Rivelatori e Apparati

Lezione 2 – Tavole e grafici su perdita di energia e MCS

Confronto material budget rivelatori diversi

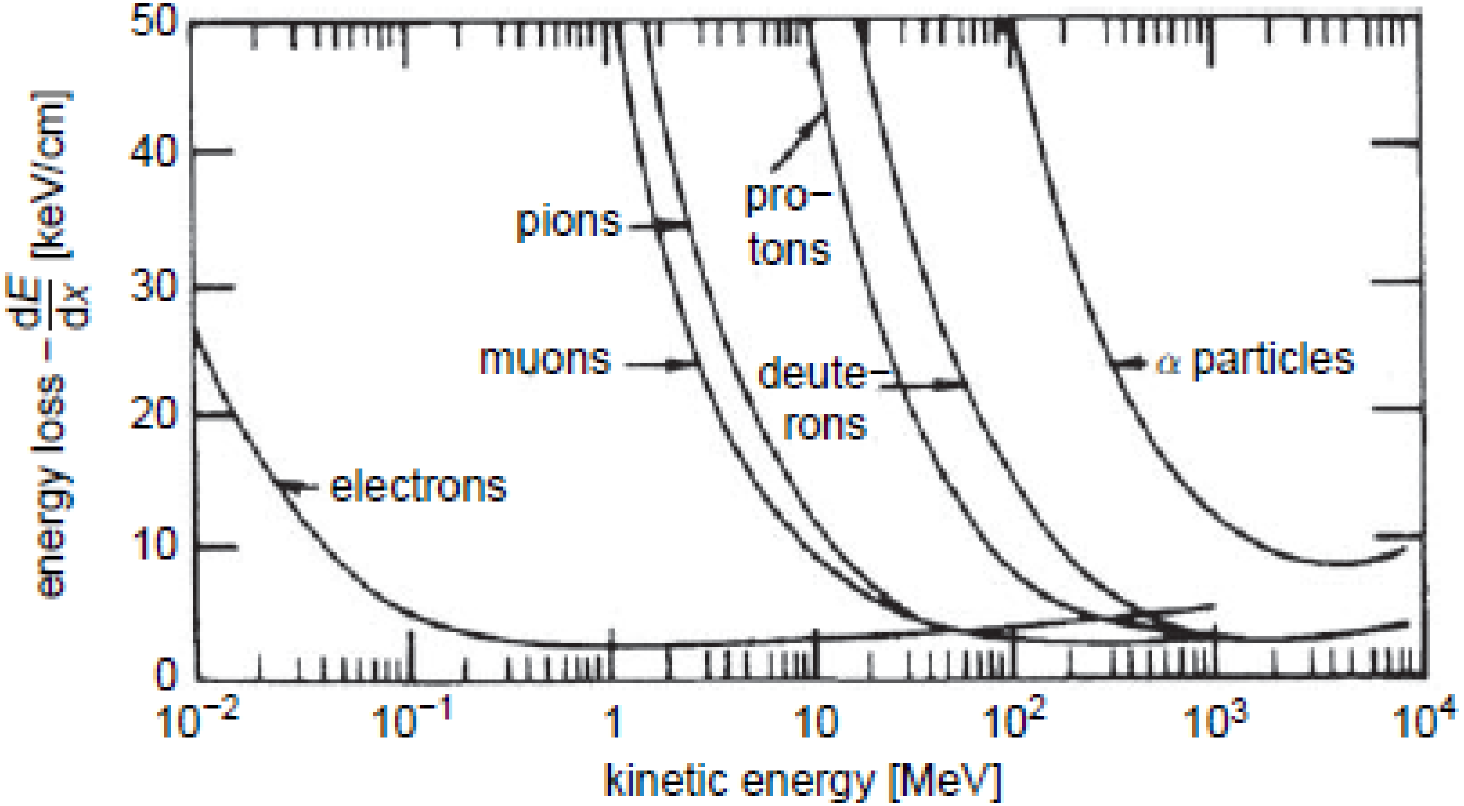


Fig. 1.2. Energy loss for electrons, muons, pions, protons, deuterons and α particles in air [14].

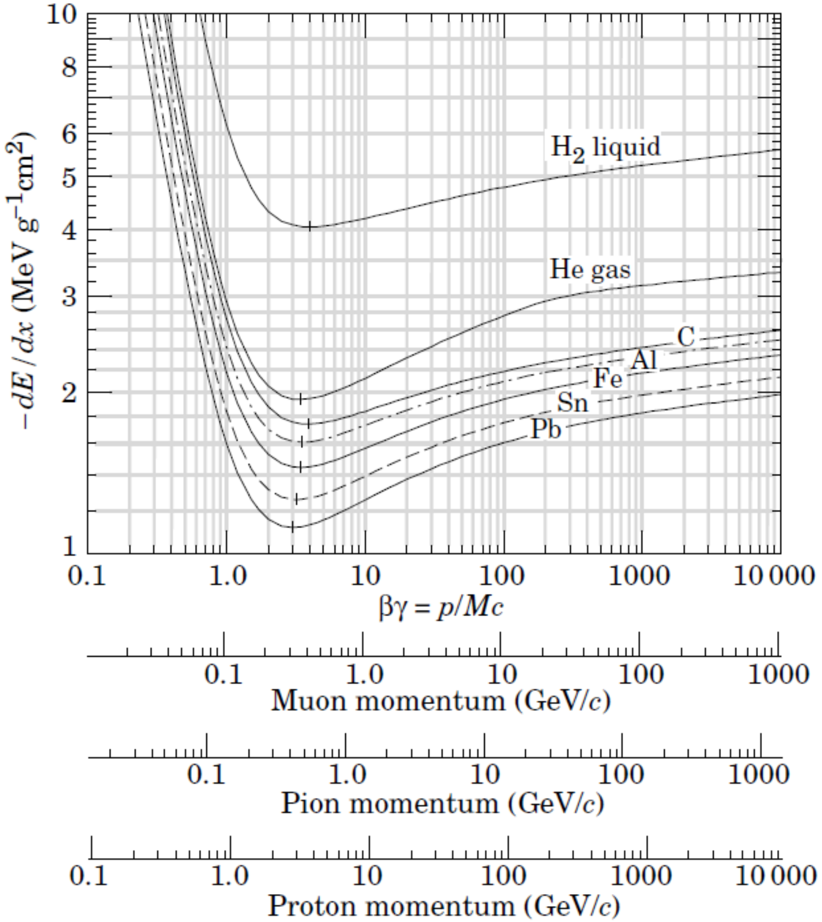


Figure 27.2: Mean energy loss rate in liquid (bubble chamber) hydrogen, gaseous helium, carbon, aluminum, iron, tin, and lead. Radiative effects, relevant for muons and pions, are not included. These become significant for muons in iron for $\beta\gamma \gtrsim 1000$, and at lower momenta for muons in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

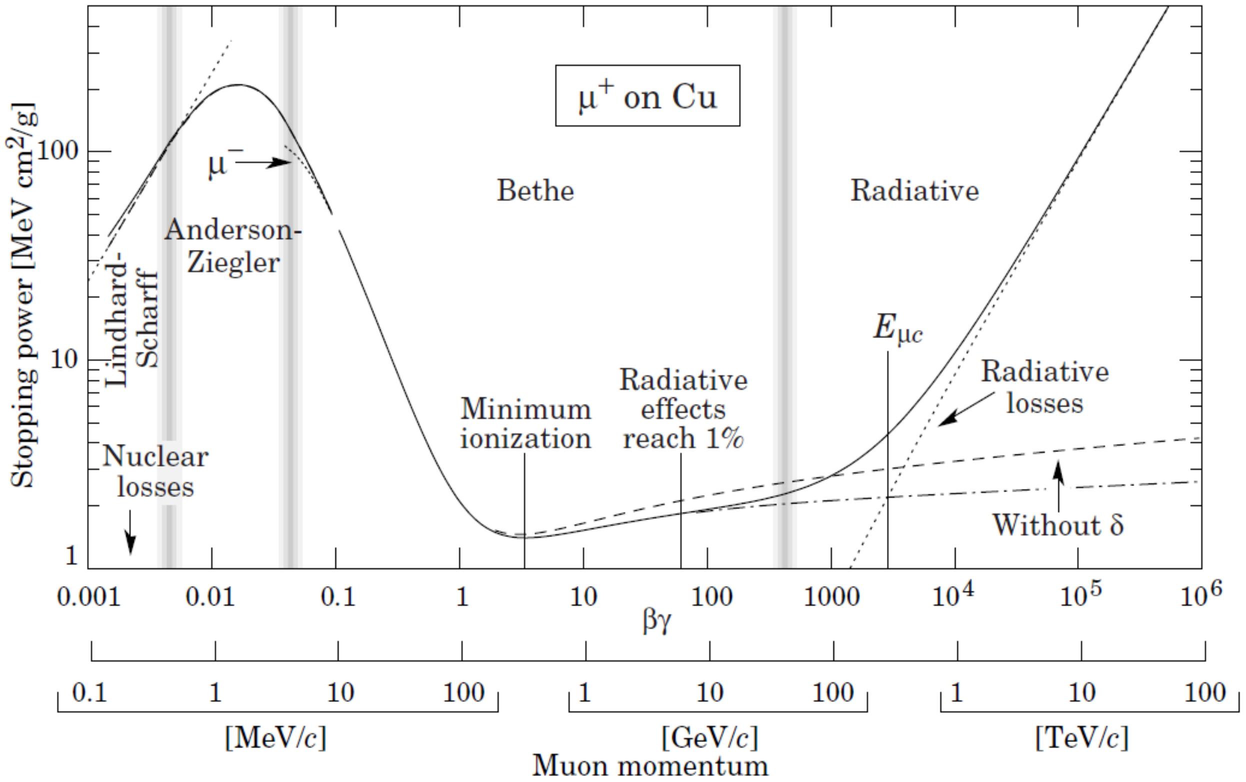


Fig. 27.1: Stopping power ($= \langle -dE/dx \rangle$) for positive muons in copper as a function of $\beta\gamma = p/Mc$ over nine orders of magnitude in momentum (12 orders of magnitude in kinetic energy). Solid curves indicate the total stopping power. Data below the break at $\beta\gamma \approx 0.1$ 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].

Grafici dE/dx

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

Absorber	$\frac{dE}{dx}\big\|_{min} \left[\frac{MeV}{g/cm^2}\right]$	$\frac{dE}{dx}\big\|_{min} \left[\frac{MeV}{cm}\right]$
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 $\times10^{-4}$	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 $\times10^{-3}$	0.74	1.754	4.321	0.118	3.291	0.00
Ne	10	0.496	137.0	8.36 $\times10^{-4}$	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 $\times10^{-3}$	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 $\times10^{-3}$	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 $\times10^{-3}$	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.

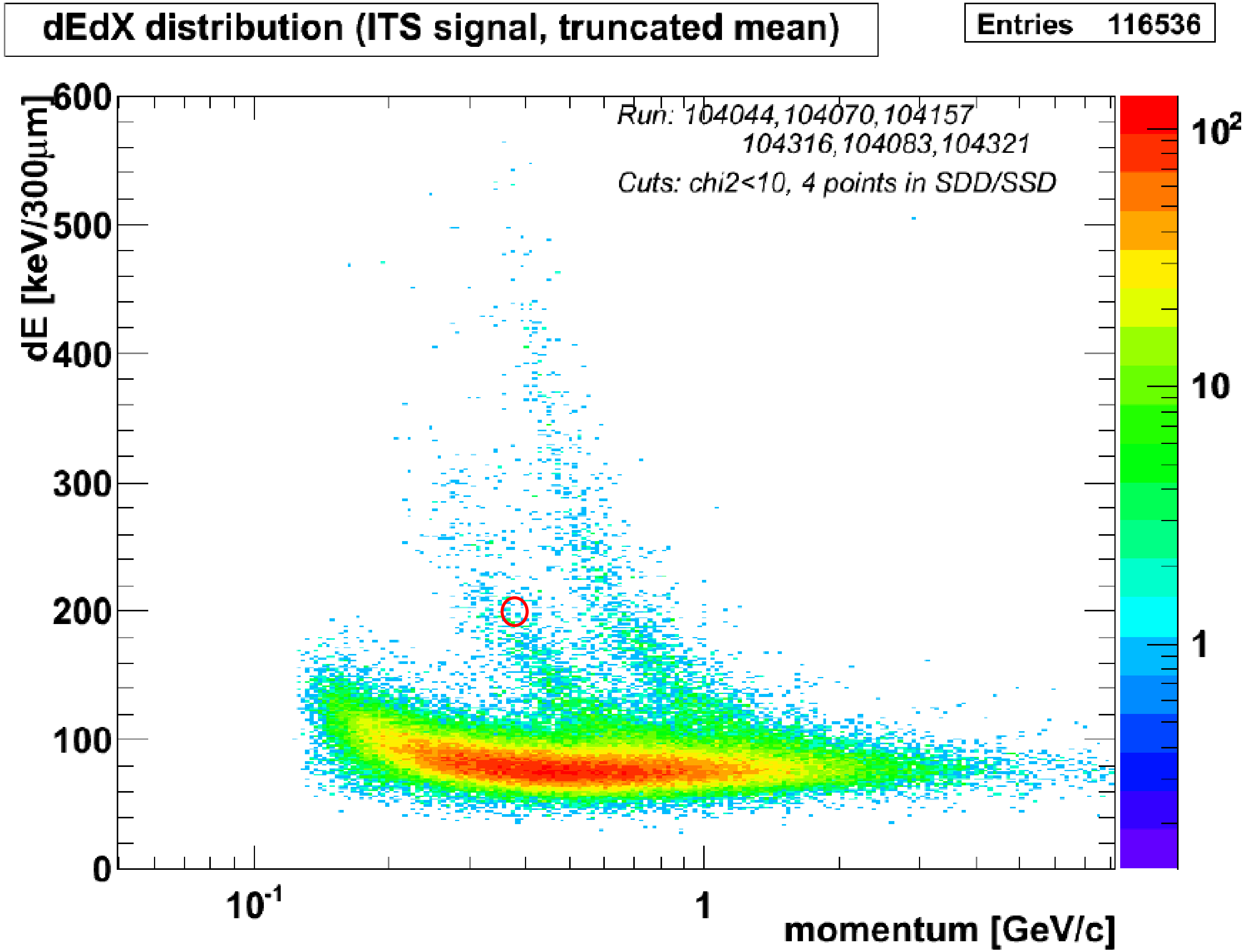
Material	Z/A	I eV	ρ g/cm^3	$h\nu_p$ eV	S_0	S_1	a	md
(dry) Air at sea level	0.499	85.7	1.21 $\times10^{-3}$	0.71	1.742	4.276	0.109	3.399
Anthracene	0.527	69.5	1.28	23.70	0.115	2.521	0.147	3.283
Ethane	0.599	45.4	1.25 $\times10^{-3}$	0.79	1.511	3.874	0.096	3.610
Ethyl Alcohol	0.564	62.9	0.79	19.23	0.222	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 $\times10^{-4}$	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 $\times10^{-3}$	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 $\times10^{-3}$	0.70	1.644	4.140	0.099	3.471
Tissue-equiv., gas (propane base)	0.550	59.5	1.83 $\times10^{-3}$	0.91	1.514	3.992	0.098	3.516

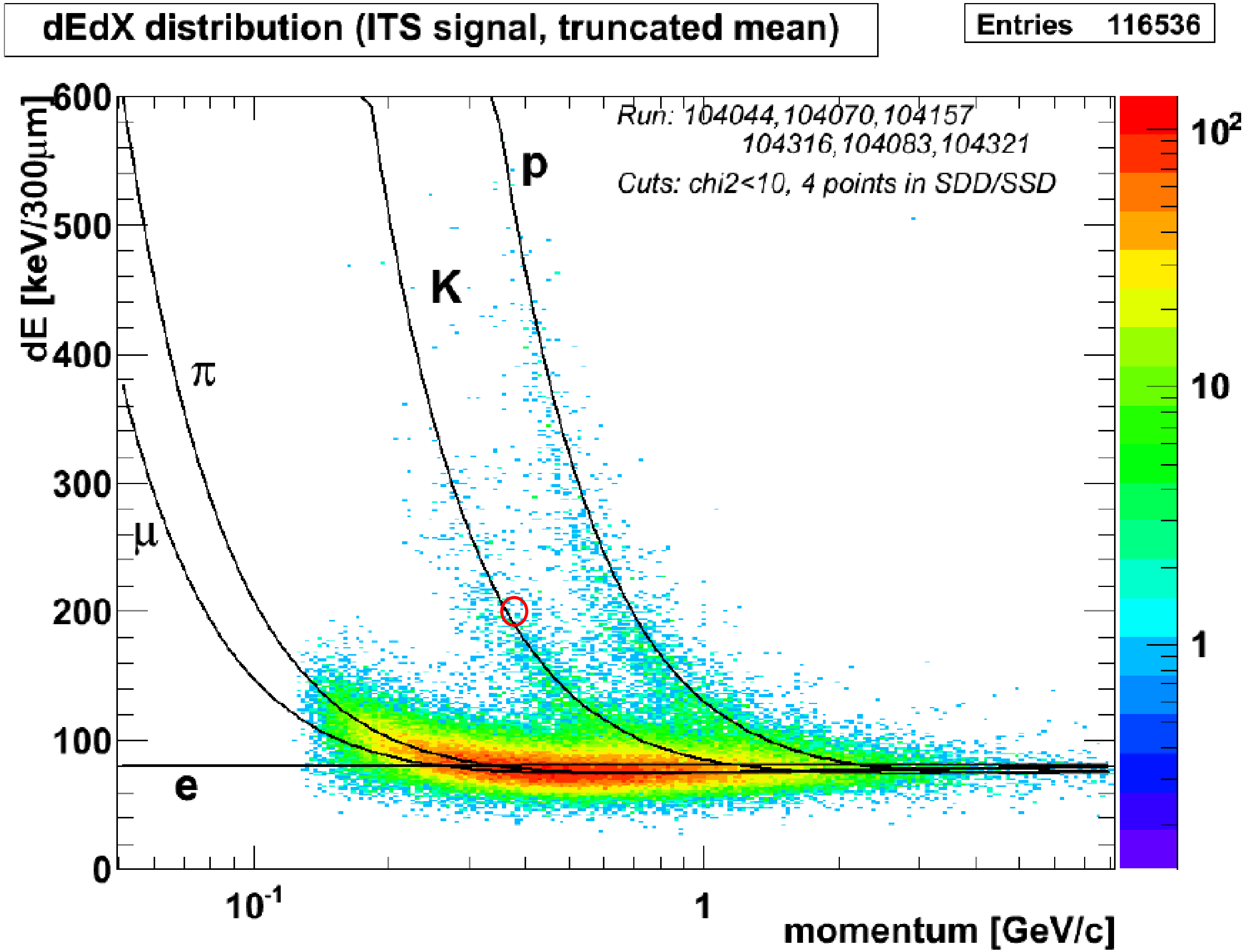
Data are from [Sternheimer, Berger and Seltzer (1984)]

- Istogramma a dispersione carica ricostruita da 4 misure

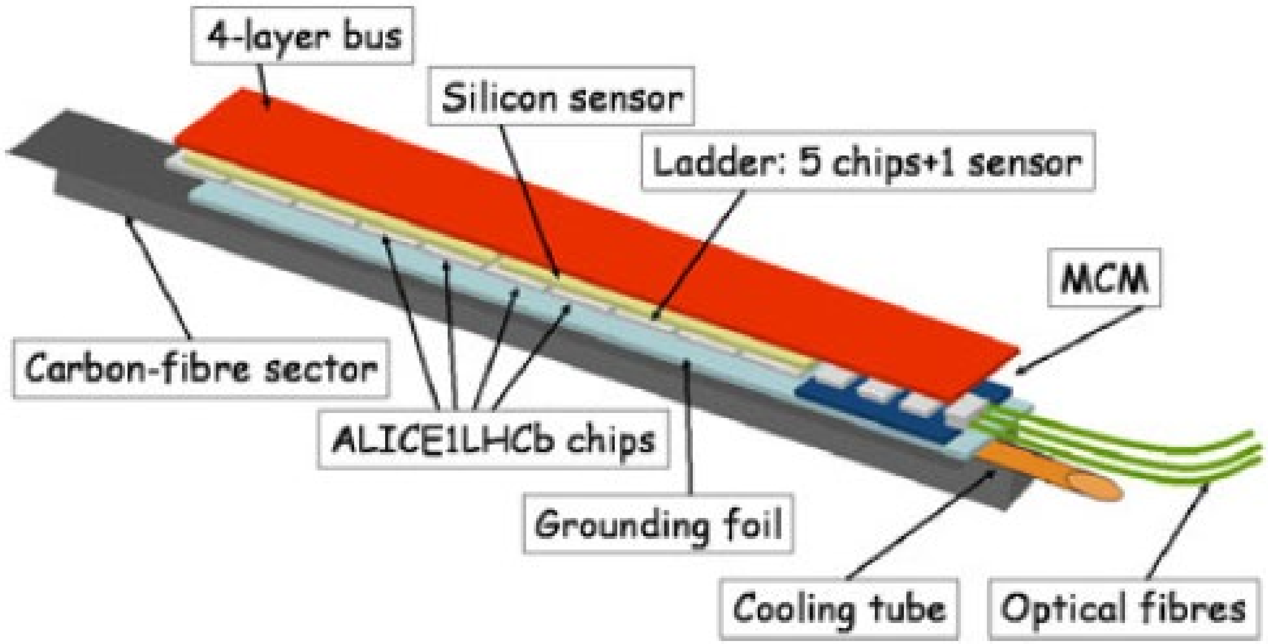
- Esempio: 200 keV @ quantita' di moto p=400 MeV/c

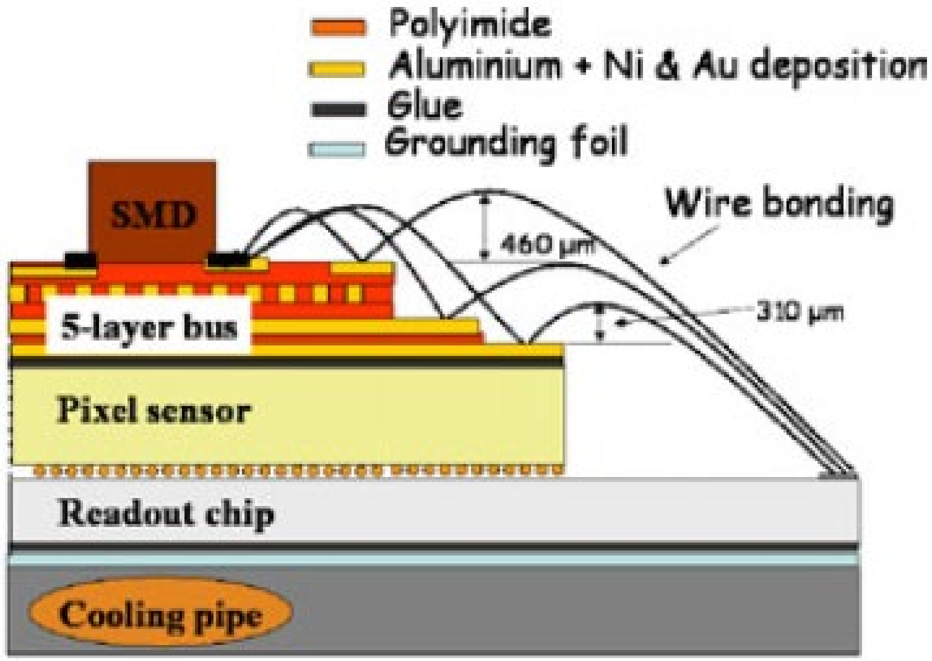
- Che tipo di particella e'?

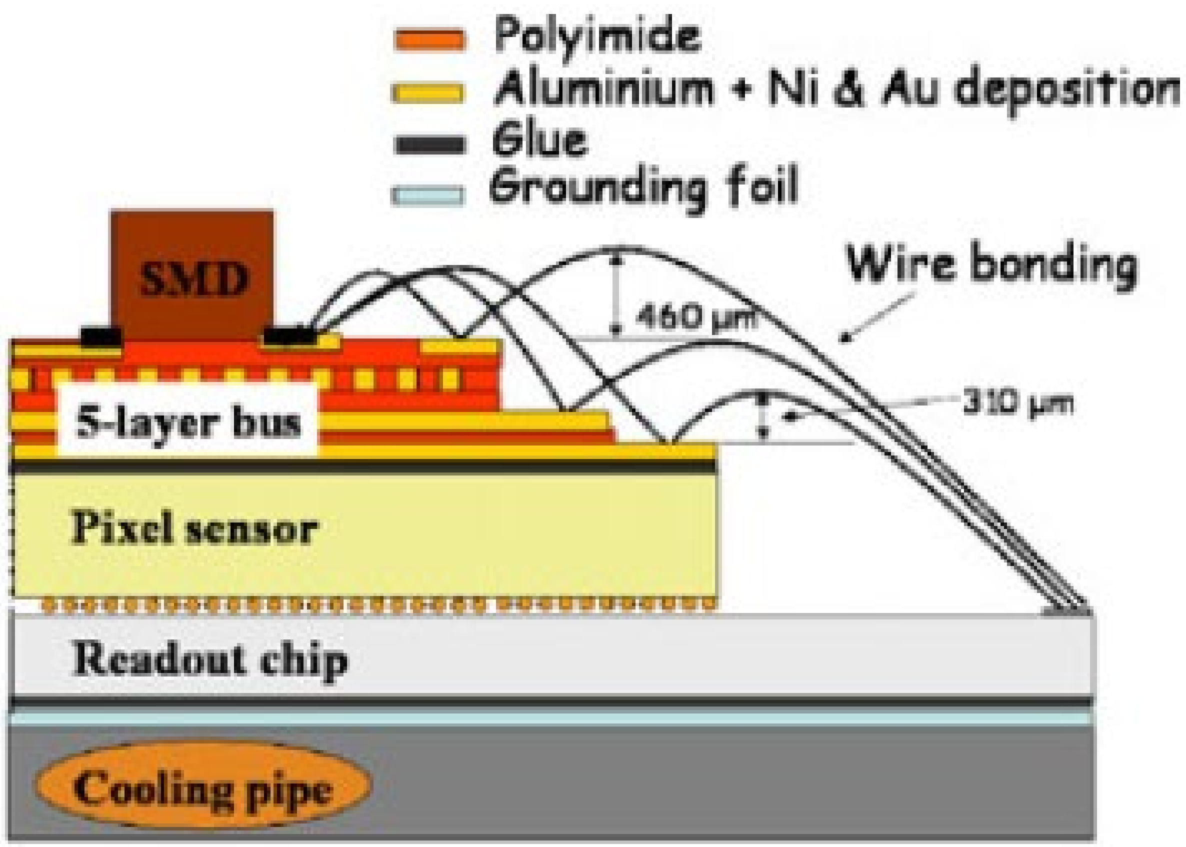



dEdX distribution (ITS signal, truncated mean)
Entries 116536
Run: 104044,104070,104157
104316,104083,104321
Cuts: chi2<10, 4 points in SDD/SSD
dE [keV/300μm]
momentum [GeV/c]
p
K
π
μ
e
0
100
200
300
400
500
600
10^{-1}
1
10^2
10
1

Silicon Pixel Detector – ALICE (2008 – 2019)



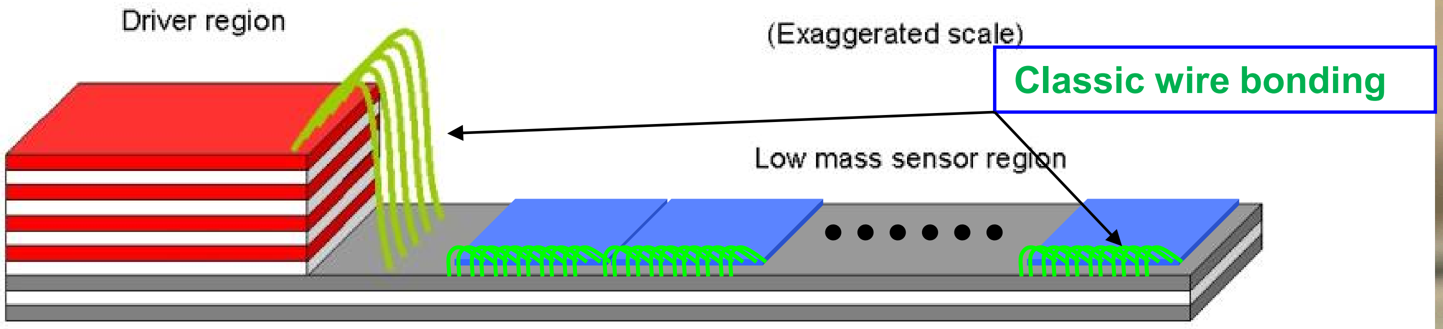


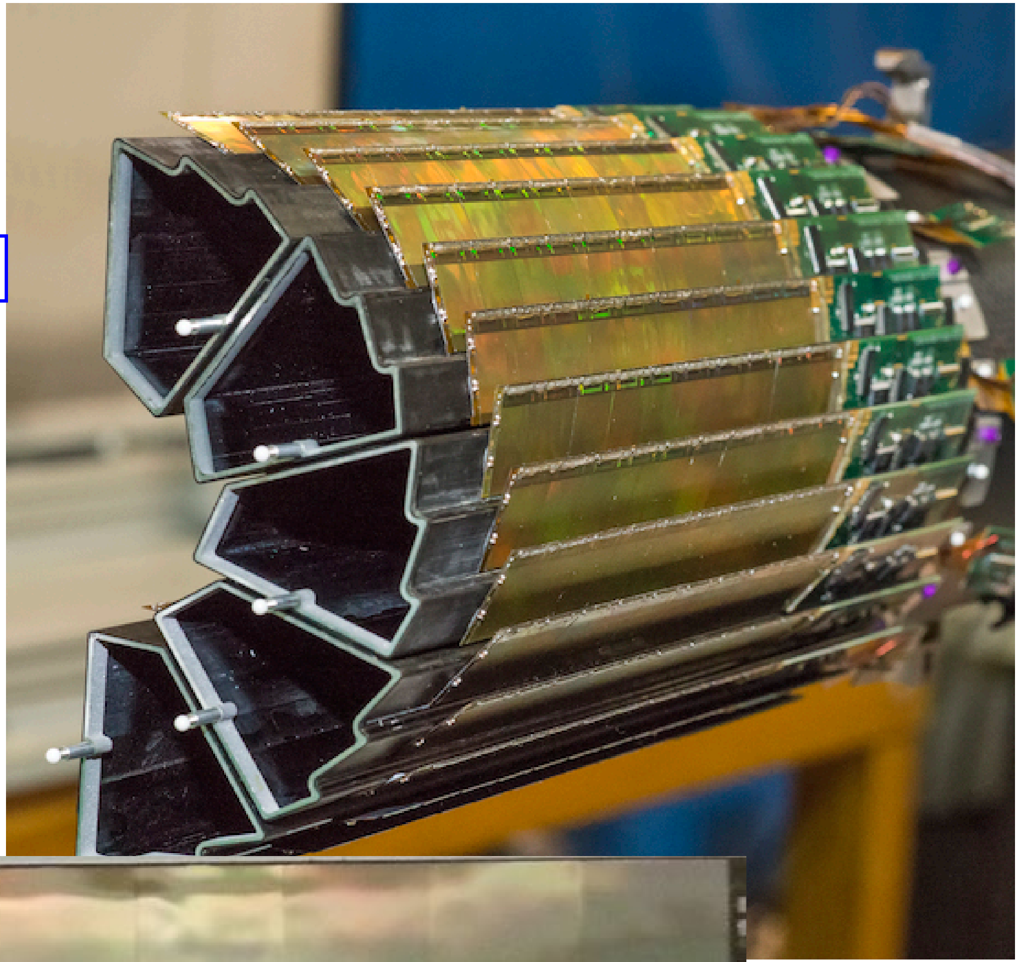


SPD Element	Thickness µm	% X_0
Al Bus		
Kapton	60	0.021
Al power	100	0.112
Al signals [50% of total surface]	17.5	0.020
Glue Epoxy	70	0.016
SMD components	16.4	0.173
Total bus		**0.341**
Other Components		
Pixel chip	150	0.160
Sensor	200	0.214
Bump bonds Sn 60%+Pb 40%	0.18+0.12	0.004
Grounding Foil-Kapton/Al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

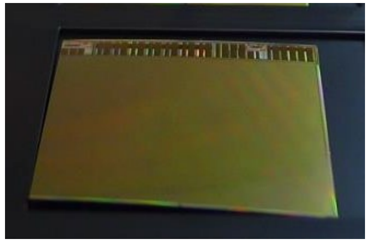
HFT Pixel detector – STAR (BNL) – 2014-2016





PXL Material Budget

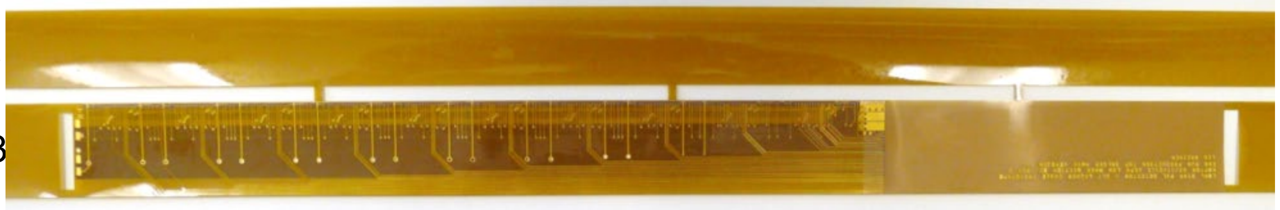
- Thinned Sensor
  - 50 μm
  - 0.068% X_0



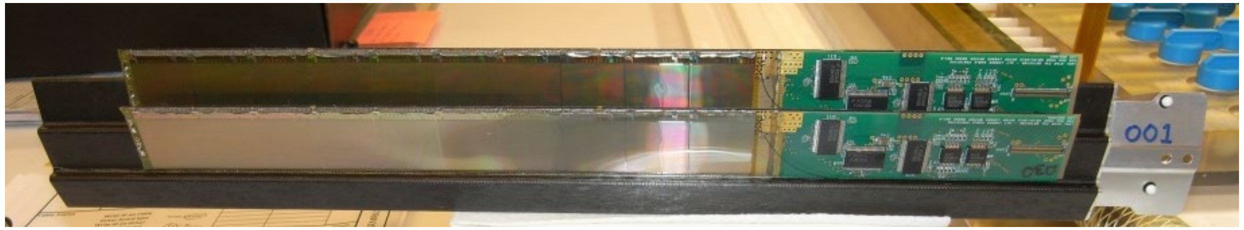
- Curved sensor
- 40-60% yield after thinning, dicing and probe testing
- Fully characterized before installation

- 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)

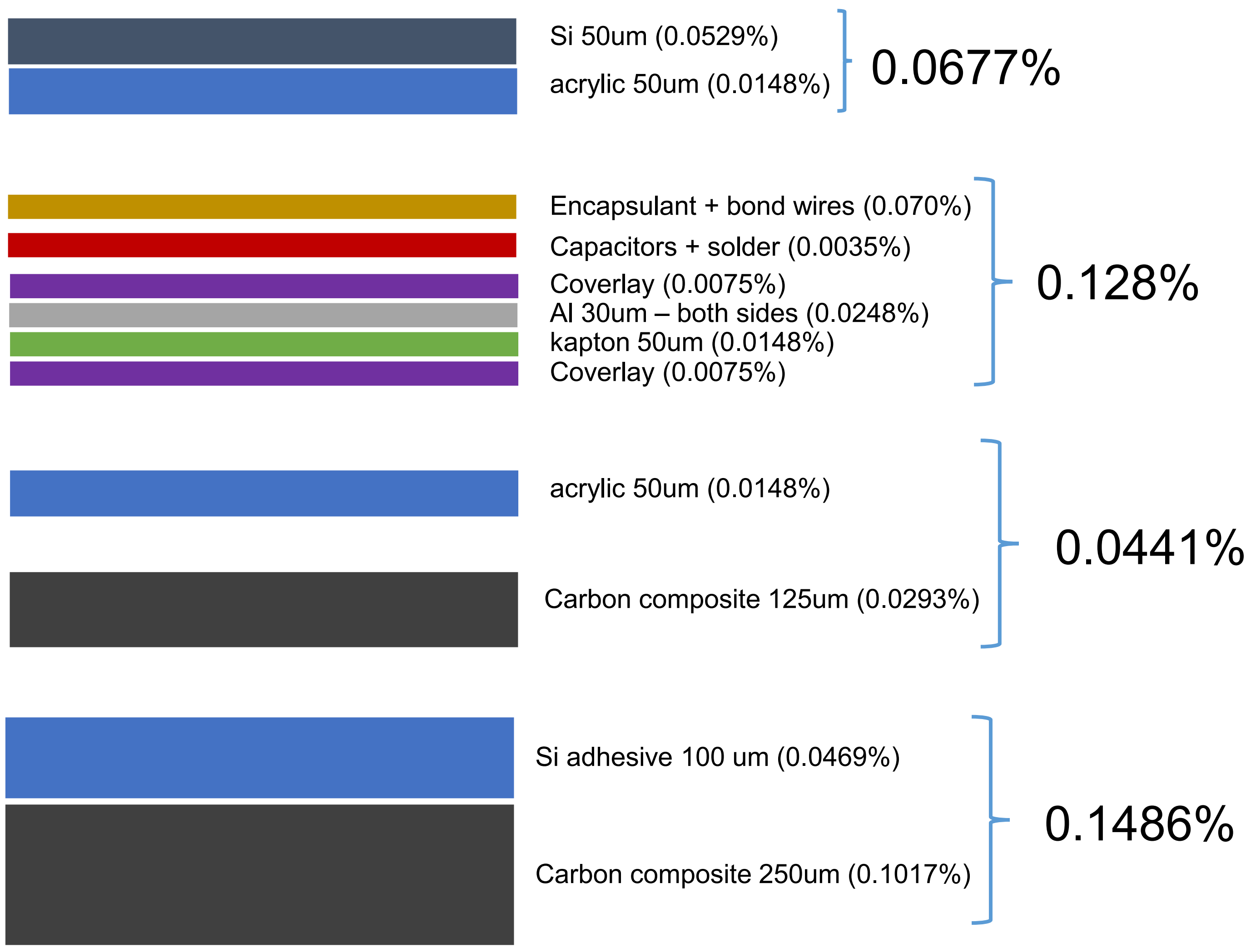
SPD

Material budget comparison

HFT

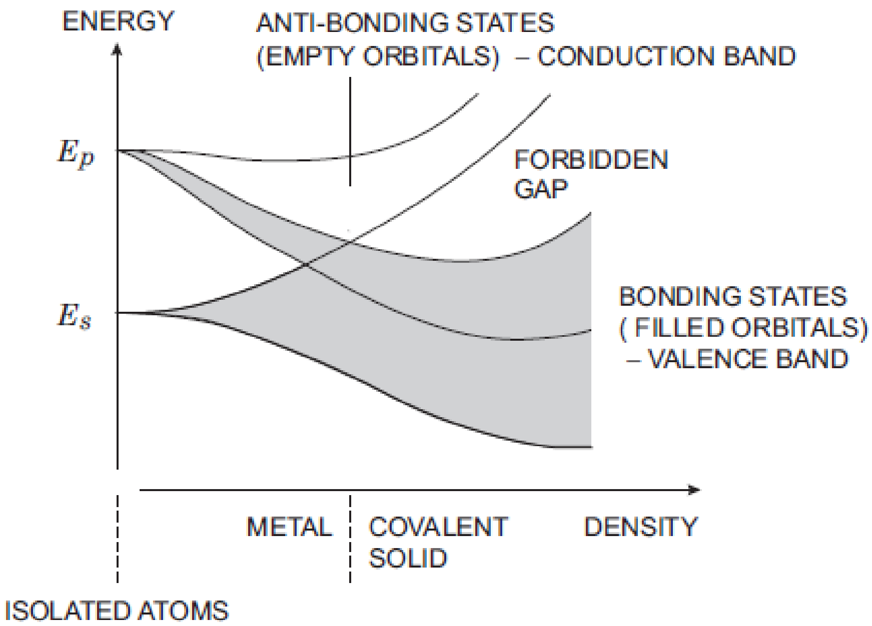
SPD Element	Thickness μm	% X_0
Al Bus		
Kapton	60	0.021
Al power	100	0.112
Al signals [50% of total surface]	17.5	0.020
Glue Epoxy	70	0.016
SMD components	16.4	0.173
Total bus		**0.341**
Other Components		
Pixel chip	150	0.160
Sensor	200	0.214
Bump bonds Sn 60%+Pb 40%	0.18+0.12	0.004
Grounding Foil-Kapton/Al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



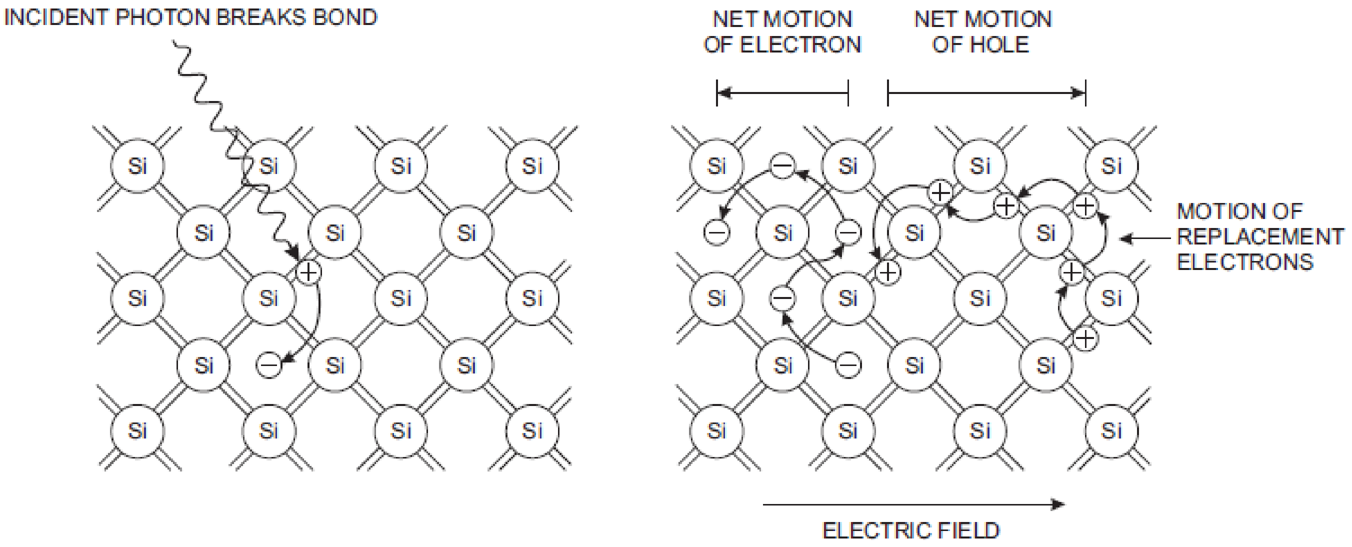


FIG. 2.7. An incident particle can break a bond, promoting an electron into the conduction band, so it can move freely. The vacant bond with positive net charge can also move by successively "borrowing" electrons from neighboring bonds. (Following Shockley 1950.)