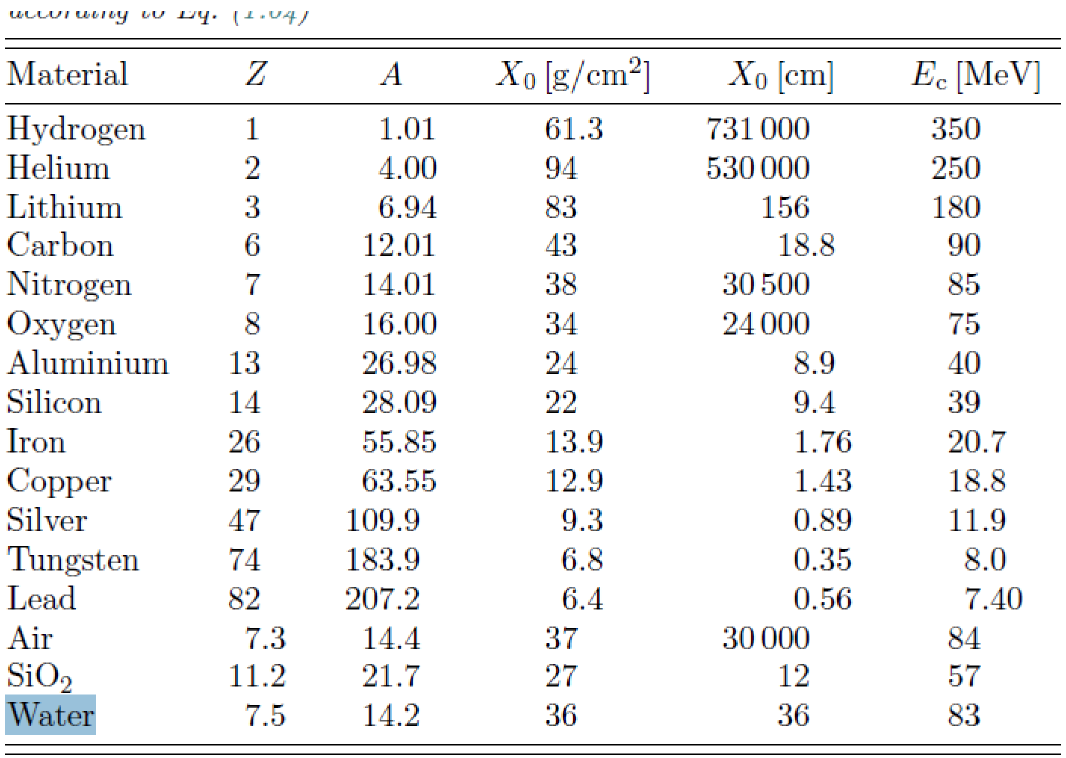


Fig. 1.2. Energy loss for electrons, muons, pions, protons, deuterons and α particles in air [14].

Grafici dE/dx



Material	Z	A	X_0 [g/cm^2]	X_0 [cm]	E_c [MeV]
Hydrogen	1	1.01	61.3	731 000	350
Helium	2	4.00	94	530 000	250
Lithium	3	6.94	83	156	180
Carbon	6	12.01	43	18.8	90
Nitrogen	7	14.01	38	30 500	85
Oxygen	8	16.00	34	24 000	75
Aluminium	13	26.98	24	8.9	40
Silicon	14	28.09	22	9.4	39
Iron	26	55.85	13.9	1.76	20.7
Copper	29	63.55	12.9	1.43	18.8
Silver	47	109.9	9.3	0.89	11.9
Tungsten	74	183.9	6.8	0.35	8.0
Lead	82	207.2	6.4	0.56	7.40
Air	7.3	14.4	37	30 000	84
SiO_2	11.2	21.7	27	12	57
Water	7.5	14.2	36	36	83

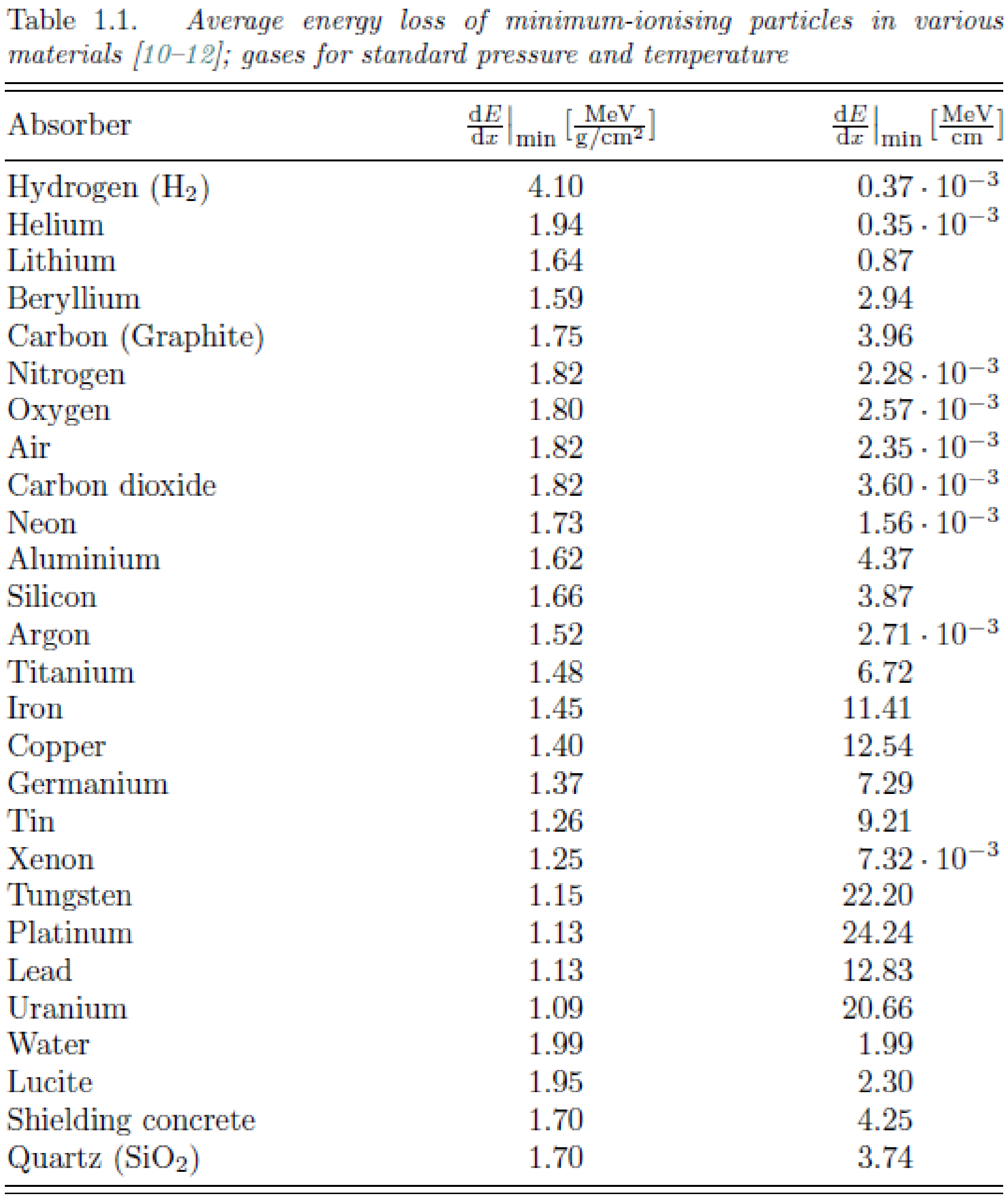


Table 1.1. *Average energy loss of minimum-ionising particles in various materials [10–12]; gases for standard pressure and temperature*

Absorber	$\frac{dE}{dx}\big\|_{\min} \left[\frac{\text{MeV}}{\text{g/cm}^2}\right]$	$\frac{dE}{dx}\big\|_{\min} \left[\frac{\text{MeV}}{\text{cm}}\right]$
Hydrogen (H_2)	4.10	$0.37 \cdot 10^{-3}$
Helium	1.94	$0.35 \cdot 10^{-3}$
Lithium	1.64	0.87
Beryllium	1.59	2.94
Carbon (Graphite)	1.75	3.96
Nitrogen	1.82	$2.28 \cdot 10^{-3}$
Oxygen	1.80	$2.57 \cdot 10^{-3}$
Air	1.82	$2.35 \cdot 10^{-3}$
Carbon dioxide	1.82	$3.60 \cdot 10^{-3}$
Neon	1.73	$1.56 \cdot 10^{-3}$
Aluminium	1.62	4.37
Silicon	1.66	3.87
Argon	1.52	$2.71 \cdot 10^{-3}$
Titanium	1.48	6.72
Iron	1.45	11.41
Copper	1.40	12.54
Germanium	1.37	7.29
Tin	1.26	9.21
Xenon	1.25	$7.32 \cdot 10^{-3}$
Tungsten	1.15	22.20
Platinum	1.13	24.24
Lead	1.13	12.83
Uranium	1.09	20.66
Water	1.99	1.99
Lucite	1.95	2.30
Shielding concrete	1.70	4.25
Quartz (SiO_2)	1.70	3.74

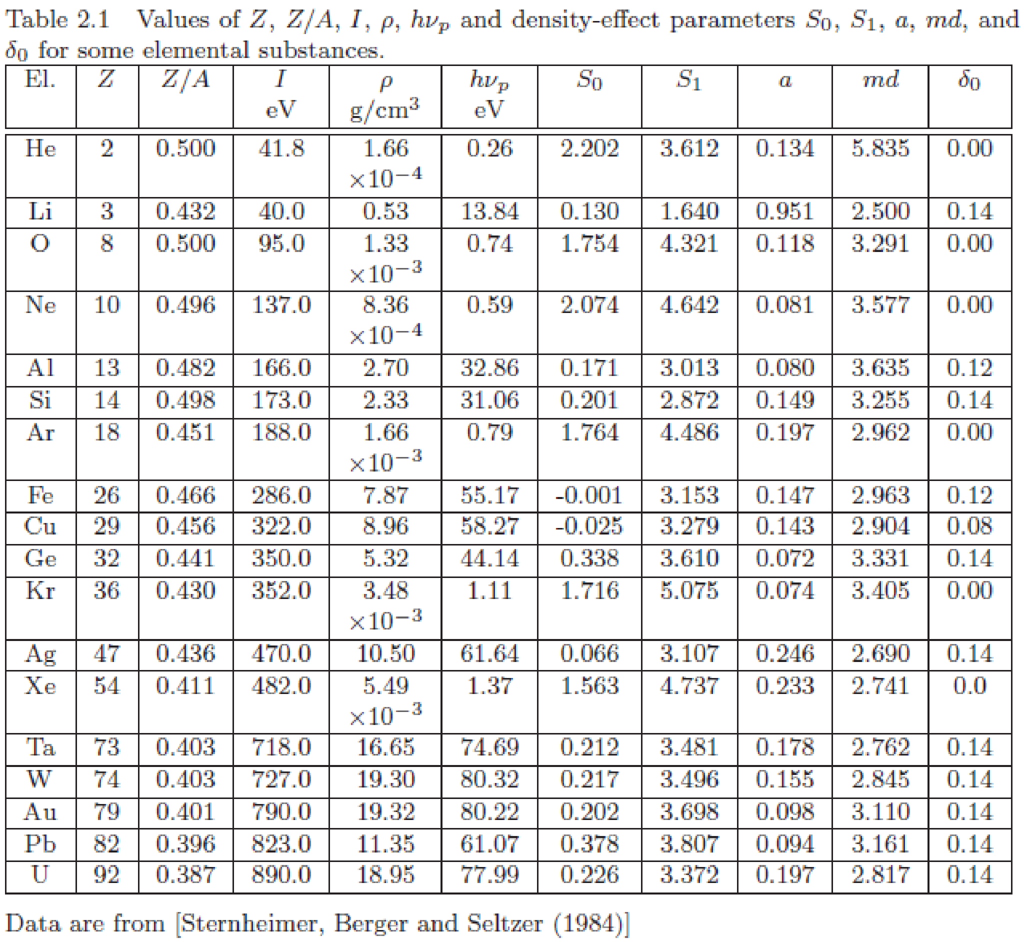


Table 2.1 Values of Z, Z/A, I, ρ, $h\nu_p$ and density-effect parameters S_0, S_1, a, md, and δ_0 for some elemental substances.

El.	Z	Z/A	I eV	ρ g/cm^3	$h\nu_p$ eV	S_0	S_1	a	md	δ_0
He	2	0.500	41.8	1.66×10^{-4}	0.26	2.202	3.612	0.134	5.835	0.00
Li	3	0.432	40.0	0.53	13.84	0.130	1.640	0.951	2.500	0.14
O	8	0.500	95.0	1.33×10^{-3}	0.74	1.754	4.321	0.118	3.291	0.00
Ne	10	0.496	137.0	8.36×10^{-4}	0.59	2.074	4.642	0.081	3.577	0.00
Al	13	0.482	166.0	2.70	32.86	0.171	3.013	0.080	3.635	0.12
Si	14	0.498	173.0	2.33	31.06	0.201	2.872	0.149	3.255	0.14
Ar	18	0.451	188.0	1.66×10^{-3}	0.79	1.764	4.486	0.197	2.962	0.00
Fe	26	0.466	286.0	7.87	55.17	-0.001	3.153	0.147	2.963	0.12
Cu	29	0.456	322.0	8.96	58.27	-0.025	3.279	0.143	2.904	0.08
Ge	32	0.441	350.0	5.32	44.14	0.338	3.610	0.072	3.331	0.14
Kr	36	0.430	352.0	3.48×10^{-3}	1.11	1.716	5.075	0.074	3.405	0.00
Ag	47	0.436	470.0	10.50	61.64	0.066	3.107	0.246	2.690	0.14
Xe	54	0.411	482.0	5.49×10^{-3}	1.37	1.563	4.737	0.233	2.741	0.0
Ta	73	0.403	718.0	16.65	74.69	0.212	3.481	0.178	2.762	0.14
W	74	0.403	727.0	19.30	80.32	0.217	3.496	0.155	2.845	0.14
Au	79	0.401	790.0	19.32	80.22	0.202	3.698	0.098	3.110	0.14
Pb	82	0.396	823.0	11.35	61.07	0.378	3.807	0.094	3.161	0.14
U	92	0.387	890.0	18.95	77.99	0.226	3.372	0.197	2.817	0.14

Data are from [Sternheimer, Berger and Seltzer (1984)]

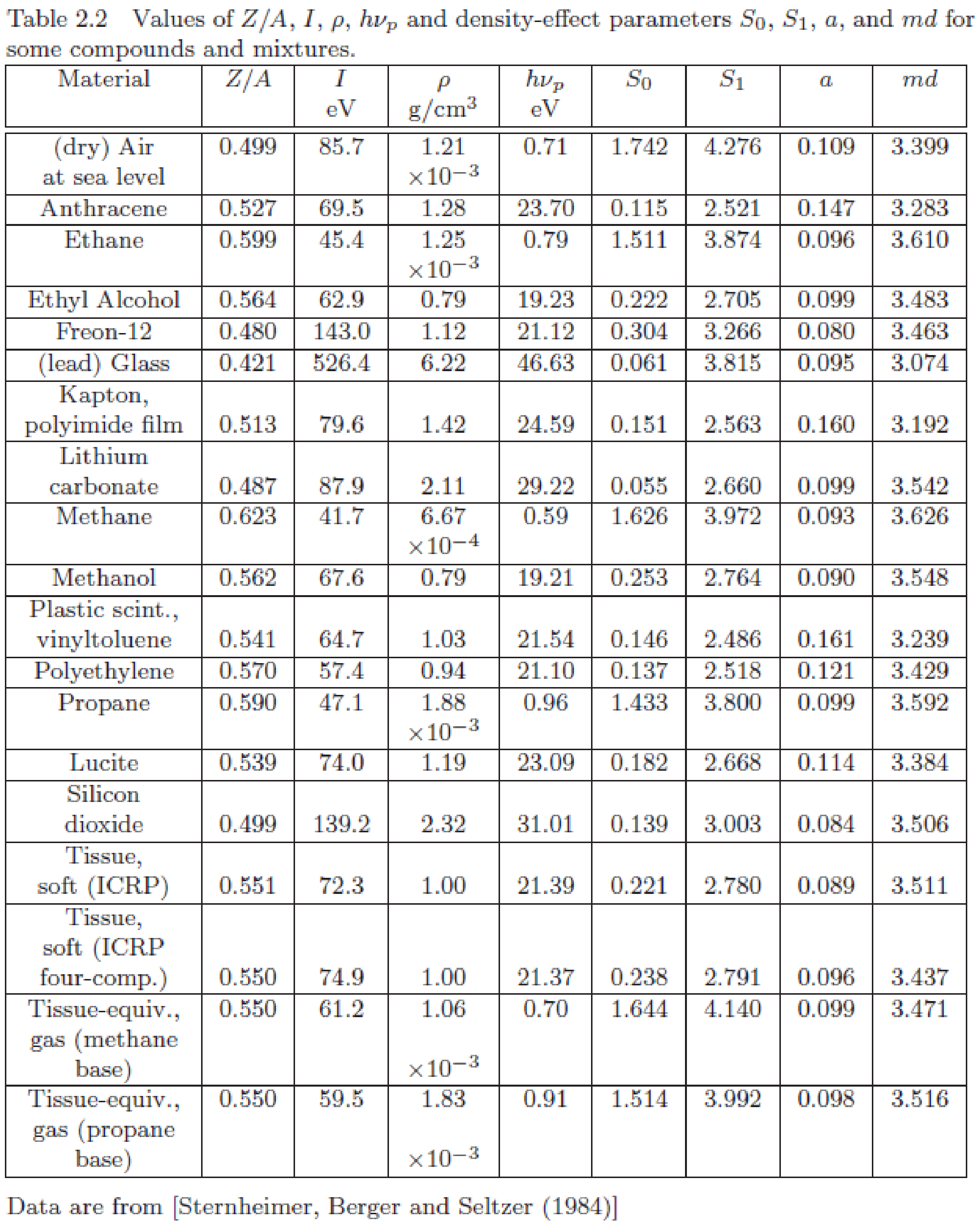
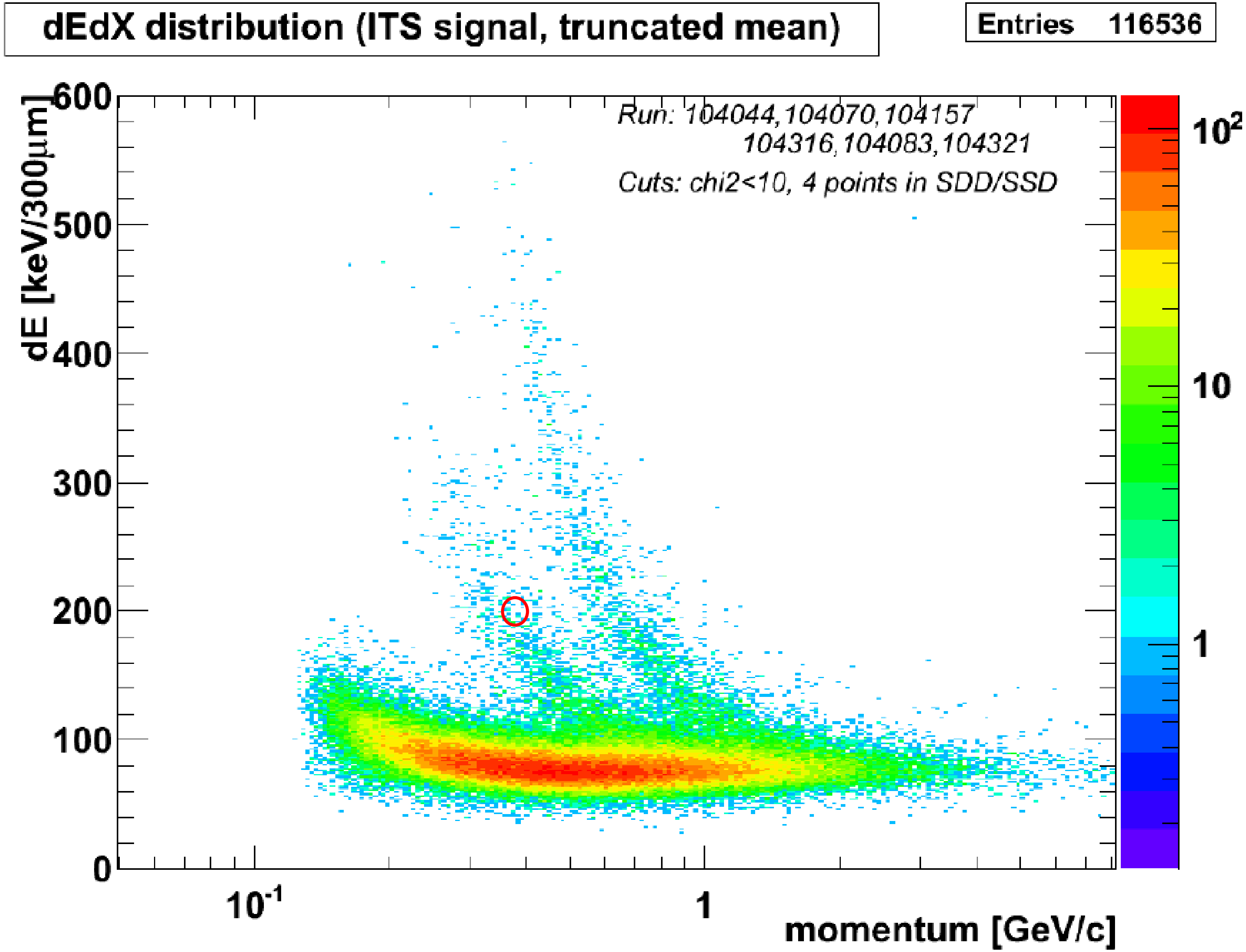


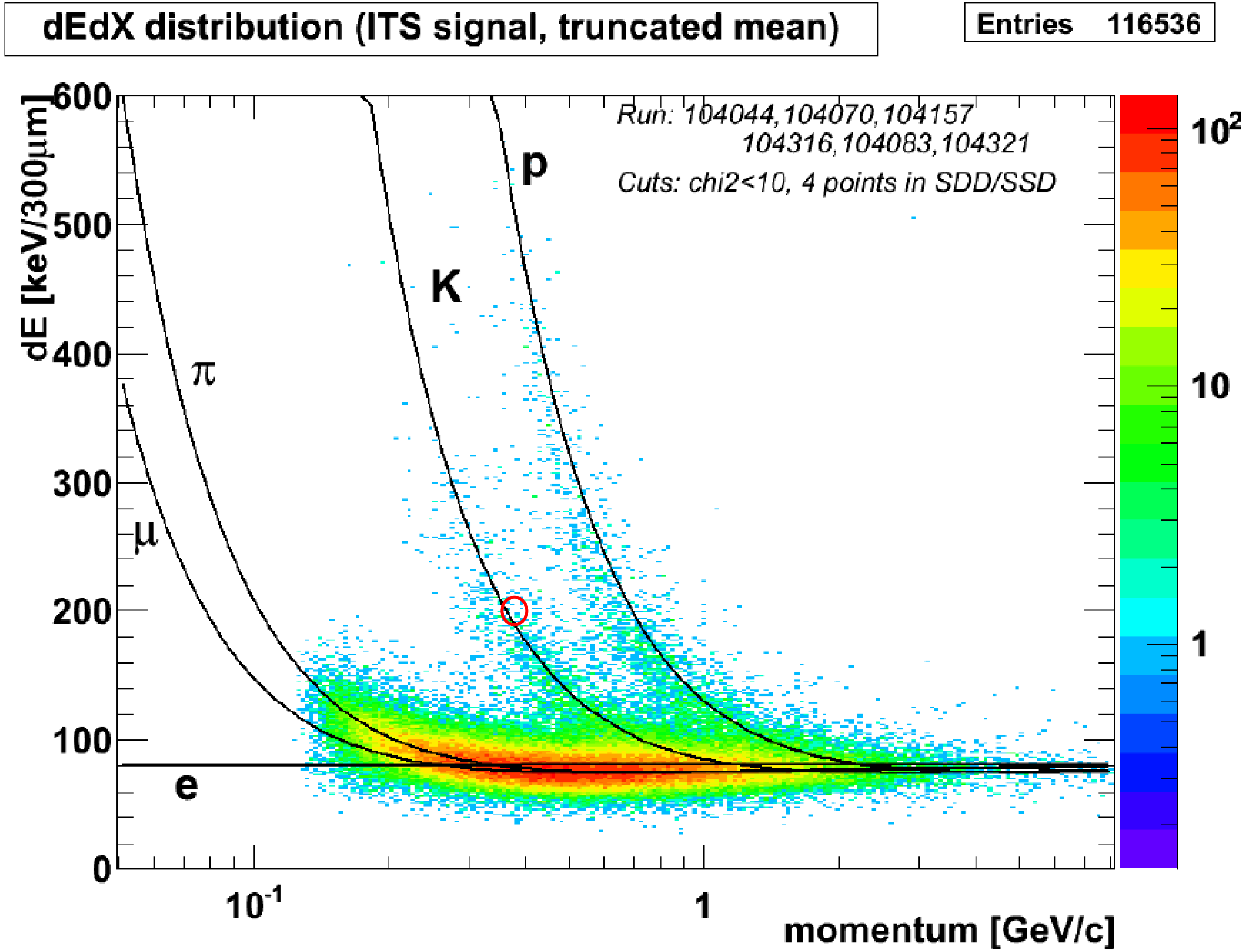
Table 2.2 Values of Z/A, I, ρ, $h\nu_p$ and density-effect parameters S_0, S_1, a, and md for some compounds and mixtures.

Material	Z/A	I eV	ρ g/cm^3	$h\nu_p$ eV	S_0	S_1	a	md
(dry) Air at sea level	0.499	85.7	1.21×10^{-3}	0.71	1.742	4.276	0.109	3.399
Anthracene	0.527	69.5	1.28	23.70	0.115	2.521	0.147	3.283
Ethane	0.599	45.4	1.25×10^{-3}	0.79	1.511	3.874	0.096	3.610
Ethyl Alcohol	0.564	62.9	0.79	19.23	0.222	2.705	0.099	3.483
Freon-12	0.480	143.0	1.12	21.12	0.304	3.266	0.080	3.463
(lead) Glass	0.421	526.4	6.22	46.63	0.061	3.815	0.095	3.074
Kapton, polyimide film	0.513	79.6	1.42	24.59	0.151	2.563	0.160	3.192
Lithium carbonate	0.487	87.9	2.11	29.22	0.055	2.660	0.099	3.542
Methane	0.623	41.7	6.67×10^{-4}	0.59	1.626	3.972	0.093	3.626
Methanol	0.562	67.6	0.79	19.21	0.253	2.764	0.090	3.548
Plastic scint., vinyltoluene	0.541	64.7	1.03	21.54	0.146	2.486	0.161	3.239
Polyethylene	0.570	57.4	0.94	21.10	0.137	2.518	0.121	3.429
Propane	0.590	47.1	1.88×10^{-3}	0.96	1.433	3.800	0.099	3.592
Lucite	0.539	74.0	1.19	23.09	0.182	2.668	0.114	3.384
Silicon dioxide	0.499	139.2	2.32	31.01	0.139	3.003	0.084	3.506
Tissue, soft (ICRP)	0.551	72.3	1.00	21.39	0.221	2.780	0.089	3.511
Tissue, soft (ICRP four-comp.)	0.550	74.9	1.00	21.37	0.238	2.791	0.096	3.437
Tissue-equiv., gas (methane base)	0.550	61.2	1.06×10^{-3}	0.70	1.644	4.140	0.099	3.471
Tissue-equiv., gas (propane base)	0.550	59.5	1.83×10^{-3}	0.91	1.514	3.992	0.098	3.516

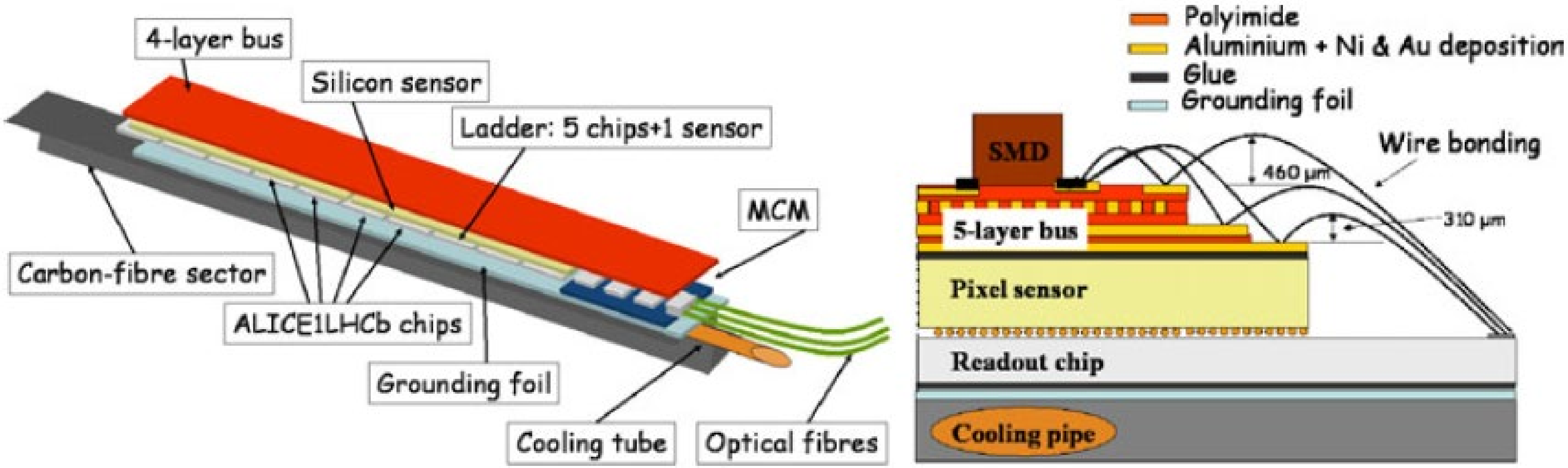
Data are from [Sternheimer, Berger and Seltzer (1984)]

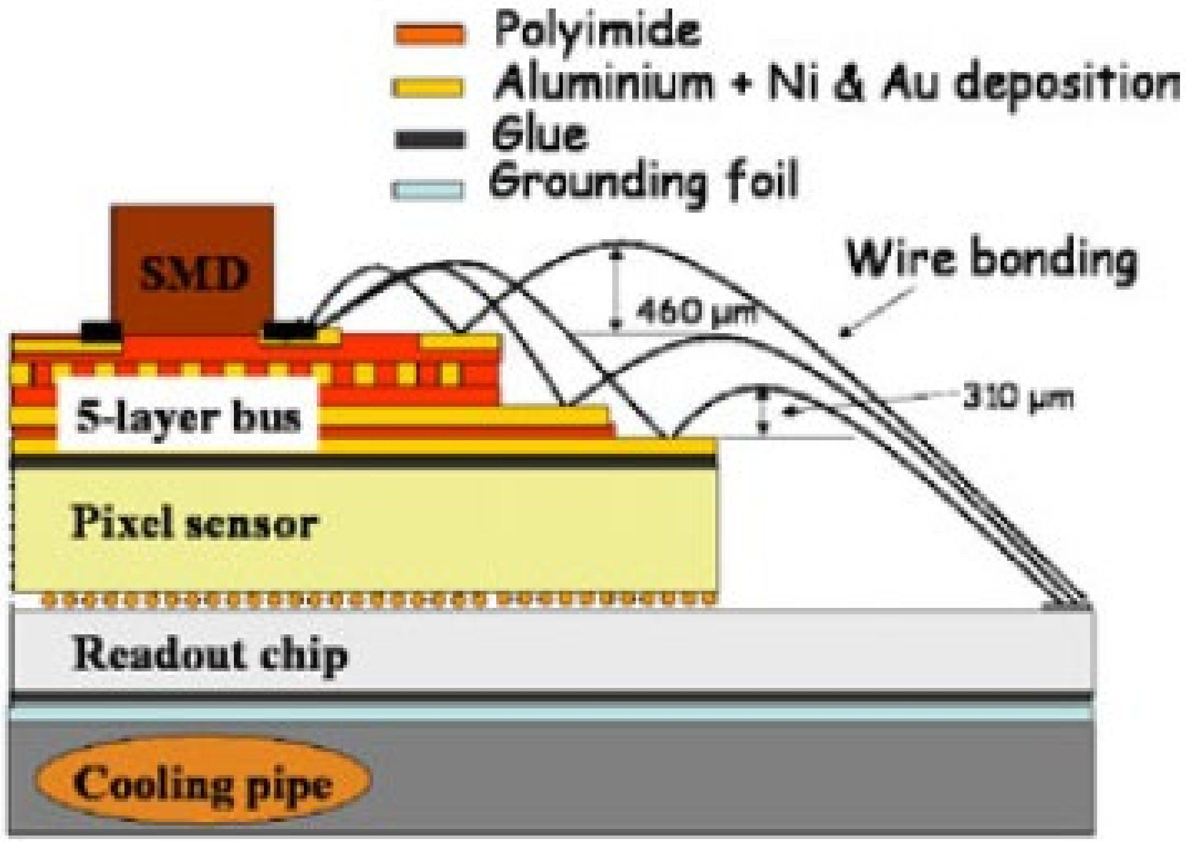
- Istogramma a dispersione carica ricostruita da 4 misure
- Esempio: 200 keV @ quantita' di moto p=400 MeV/c
- Che tipo di particella e'?




dEdX distribution (ITS signal, truncated mean)
Entries 116536
Run: 104044,104070,104157
104316,104083,104321
Cuts: chi2<10, 4 points in SDD/SSD
dE [keV/300μm]
600
500
400
300
200
100
0
10^{-1}
1
momentum [GeV/c]
p
K
π
μ
e
10^2
10
1

Silicon Pixel Detector – ALICE (2008 – 2019)

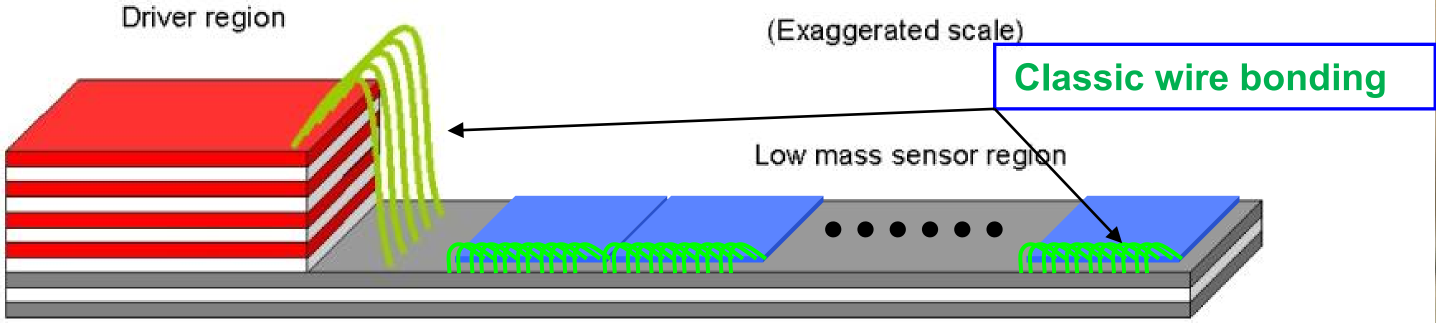


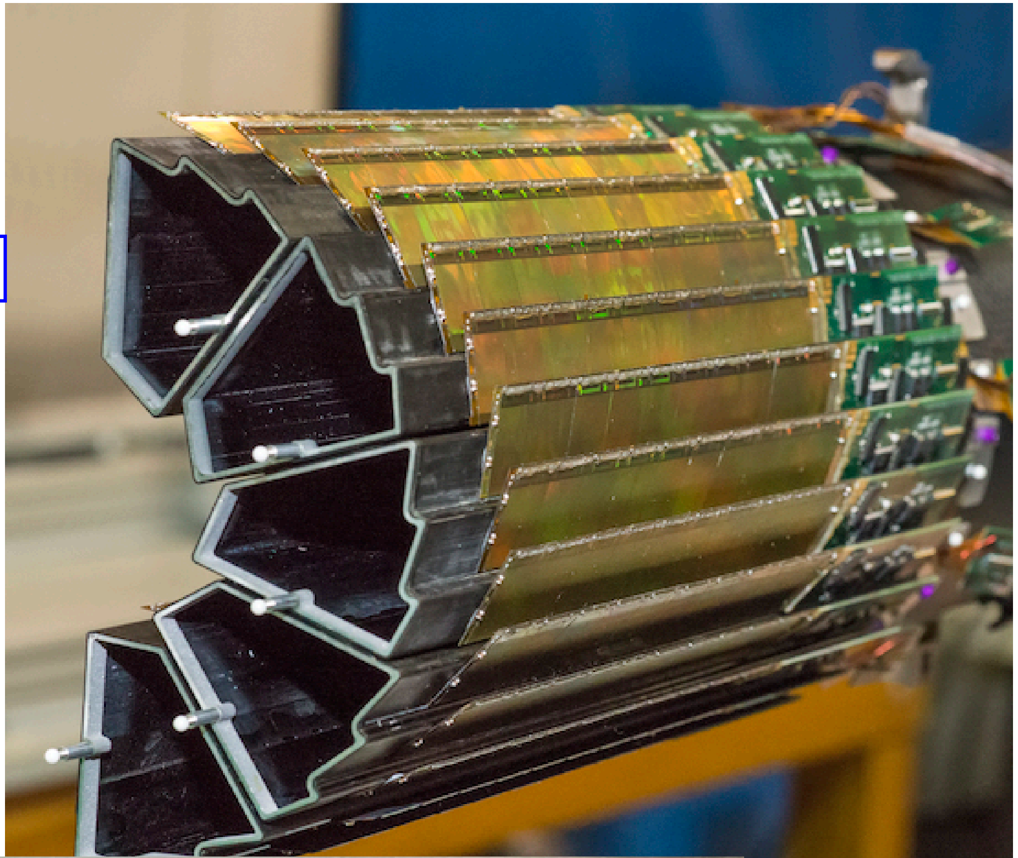


SPD Element	Thickness μm	% X_0
Al Bus		
Kapton	60	0.021
Al power	100	0.112
Al signals [50% of total surface]	17.5	0.020
Glue Epoxy	70	0.016
SMD components	16.4	0.173
Total bus		**0.341**
Other Components		
Pixel chip	150	0.160
Sensor	200	0.214
Bump bonds Sn 60%+Pb 40%	0.18+0.12	0.004
Grounding Foil-Kapton/Al	50+10	0.029
Glue Epoxy/thermal grease	200	0.049
Carbon fiber	200	0.106
Total components		**0.561**
Total bus and components		**0.903**

MATERIAL BUDGET OF ONE SPD LAYER

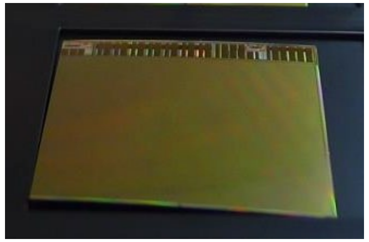
HFT Pixel detector – STAR (BNL) – 2014-2016





PXL Material Budget

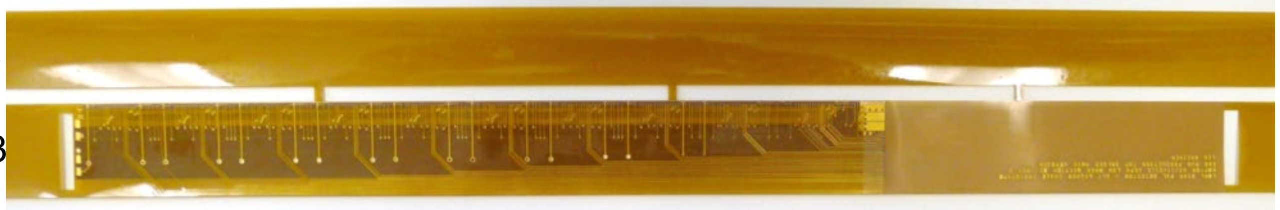
- Thinned Sensor
  - 50 μm
  - 0.068% X_0



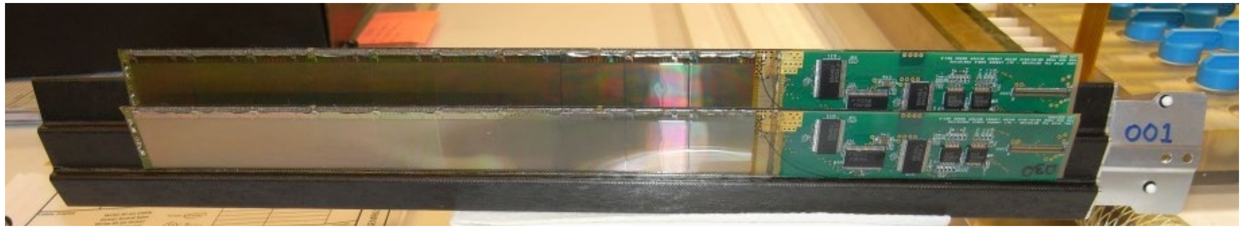
- Curved sensor
- 40-60% yield after thinning, dicing and probe testing
- Fully characterized before installation

- Flex Cable
  - Aluminum-Kapton
  - two 32 μm-thick Al layers
  - 0.128% X_0
    - *Copper* version → 0.23

- Power and signal lines
- Wire bond encapsulant largest contribution
- Acrylic adhesive to deal with different CTE



- Carbon fiber supports
  - 125 μm stiffener
  - 250 μm sector tube
  - 0.193% X_0



- Cooling
  - Air cooling: negligible contribution

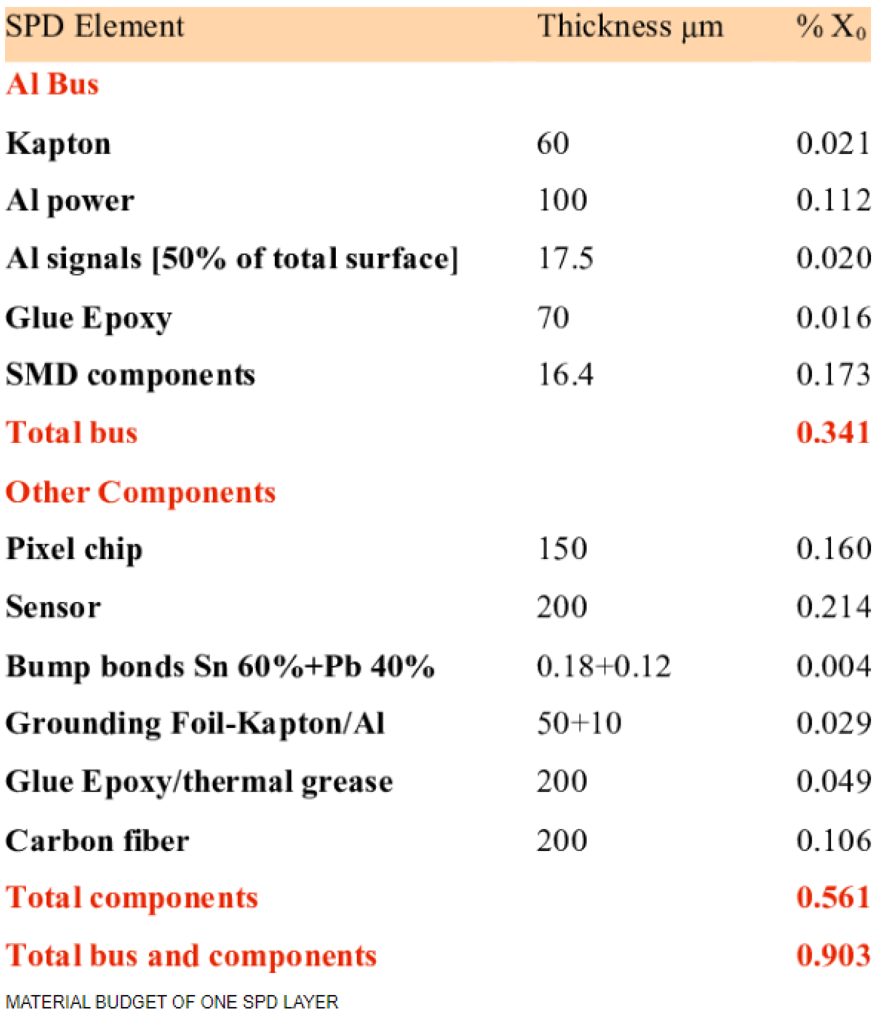
- **Total material budget on inner layer: 0.388% X_0**

(0.492% X_0 for the Cu conductor version)

SPD

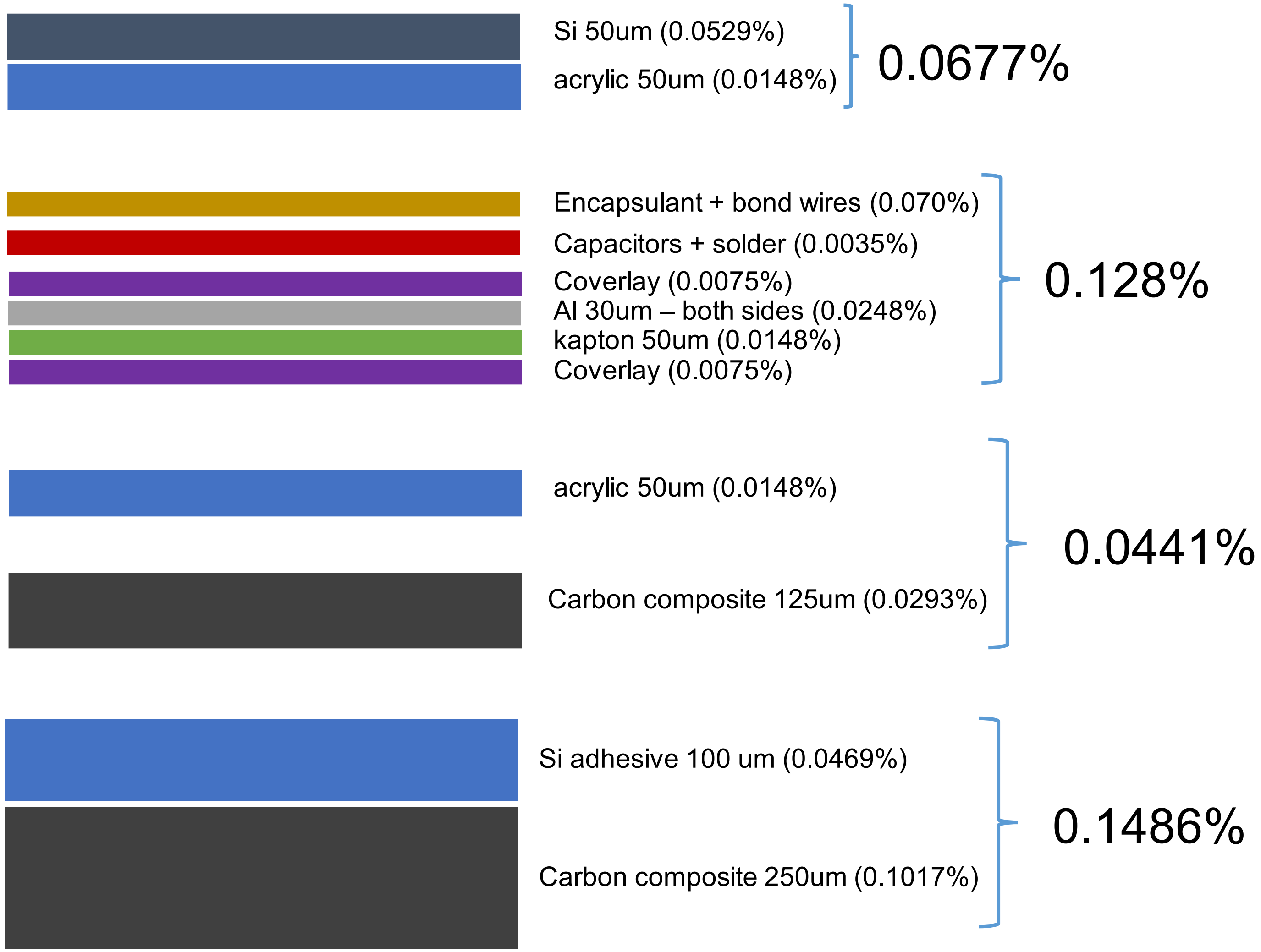
Material budget comparison

HFT



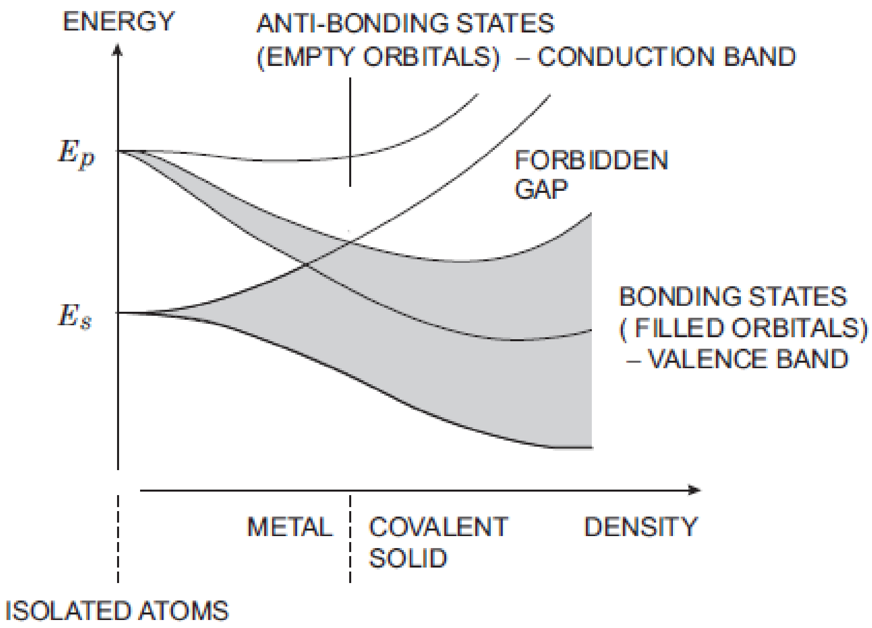
SPD Element	Thickness µm	% X_0
Al Bus		
Kapton	60	0.021
Al power	100	0.112
Al signals [50% of total surface]	17.5	0.020
Glue Epoxy	70	0.016
SMD components	16.4	0.173
Total bus		0.341
Other Components		
Pixel chip	150	0.160
Sensor	200	0.214
Bump bonds Sn 60%+Pb 40%	0.18+0.12	0.004
Grounding Foil-Kapton/Al	50+10	0.029
Glue Epoxy/thermal grease	200	0.049
Carbon fiber	200	0.106
Total components		0.561
Total bus and components		0.903

MATERIAL BUDGET OF ONE SPD LAYER



Total = 0.388%

Figura reticolo e bande



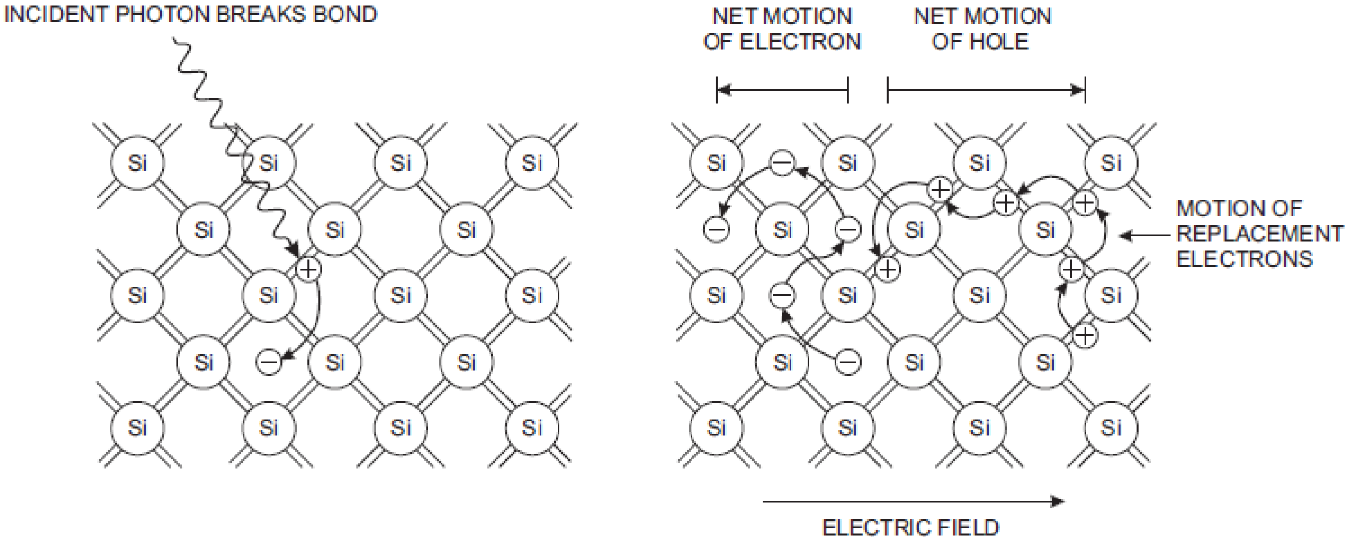
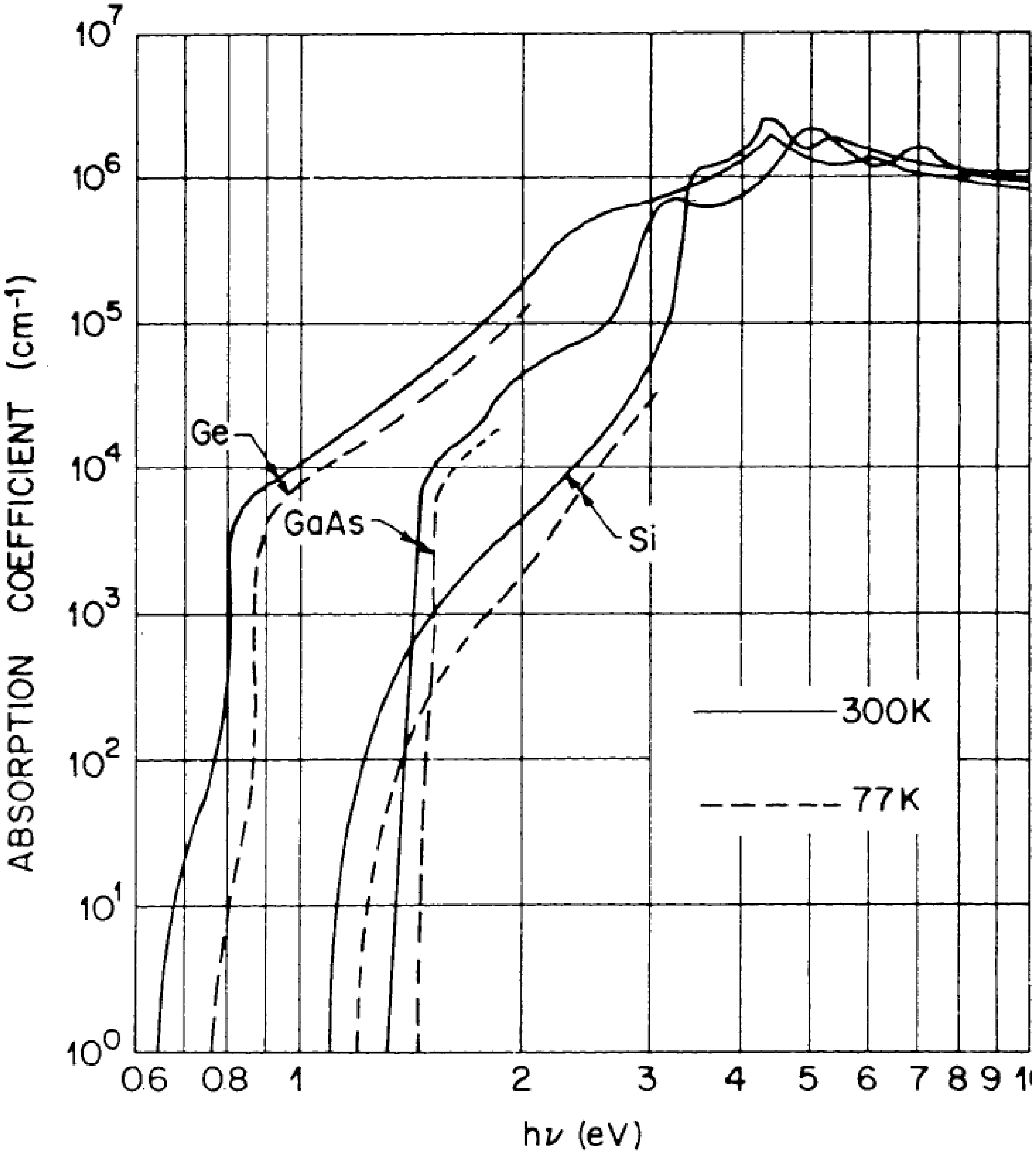
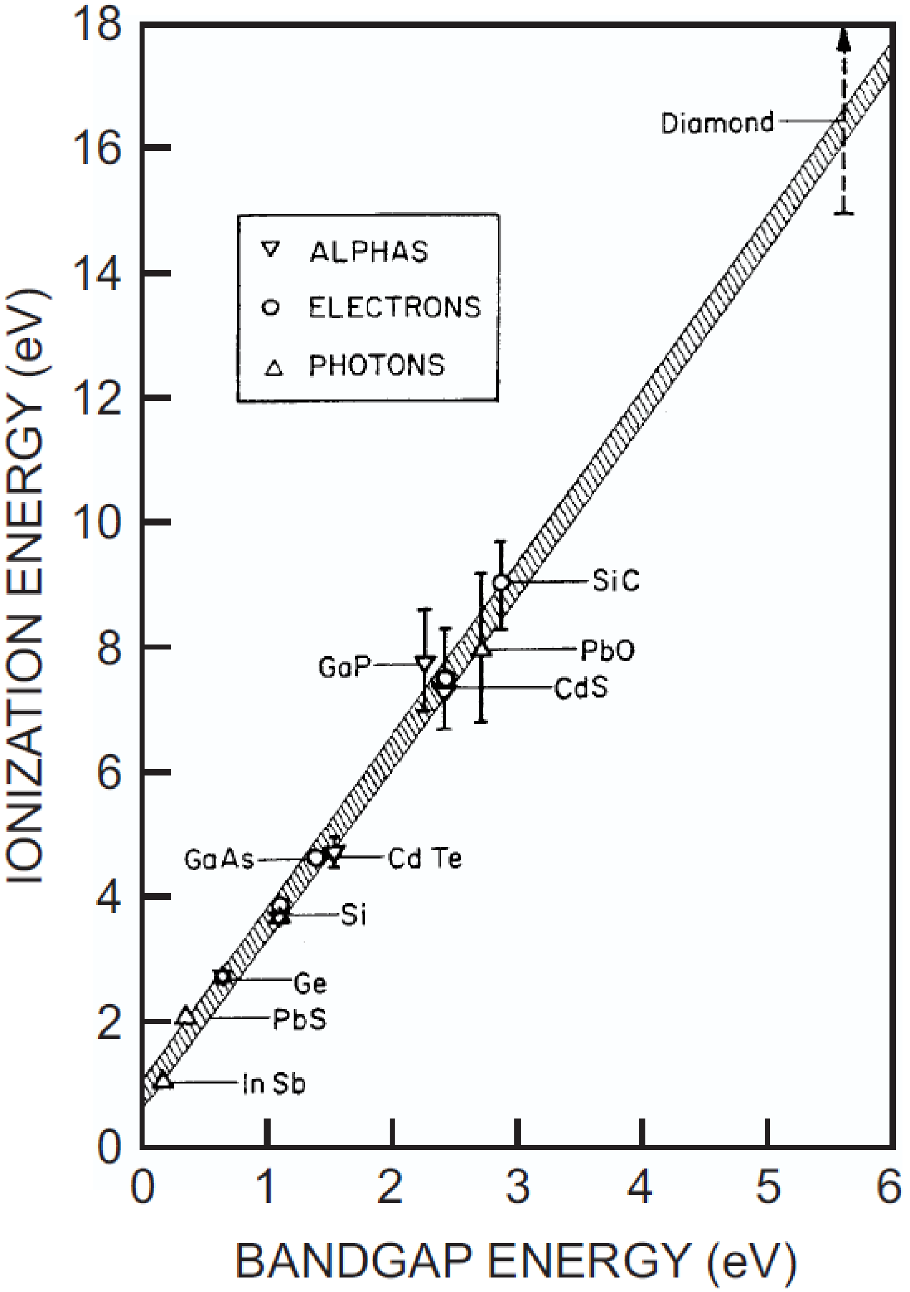


Fig. 2.7. An incident particle can break a bond, promoting an electron into the conduction band, so it can move freely. The vacant bond with positive net charge can also move by successively "borrowing" electrons from neighboring bonds. (Following Shockley 1950.)



ABSORPTION COEFFICIENT (cm⁻¹)
10⁷
10⁶
10⁵
10⁴
10³
10²
10¹
10⁰
Ge
GaAs
Si
300K
77K
0.6
0.8
1
2
3
4
5
6
7
8
9
10
hν (eV)



IONIZATION ENERGY (eV)
18
16
14
12
10
8
6
4
2
0
ALPHAS
ELECTRONS
PHOTONS
Diamond
SiC
PbO
CdS
GaP
GaAs
Cd Te
Si
Ge
PbS
In Sb
0
1
2
3
4
5
6
BANDGAP ENERGY (eV)

Giunzione pn

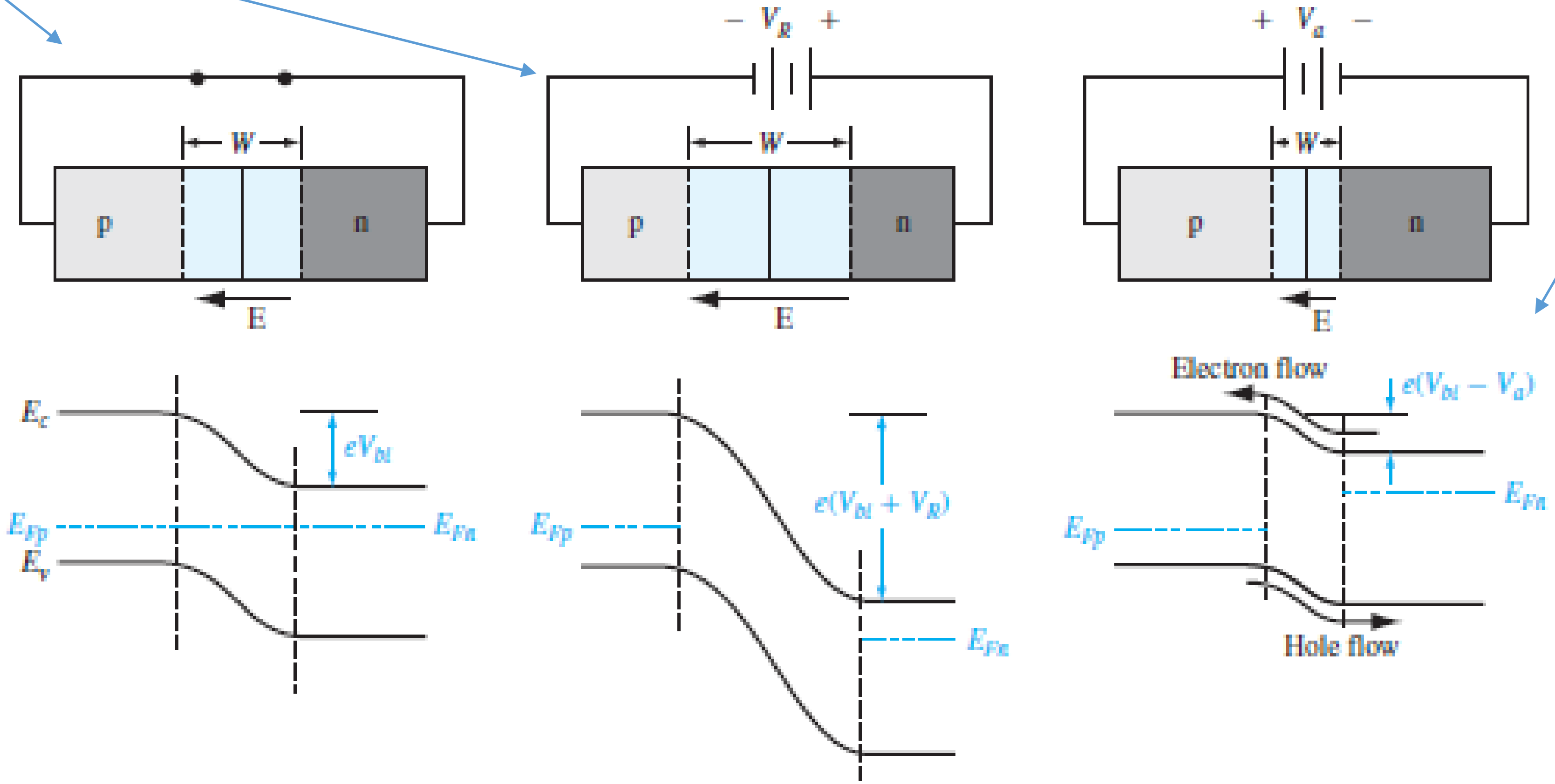
Non c'e' passaggio di corrente
(a parte corrente di leakage)

Non
polarizzata

Inversamente
polarizzata

Direttamente
polarizzata

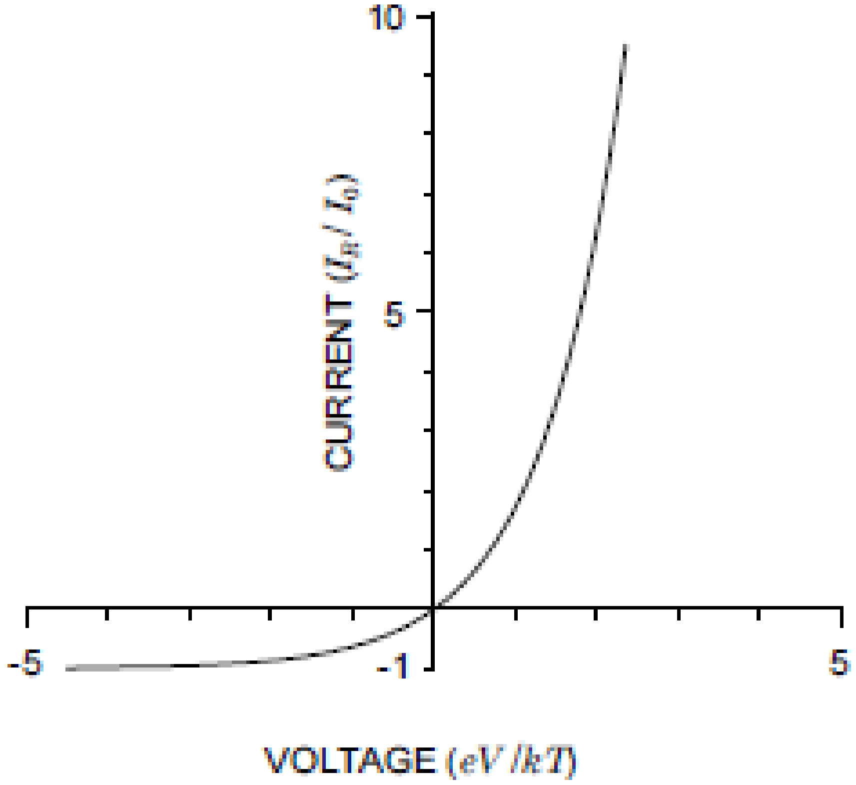
Corrente attraverso
la giunzione

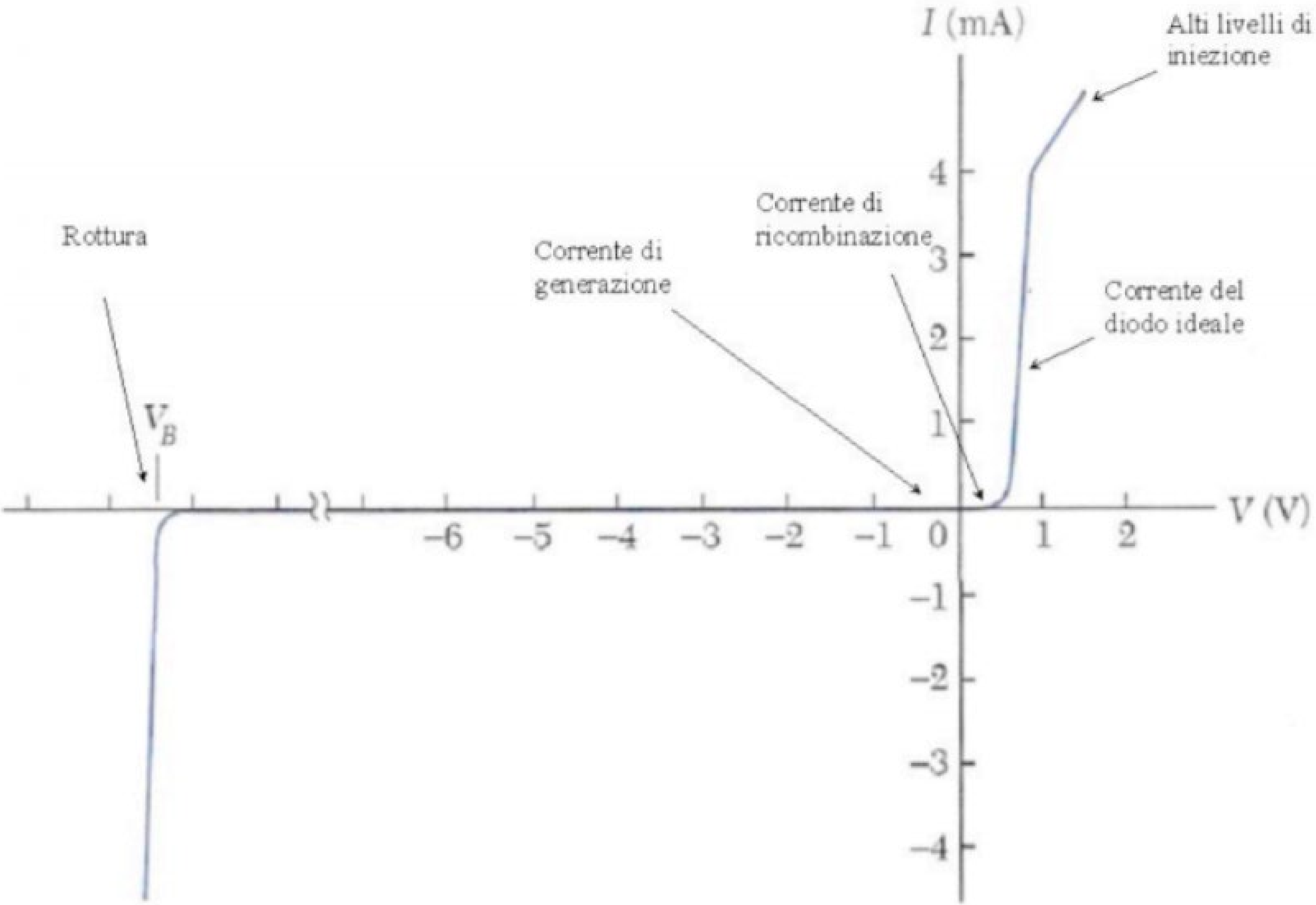


Corrente della giunzione pn

Inversamente polarizzata

Direttamente polarizzata





I (mA)
Alti livelli di iniezione
4
3
2
1
−1
−2
−3
−4
Corrente di ricombinazione
Rottura
Corrente di generazione
Corrente del diodo ideale
V_B
−6
−5
−4
−3
−2
−1
0
1
2
V (V)

Capacita' Vs V_R

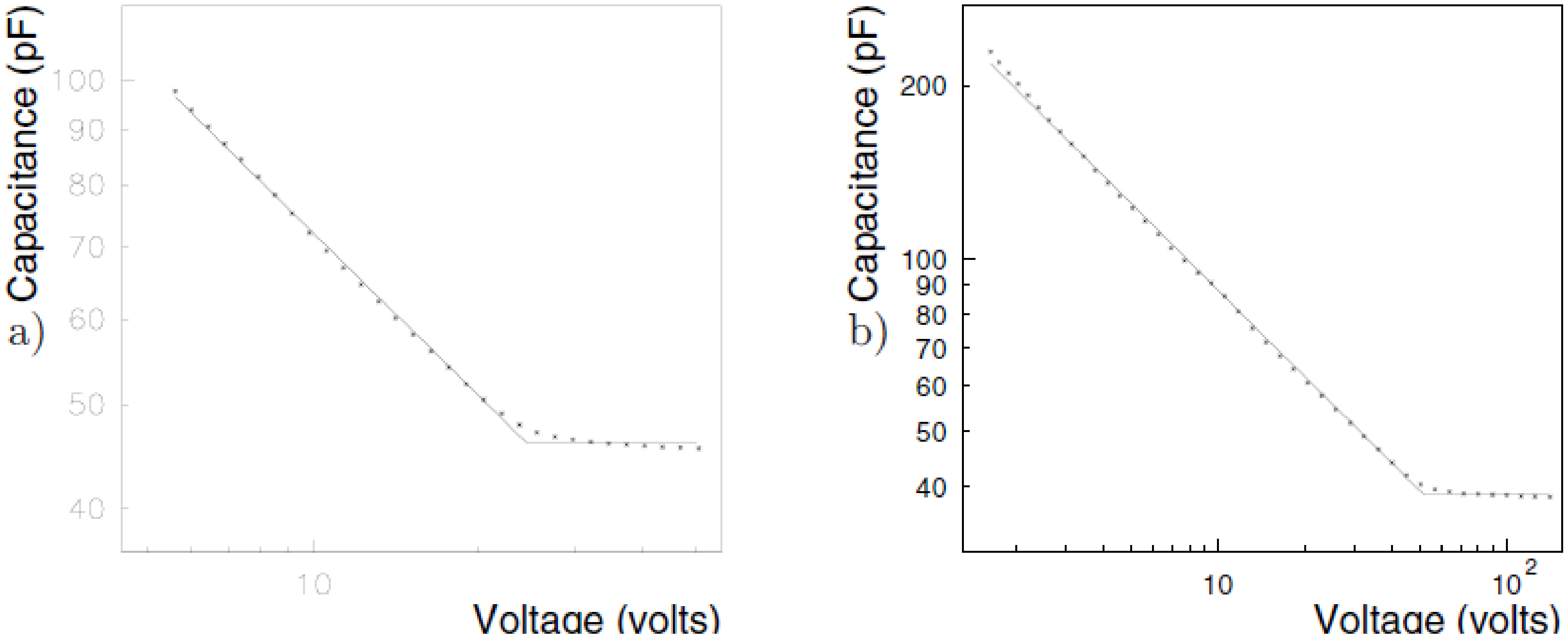


Fig. 6.3 Capacitance (in pF) curves as a function of applied voltage (in V) for two detectors of $1\,\mathrm{cm}^2$ area [Leroy (1998)]: (a) resistivity of $\rho = 8\,\mathrm{k}\Omega\mathrm{cm}$ and thickness $w = 247\,\mu\mathrm{m}$; (b) resistivity of $\rho = 6\,\mathrm{k}\Omega\mathrm{cm}$ and thickness $w = 300\,\mu\mathrm{m}$. The curve represents a fit of Eq. (6.34) to the data points.

Carica raccolta Vs V

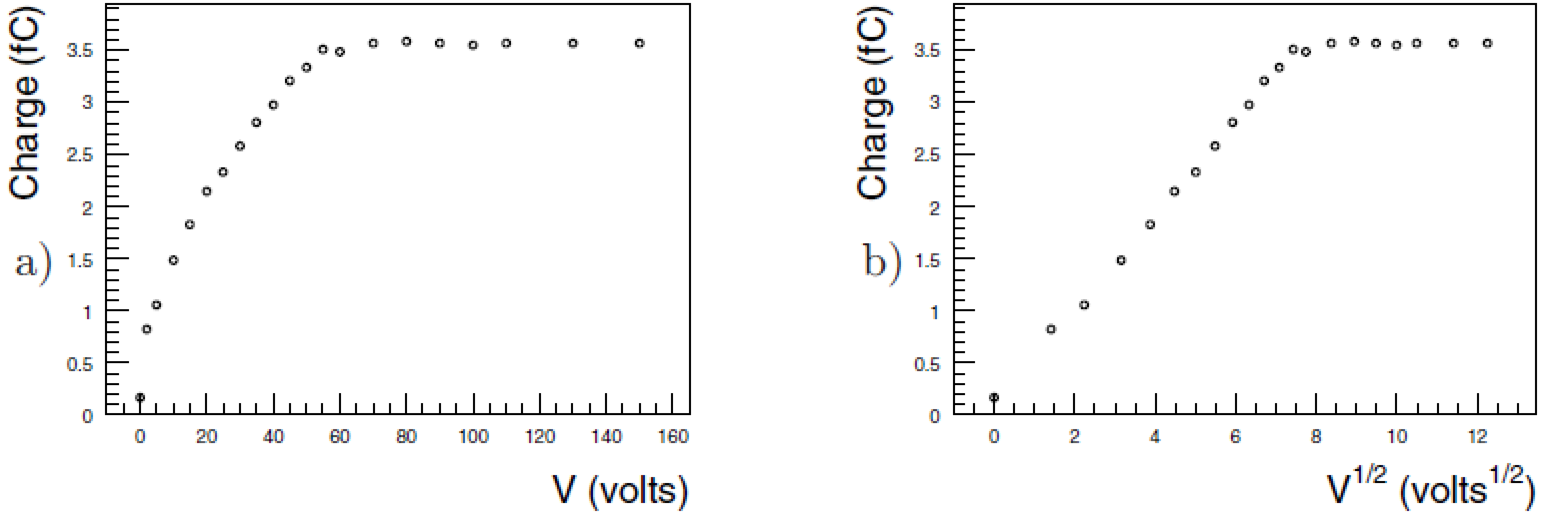


Fig. 6.4 Charge collected with a silicon detector 300 μm thick, area 1 cm^2, exposed to incoming electrons of energy larger than 2 MeV, as a function of the applied bias (a) and as a function of the square root of the applied voltage (b). The value of the full depletion voltage is 60 volts which corresponds to a collected charge of 3.5 fC, as expected from the most probable energy deposited by relativistic electrons in this detector [Leroy (1998)].

Segnale raccolto in funzione del tempo

Esempi:

giunzione p^+n
$d=300\ \mu m$
$A=1\ cm^2$
$\rho=23\ k\Omega\ cm$
$N_{eff} = 2.1 \times 10^{11}\ cm^{-3}$

Nota:

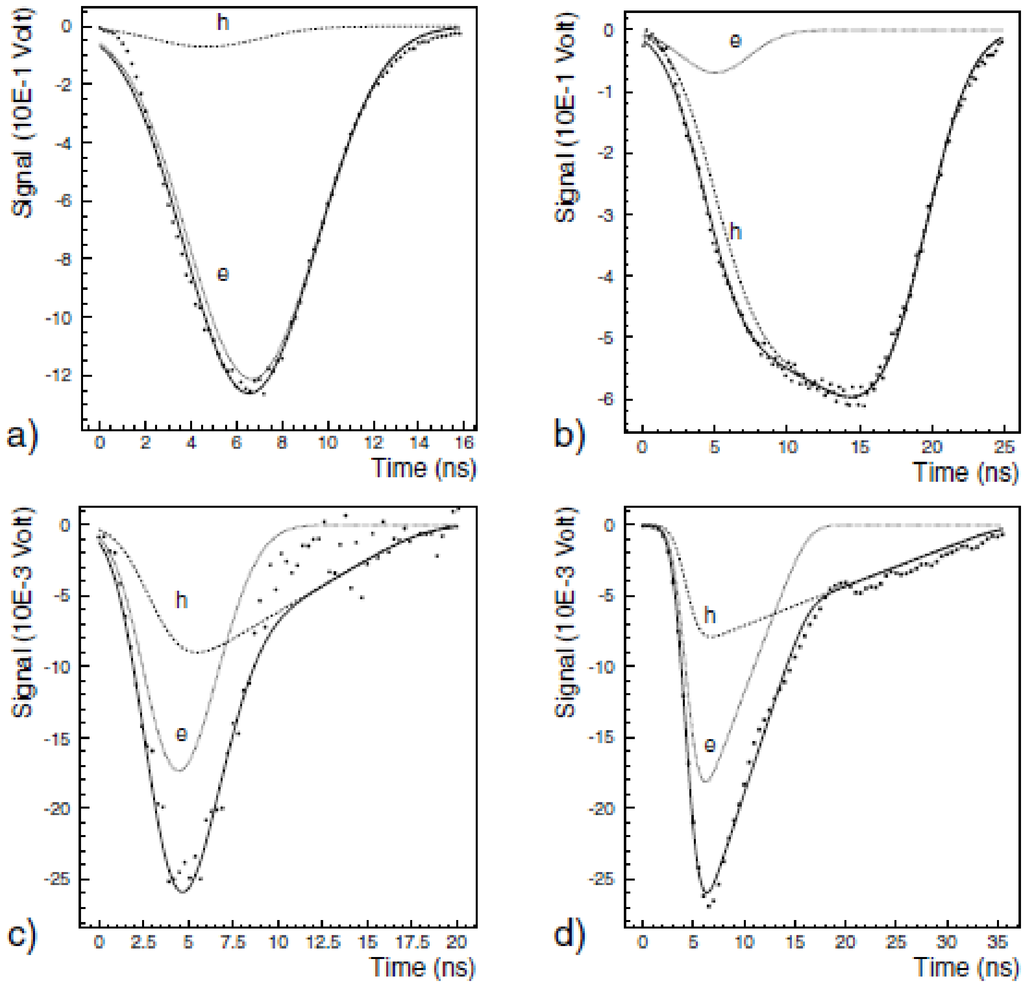
- α totalmente assorbita in qualche decina di μm: la carica generata e' localizzata da una o dall'altra parte della giunzione → contributi alla carica di e^- e h^+ differiscono a seconda della distanza dall'elettrodo:
- $Q_e = \frac{q}{w} * (w - x_0) \qquad Q_h = \frac{q}{w} * x_0$
- e^- MIP rilascia cariche lungo lo spessore
- picco delle lacune piu' esteso della distribuzione degli e^- perche' mobilita' minore

Entranti da p
Catodo (negativo)

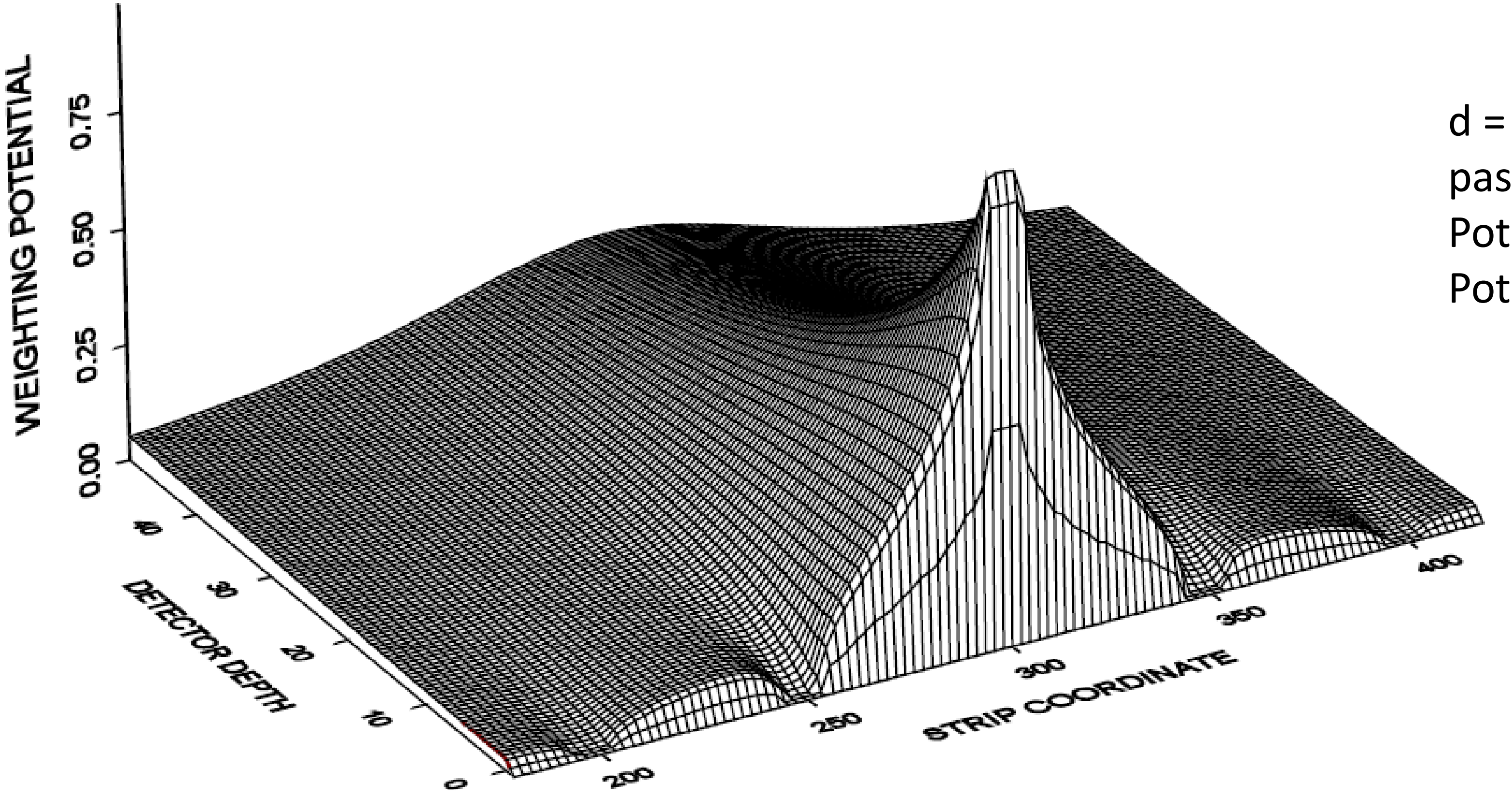
Entranti da n^+
Anodo (positivo)

Particella α
Emessa da
sorgente Am
E= 5.45 MeV

e^- relativistico
Emesso da Ru
MIP
E_i = 80 keV



Campo Peso in sensore a microstrisce

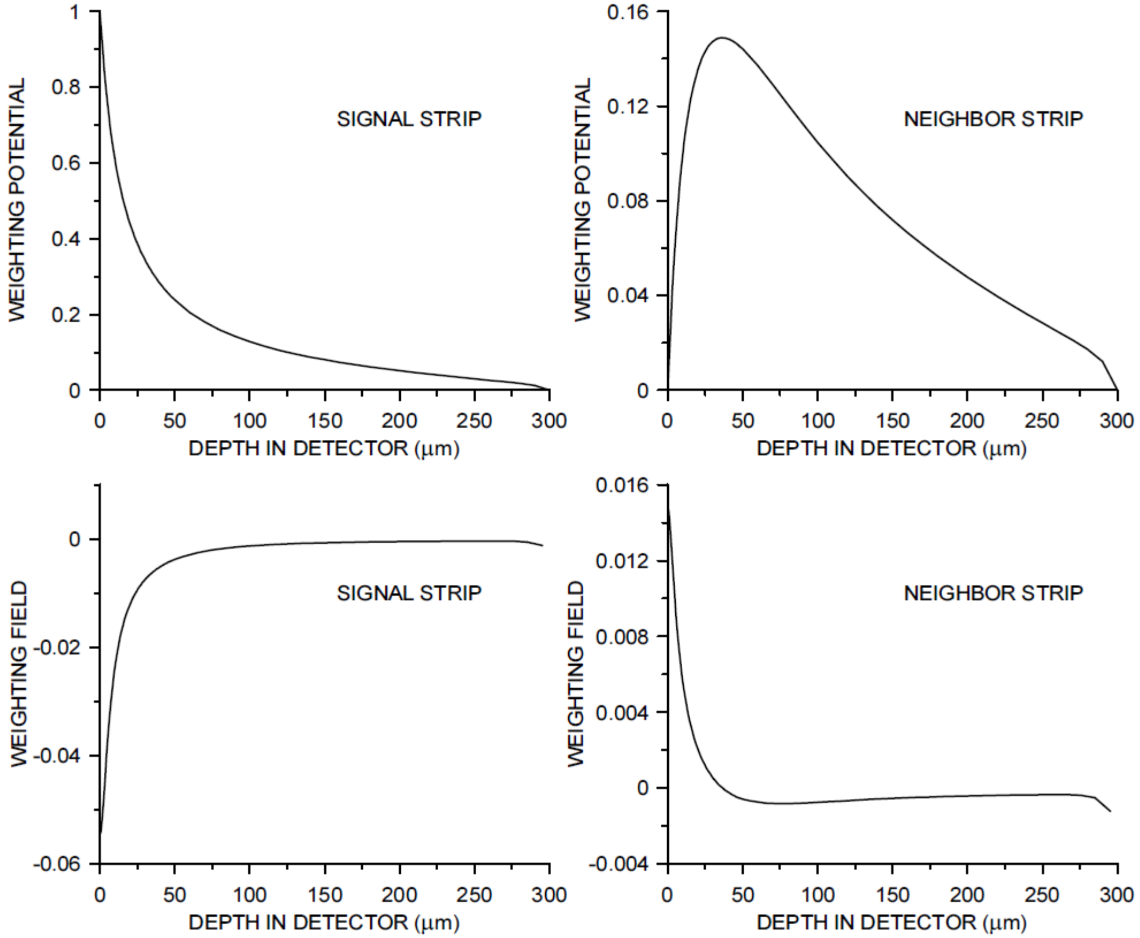


d = 300 um
passo = 50 um
Potenziale = 1 sulla strip letta
Potenziale = 0 sulle altre

Sezione trasversa del p. e c. peso in strip detector

Strip letta
Potenziale a 1

E_F aumenta monotono
Il segnale aumenta mano a mano che la carica si avvicina all'elettrodo



Strip vicina
Potenziale a 0

E_F scende fino a diventare negativo intorno a 40 um dall'elettrodo. Il segnale prima aumenta poi si inverte: l'integrale e' nullo