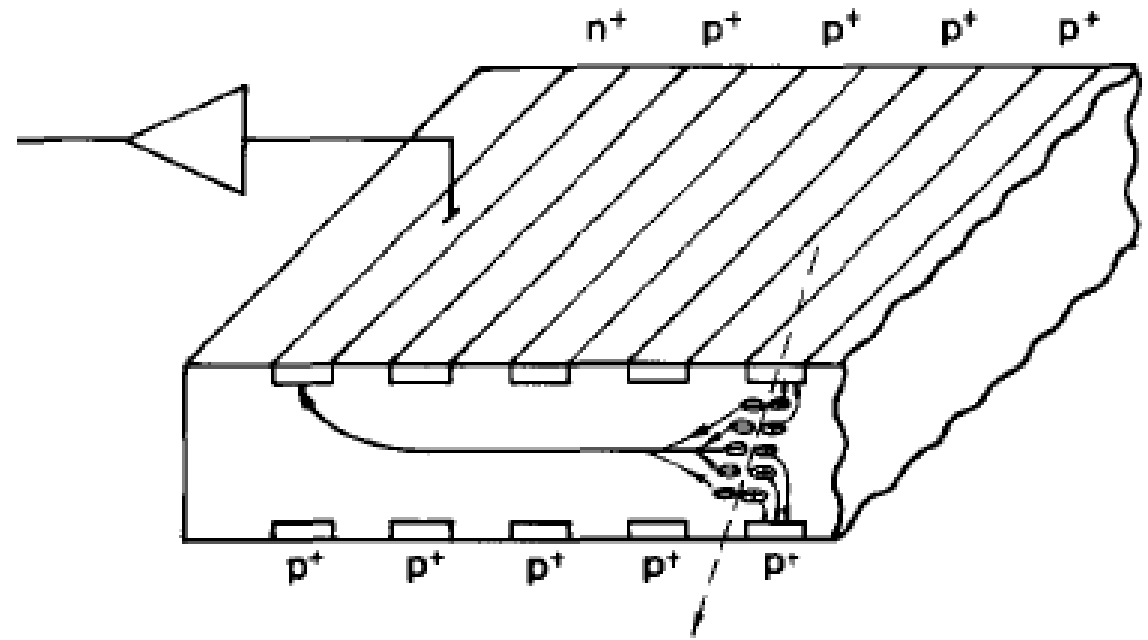
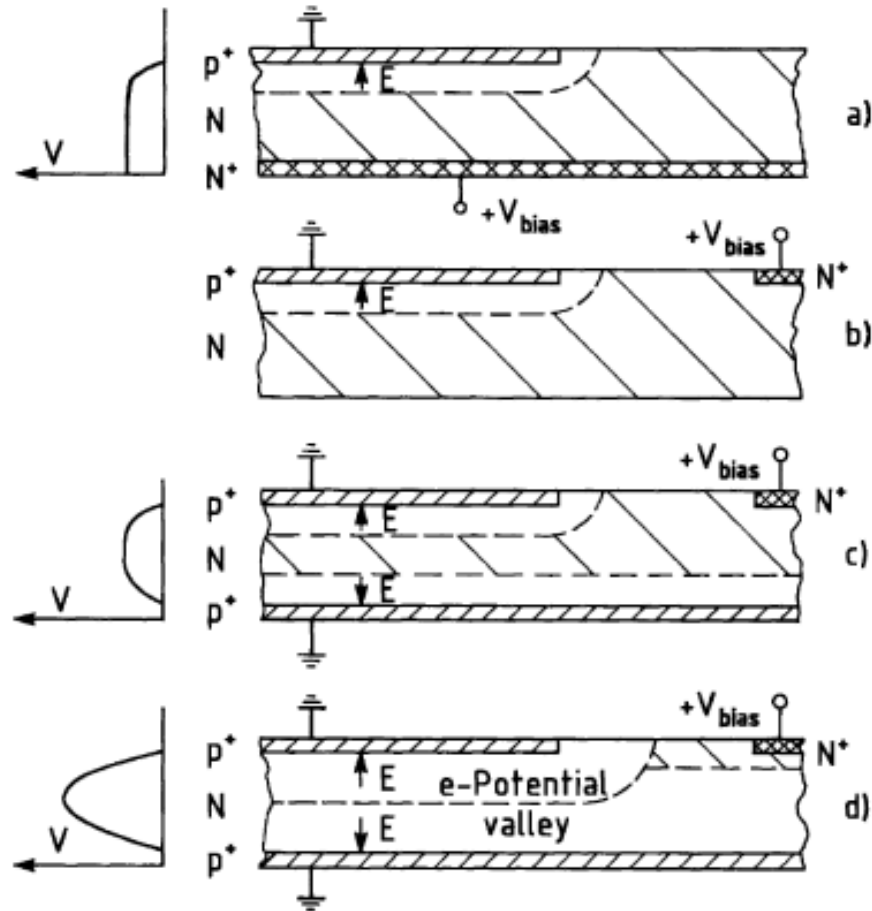


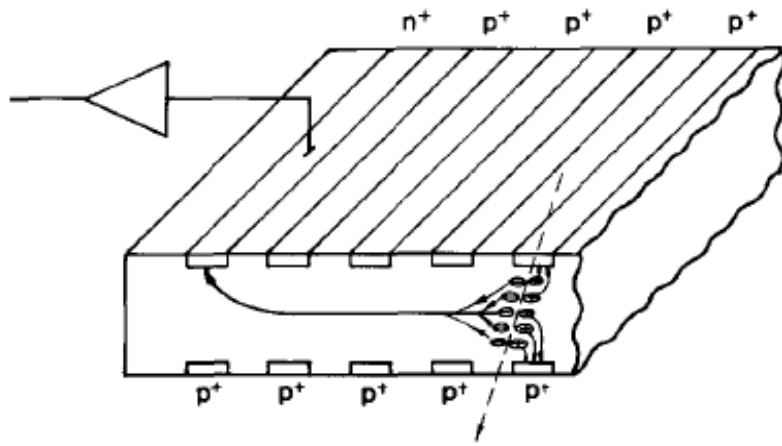
Rivelatori e Apparati

Slides_6 – Deriva di silicio

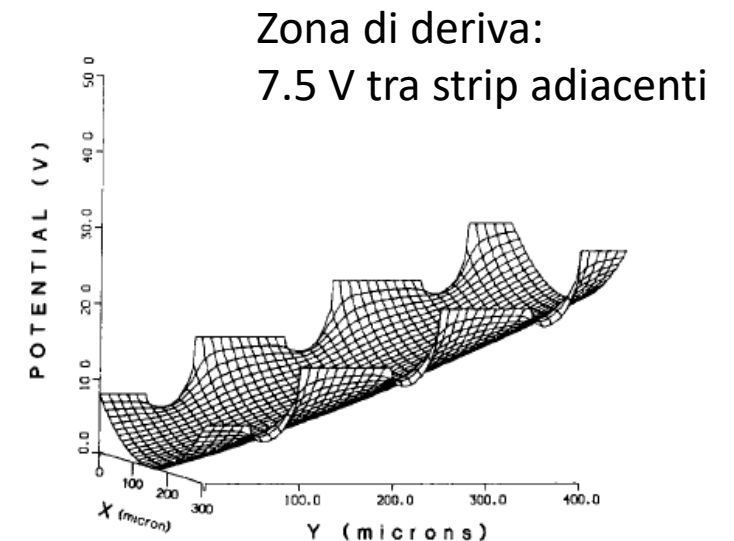
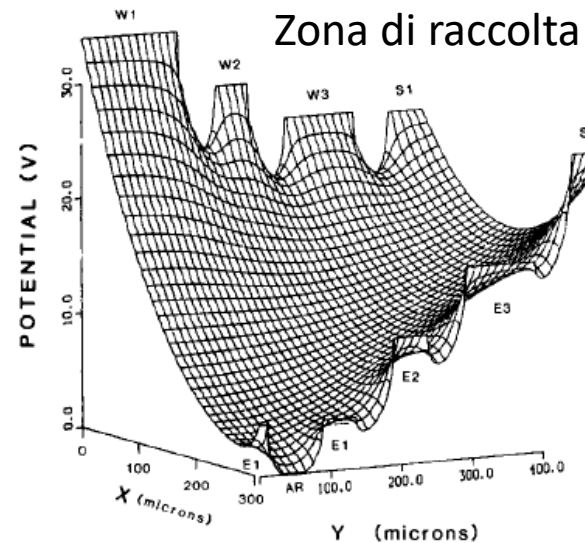
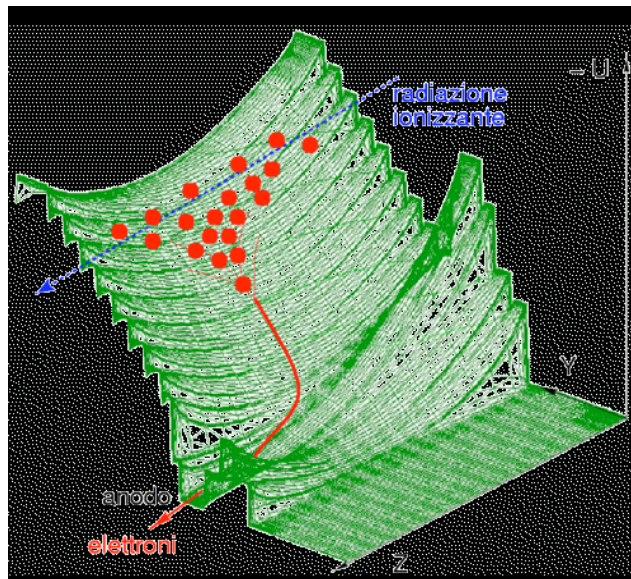
Verso i rivelatori a drift (deriva) di silicio



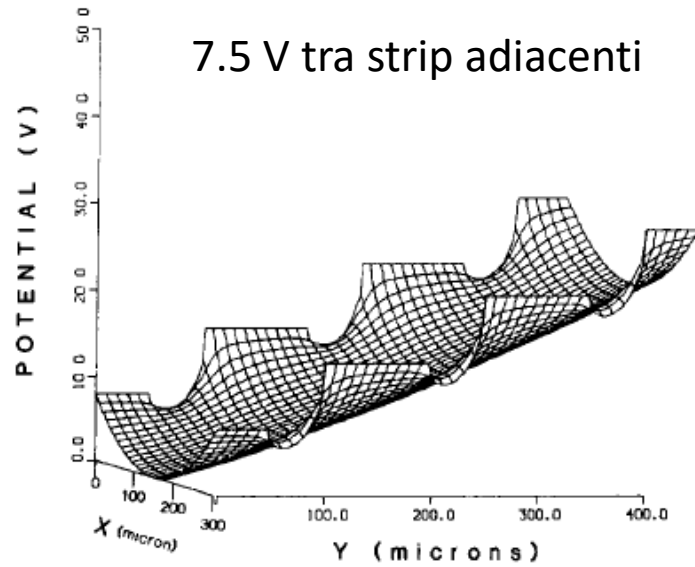
Silicon Drift Detector – Deriva di silicio



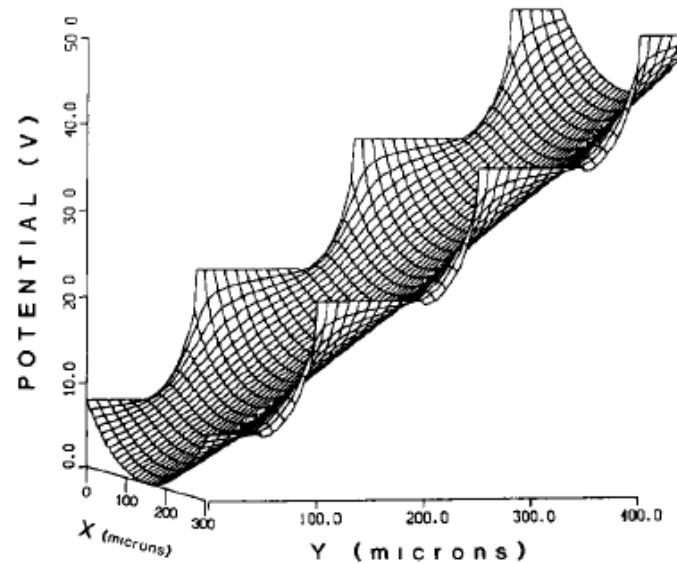
- Regione di deriva: minimo potenziale sul piano di simmetria dello spessore, decresce lungo la direzione perpendicolare alle strip p+
 - Il potenziale viene formato fornendo la differenza di potenziale tra la prima e ultima strip, e diviso grazie a corrente di lacune che fluisce tra le strip non connesse a bias, finche esse si posizionano a livelli equidistanti nel potenziale
- Regione di raccolta: potenziale ha un'asimmetria verso l'anodo di raccolta, anche aiutato da un contropotenziale sul lato opposto



Limitazioni potenziale tra strip p+



15 V tra strip adiacenti

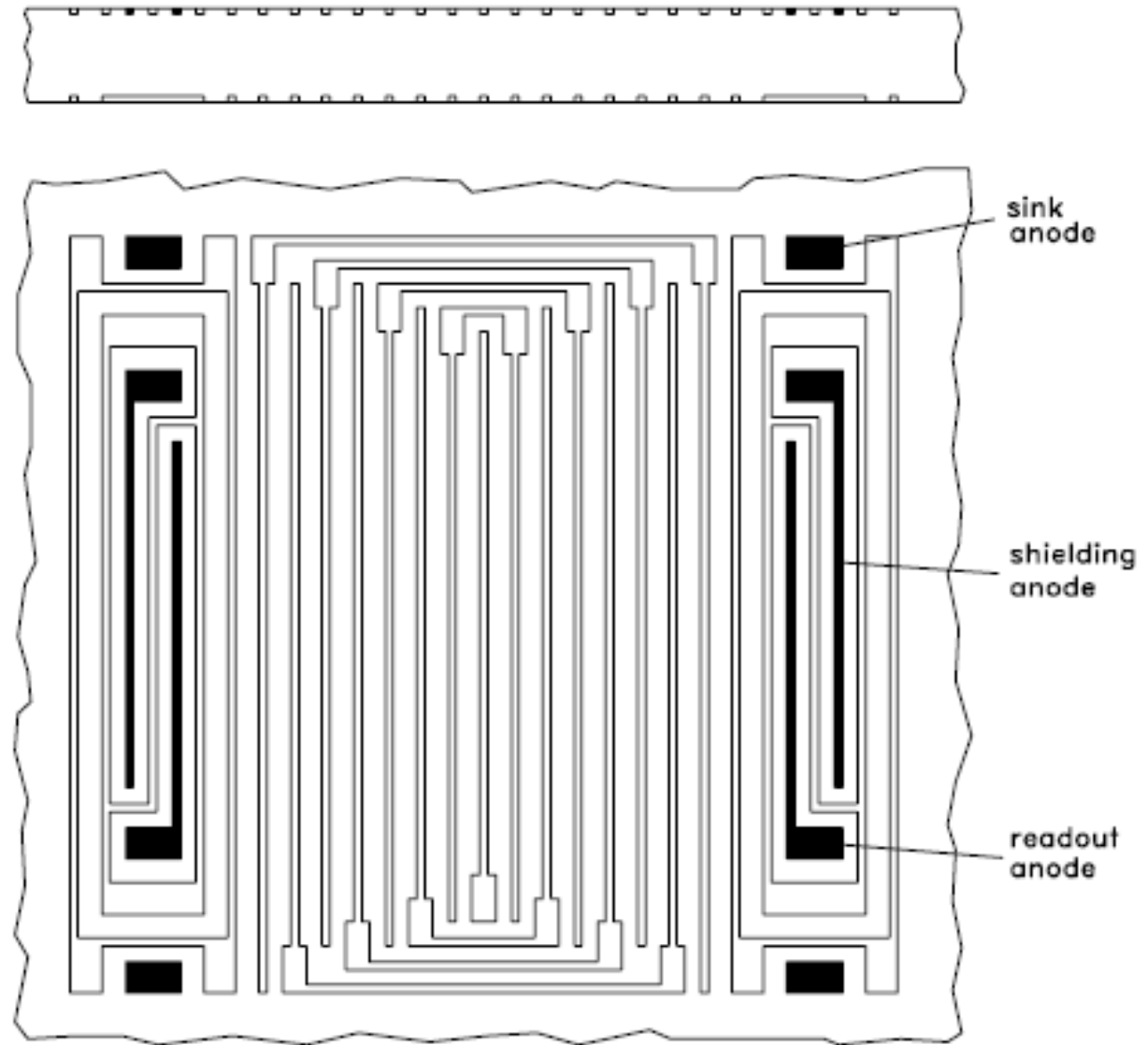


- Potenziale degli e- cala in tutte le direzioni dal contatto p+: non ci può essere flusso di buche
- Le resistenze esterne sulle due strip estreme limitano la corrente.
- La tensione viene divisa con collegamento a catena tra strip vicine.
- Alimentarle tutte esternamente provoca una corrente elevata di lacune.

- Non si può aumentare più di tanto la differenza di potenziale tra strip p+, altrimenti si annulla la barriera di potenziale per le buche: si creerebbe una grande corrente di buche tra strip p+ adiacenti

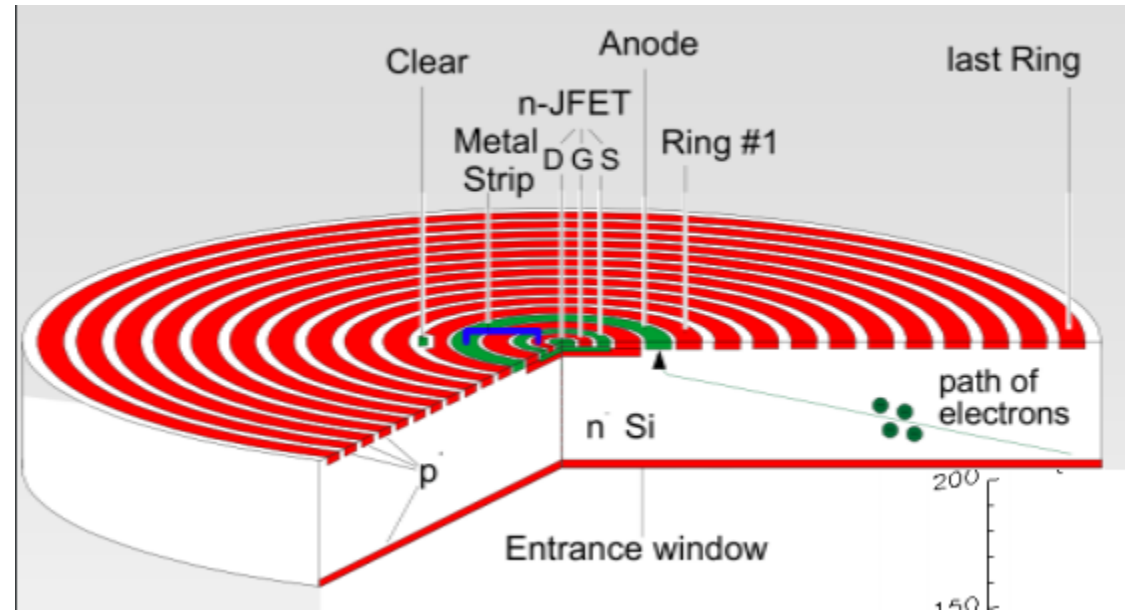
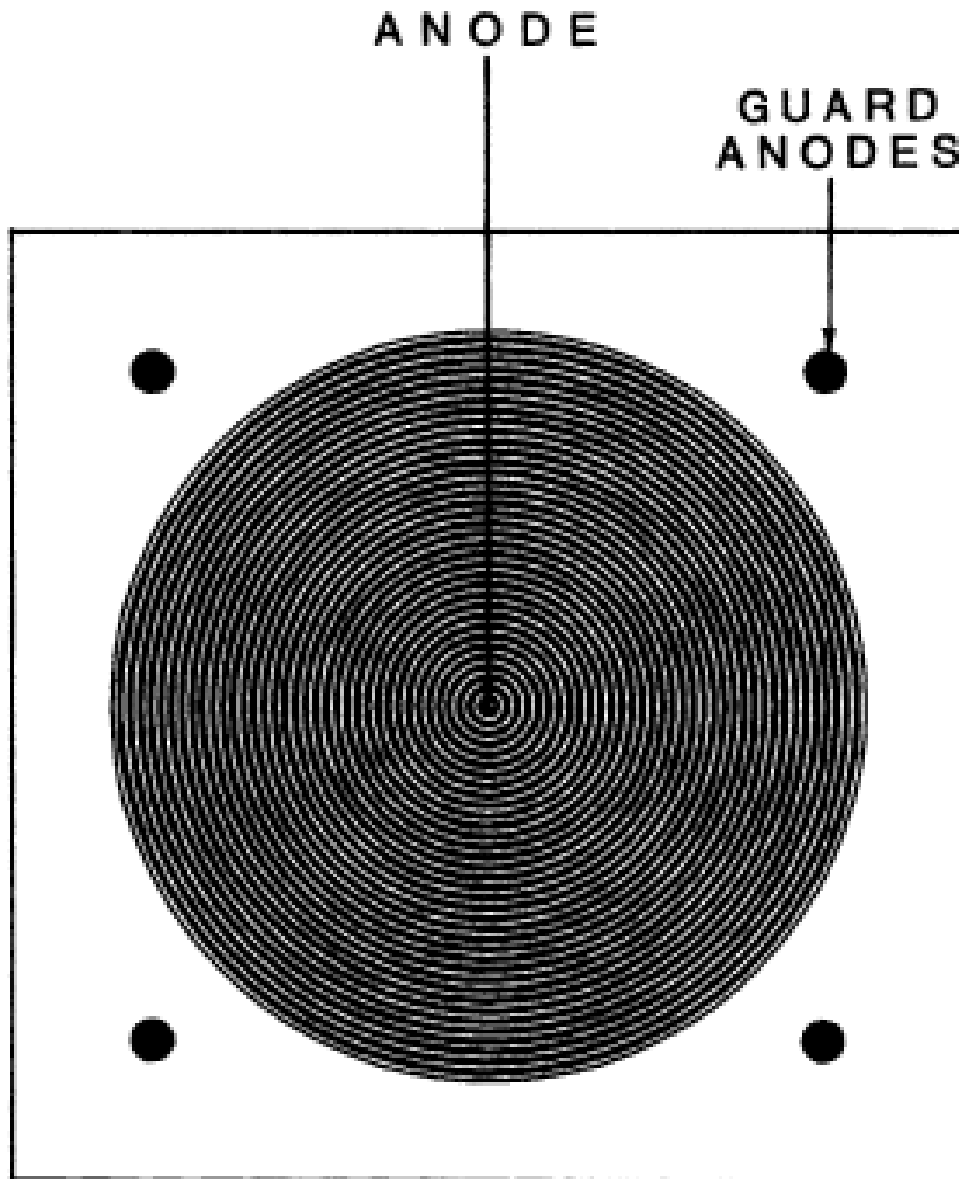
Per misura di posizione

Simmetria rispetto all'asse centrale, raccolta da entrambi i lati opposti del sensore



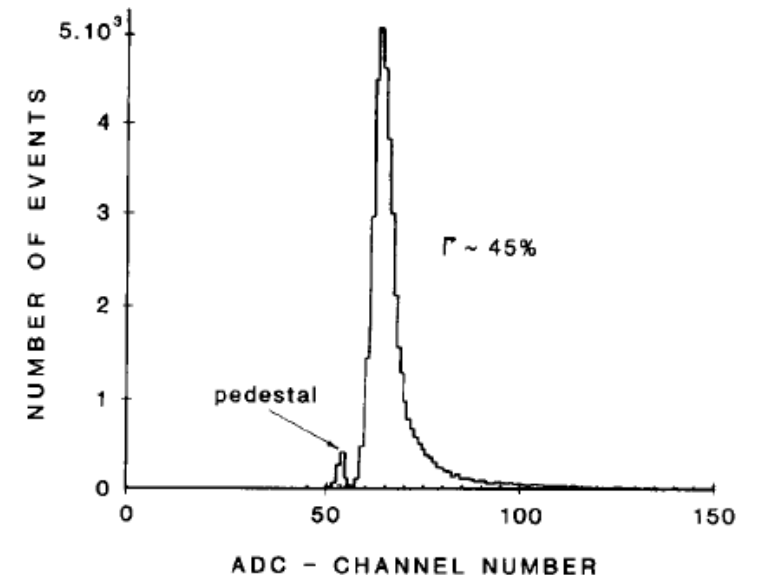
Per spettroscopia

- Piccolo anodo al centro: 100 fF
- Campo di deriva simmetrico
- Contatto inferiore continuo p+



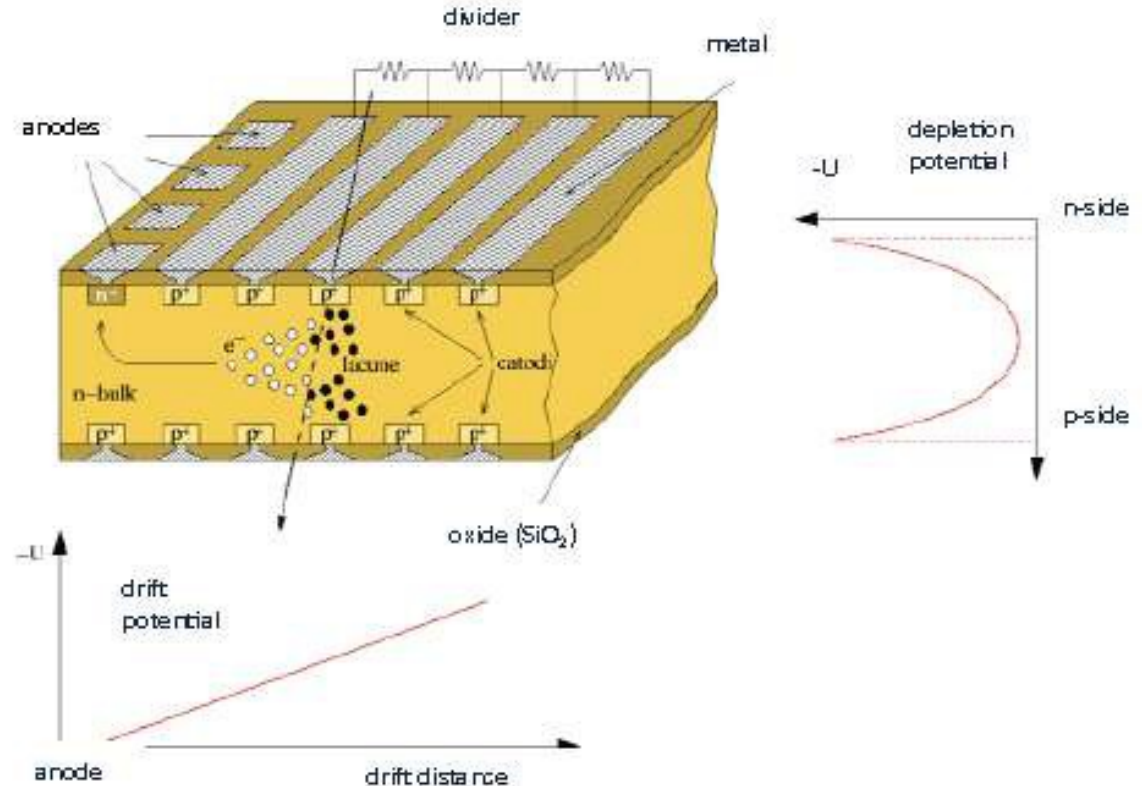
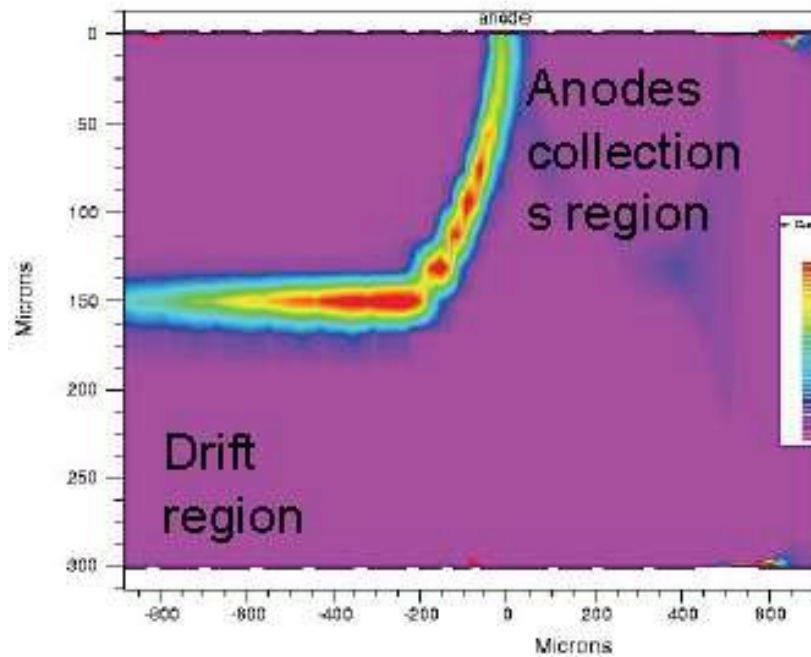
Prestazioni prima camera a deriva di silicio

- Velocita' di deriva
 - T deve essere mantenuta stabile (v varia di $\sim 1\%$ /K)
 - Velocita' deve essere calibrata e mappata
- Rumore:
 - La corrente di bias non influenza la corrente di leakage all'anodo
 - La corrente di lacune che entrano nel partitore di tensione modifica il potenziale
 - 4nA leakage dopo divisione della tensione
- Capacita'
 - Anodi piccoli (25 μ m) introducono piccola capacita
 - Capacita totale
- Misura Perdita energia particelle

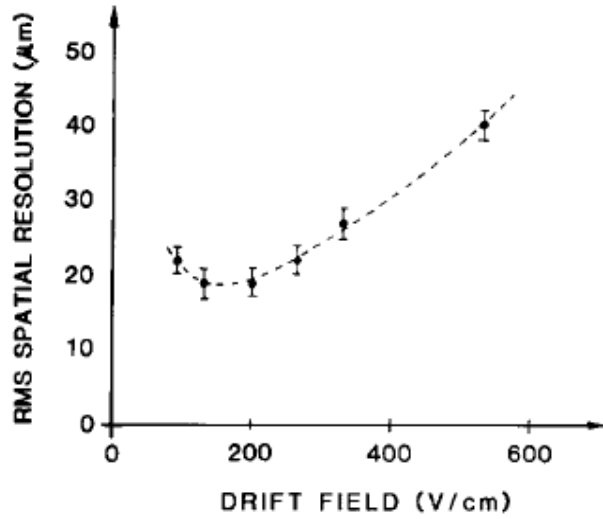


Drift detector – Movimento delle cariche

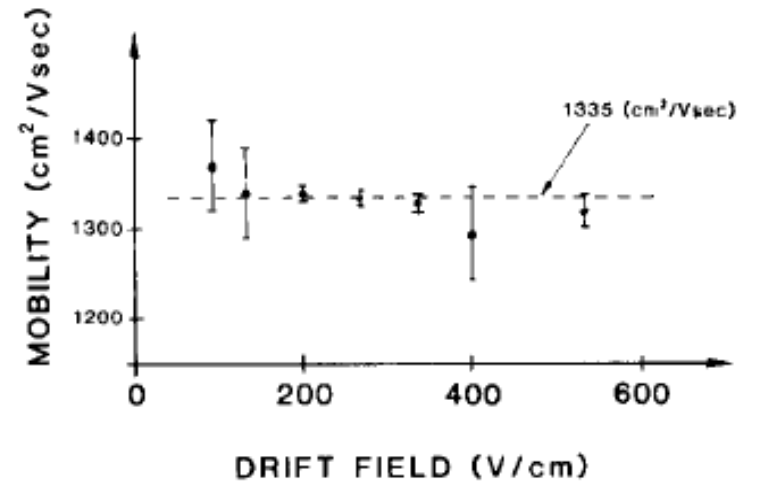
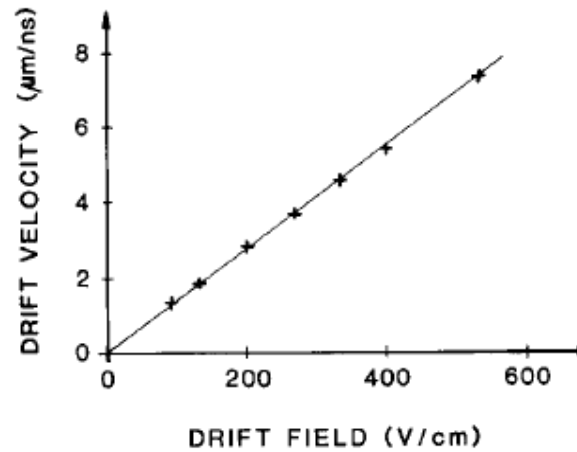
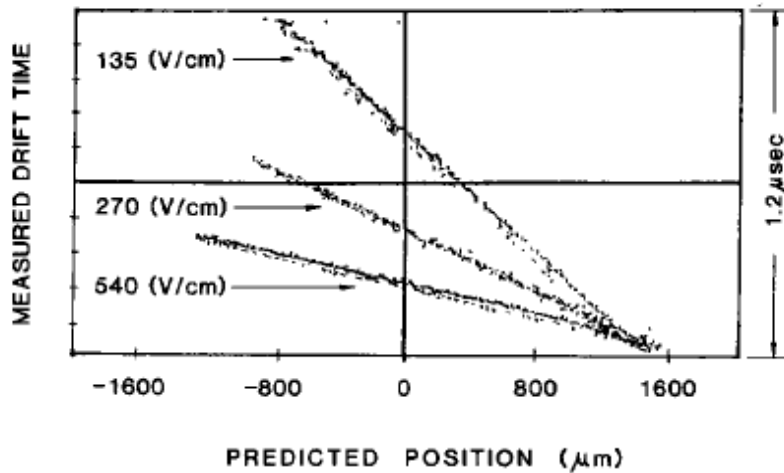
- Lacune derivano ai catodi p+ (non letti)
- e- derivano lungo y seguendo il minimo del potenziale in un tempo t_D di deriva e poi derivano all'anodo sul lato per la raccolta:
 - La segmentazione dell'anodo fornisce la coordinata x
 - Il tempo di deriva lungo y fornisce la seconda coordinate: $v \sim 5 \mu\text{m/ns}$



Prestazioni deriva di silicio

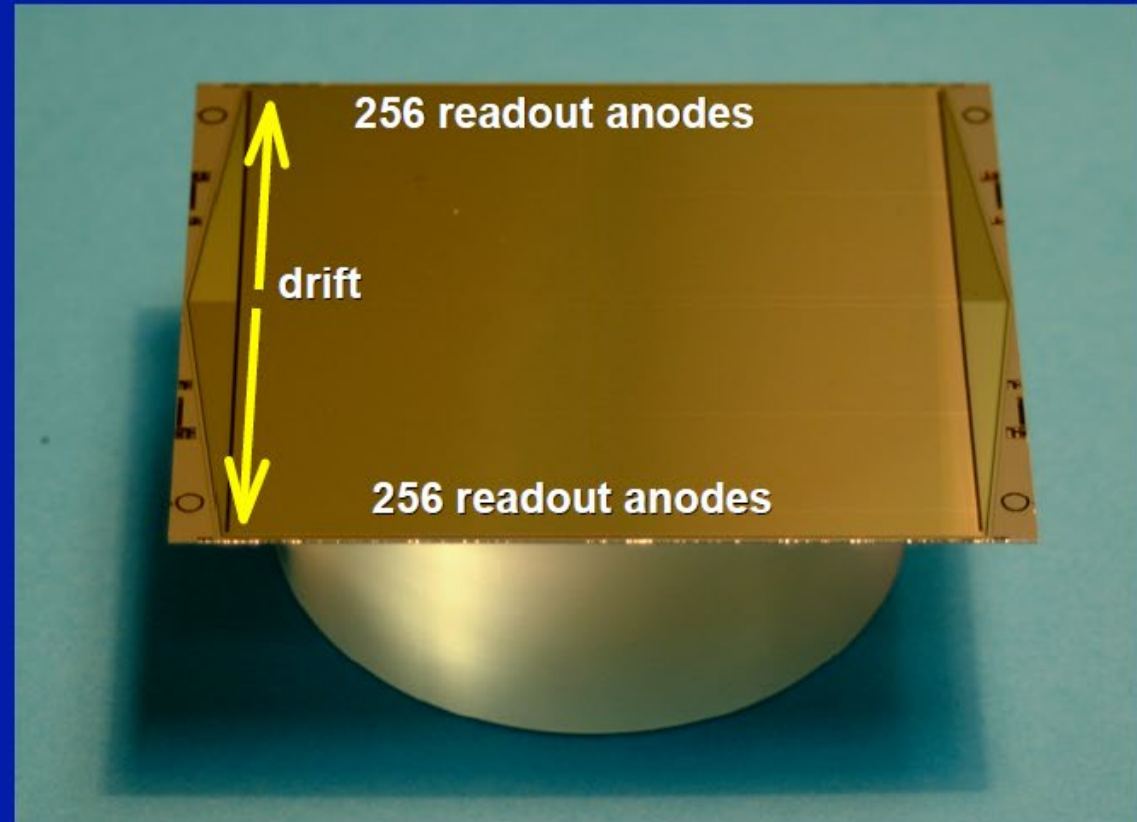


- Risoluzione temporale in funzione di campo di deriva:
 - Riferita a distanza fissa
- Linearita'
- Necessita di un tempo zero
- Velocita' di deriva in funzione del campo di deriva
- Stima della mobilita' degli e- in funzione del campo



The SDD was selected to equip the 3rd and 4th layers of the Inner Tracking System (ITS) of the ALICE experiment at LHC. The finger print of this silicon drift detector is:

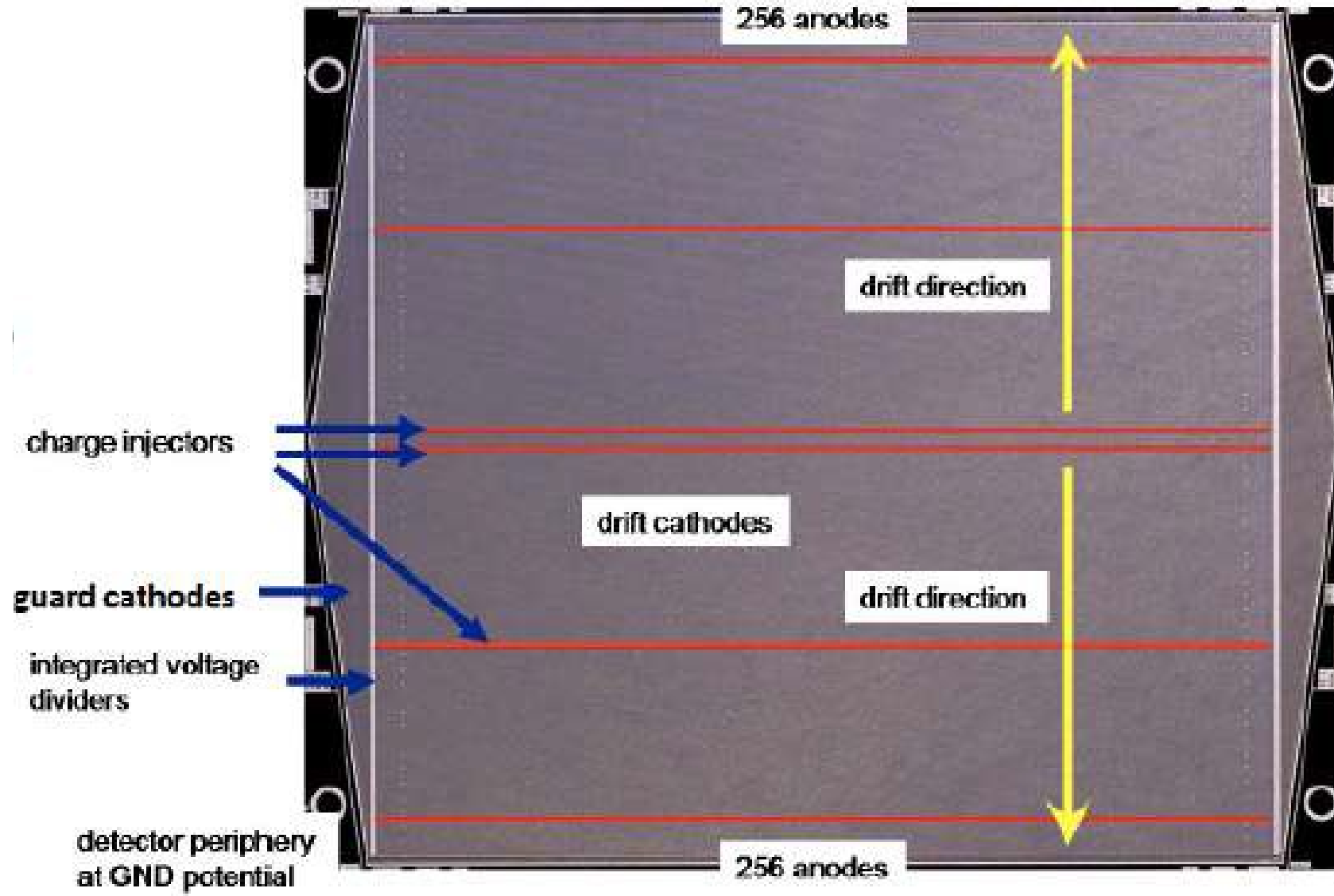
- **Wafer type:**
- **5" Neutron Transmutation Doped <111> 3 kΩ.cm, 300 μm thick**
- **Area:**
 - sensitive: 7.02 × 7.53 cm², divided into two drift regions
 - total: 7.25 × 8.76 cm², (ratio = 0.83)
- **Each drift region:**
 - 35 mm long
 - 291 cathodes driven by built-in voltage divider
 - 256 anodes – 294 μm pitch
 - 3 rows of 33 MOS charge injectors (for the drift velocity calibration)
- **Guard regions:**
 - independent built-in voltage dividers



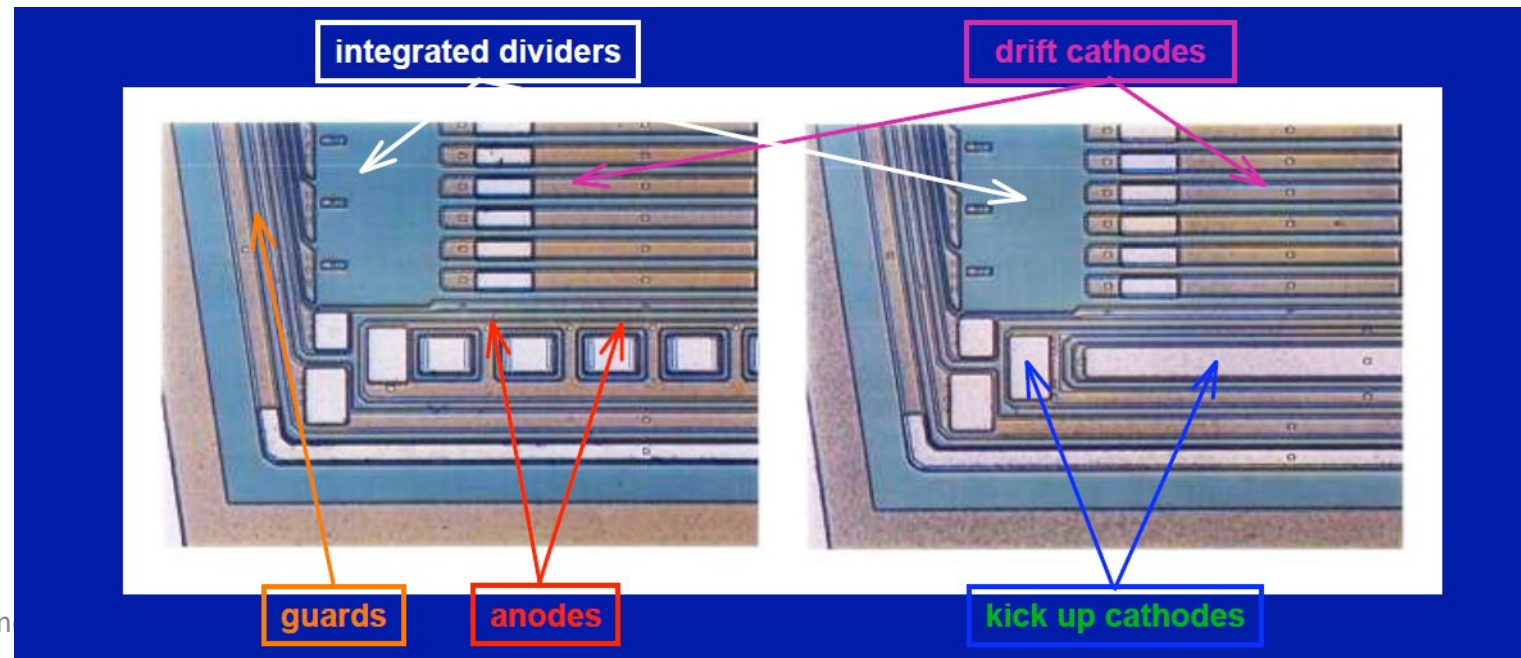
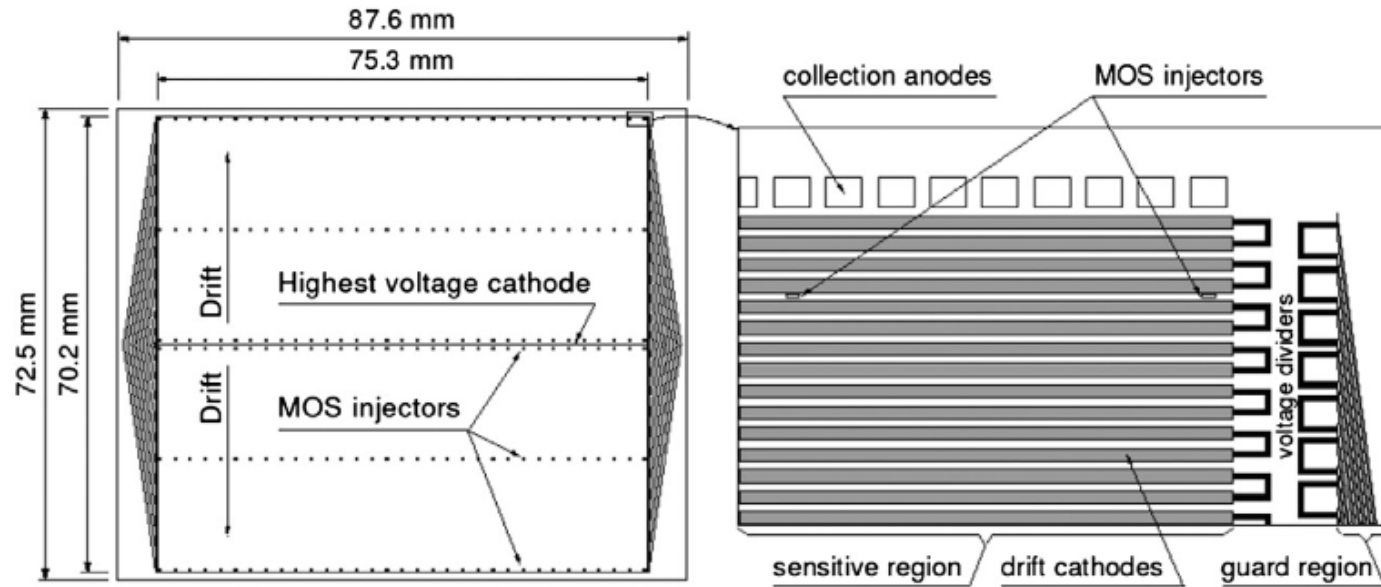
Typical operating parameters:

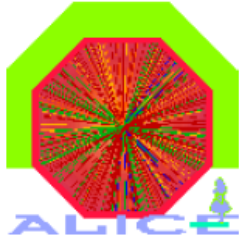
- **Drift bias voltage: -2.4 kV, 8V/cathode E=670V/cm**
- **Maximum drift time : 4.3 μs, v_d = 8 μm/ns**
- **Power dissipation on board: 0.95 W**
 - equivalent R_{tot} of all drift + guard dividers 4781 kΩ
 - total current in all dividers ~0.40 mA

- ALICE
SDD



Struttura iniettore MOS e partitori di tensione





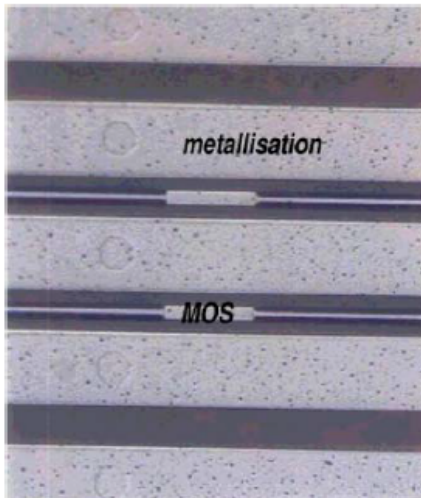
Drift Velocity Calibration

$$V_{\text{drift}} \sim 8 \mu\text{m/ns}$$

But $V_{\text{drift}} = f(\text{HV}, T) \propto T^{-2.4}$

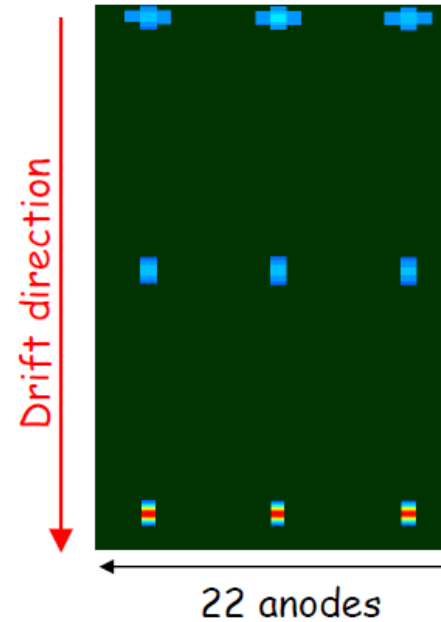
During the experiment, T must be stable within 0.1 K

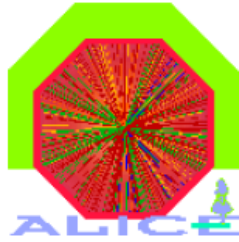
- ⇒ Cooling system based on water flowing in tubes along the support
- Calibration by using electron injectors (MOS) located at precise locations



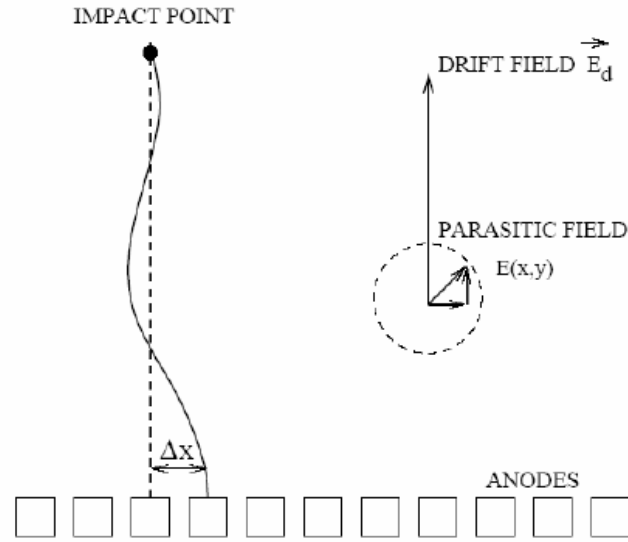
In SDD, there is 3 lines of 33 injectors
 1 close to the anods
 1 in the middle
 1 at the far side

The drift time allows to deduce the velocity of electrons and therefore to make the conversion
 $T_{\text{drift}} \rightarrow \text{Position}$

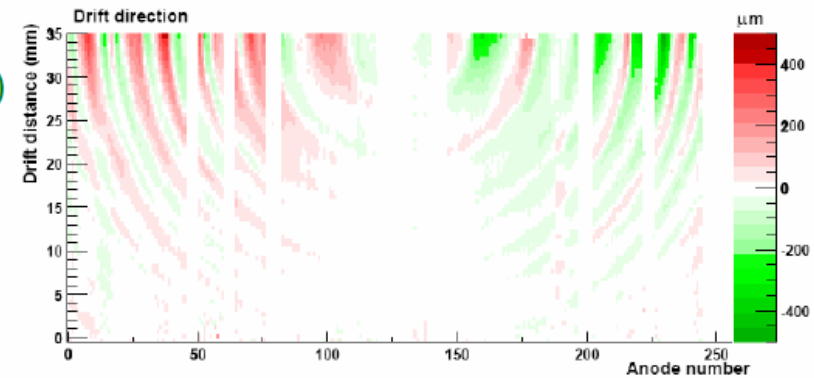
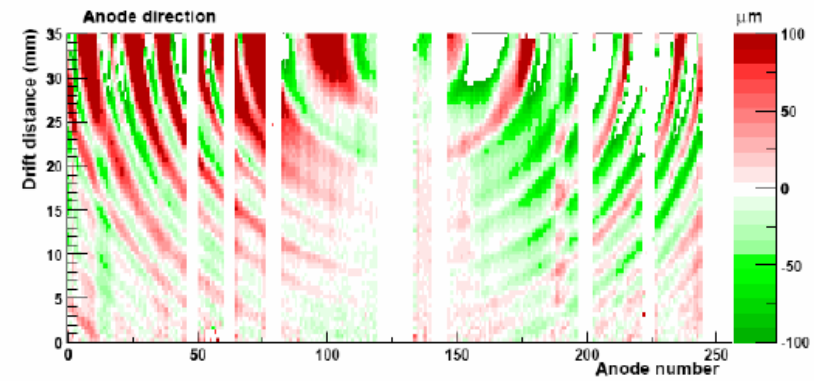




Deviations in Position



Defects in the doping induce
Parasitic field (up to ~ 15%)
⇒ Error on the true position



Deviations :

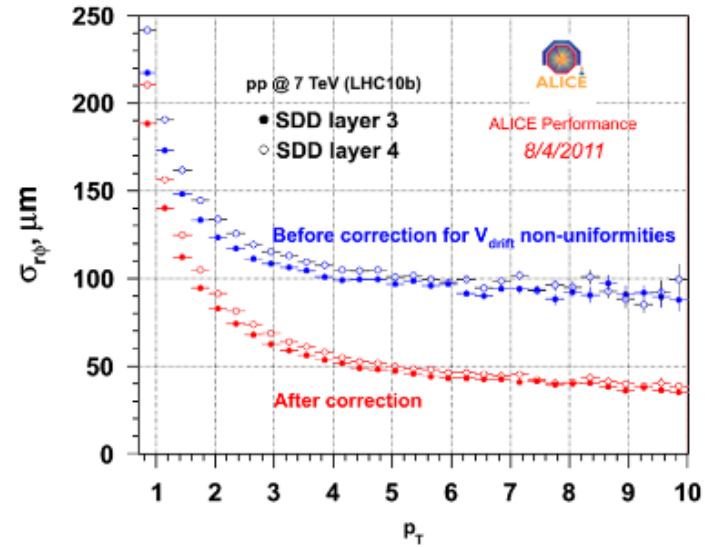
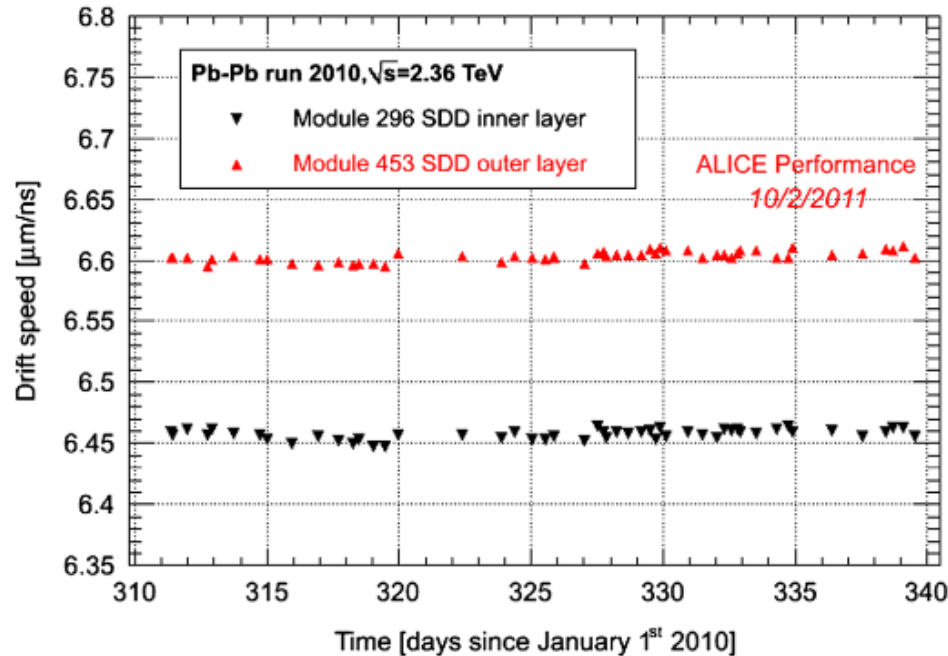
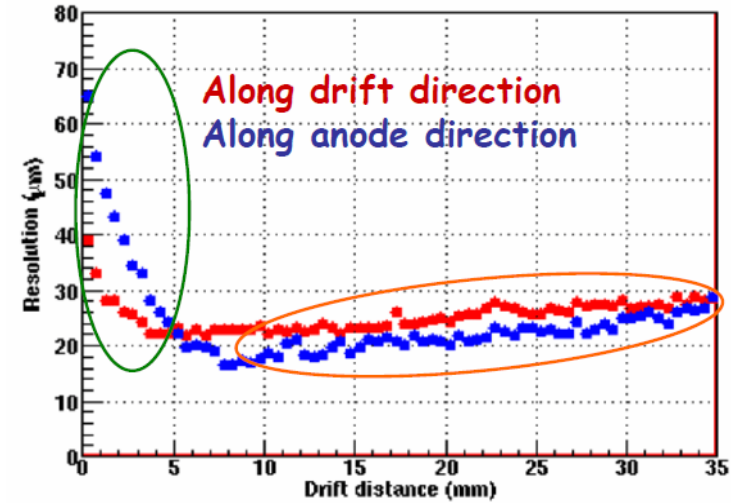
$$Pos_{meas} - Pos_{real} \rightarrow \pm 500 \mu\text{m} \text{ (drift direction)}$$

Systematic effect

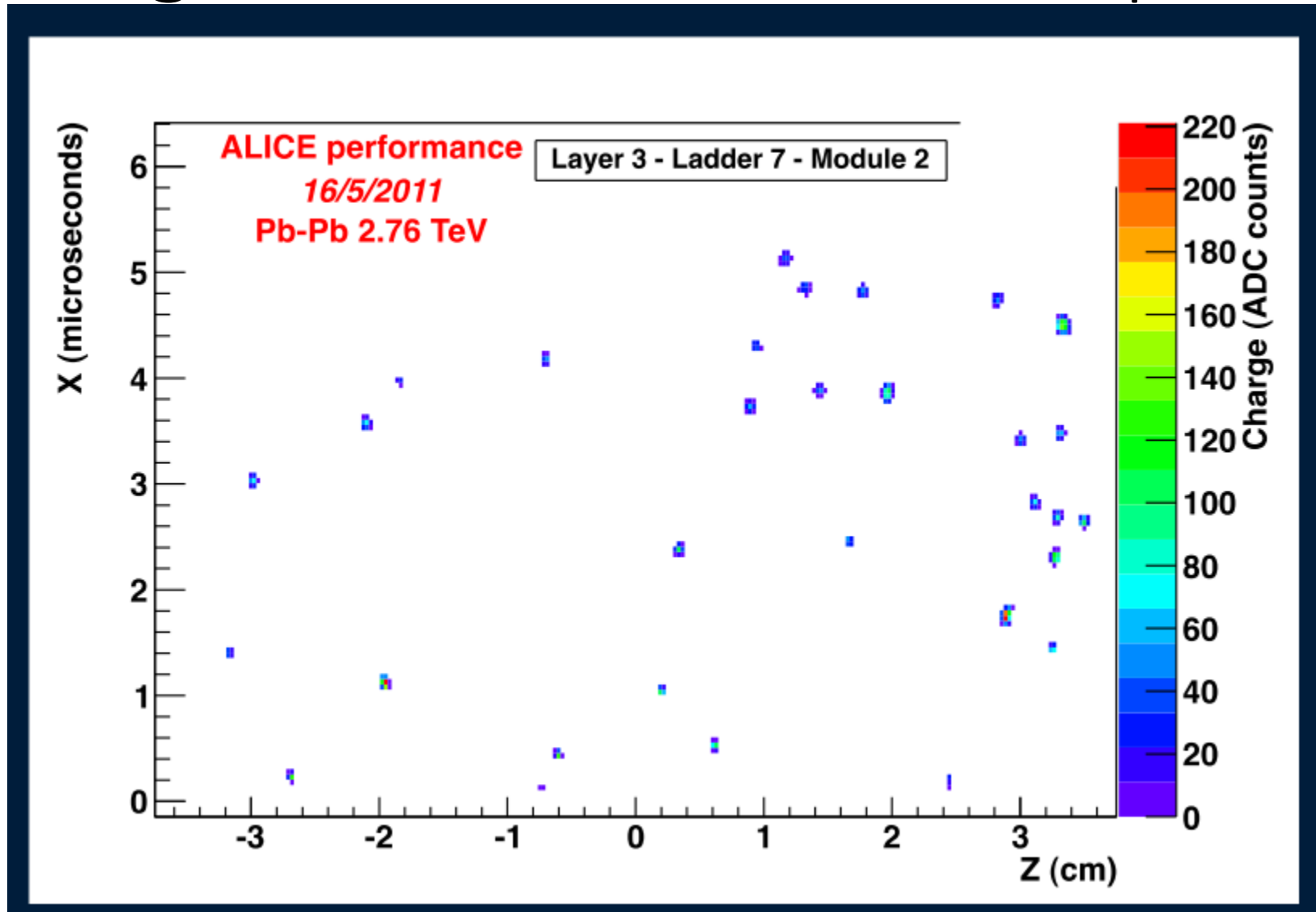
Measured with a laser in order to « map » each detector

ALICE SDD

- Prestazioni misurate
 - Risoluzione spaziale in funzione distanza
 - Risoluzione spaziale vs pt particelle
 - Stabilità velocità deriva



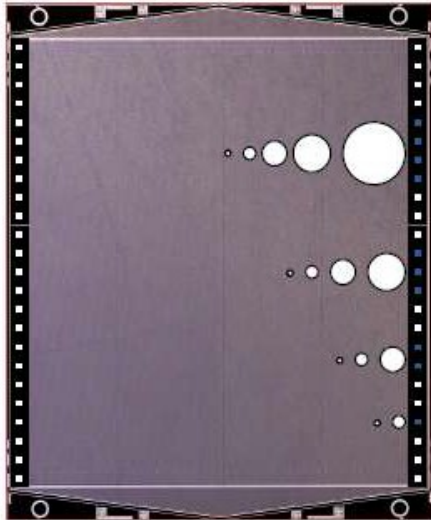
Chiario segnale anche ad alta molteplicita'



Altre applicazioni

- Spettroscopia + ricostruzione posizione 2D
 - Risoluzione all'anodo di decine di μm 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)
- ⇒ Medical field: Compton camera
- ⇒ Nuclear physics precision spectroscopy
- ⇒ X-ray astronomy/astrophysics
- ⇒ X-ray imaging for Advanced Light Sources (SR and FEL)

2-D imaging with photons?



The charge cloud has a Gaussian shape. Its width depends on the drift time which, for a constant electric field, is a linear function of the drift distance:

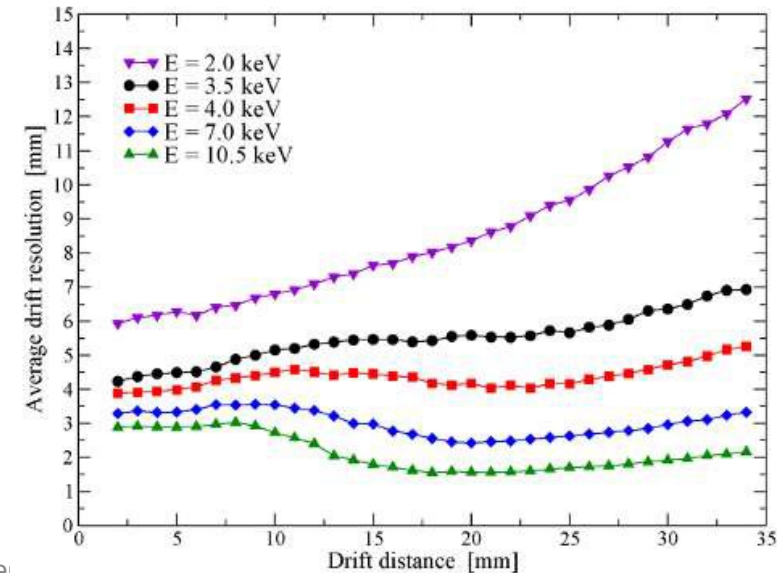
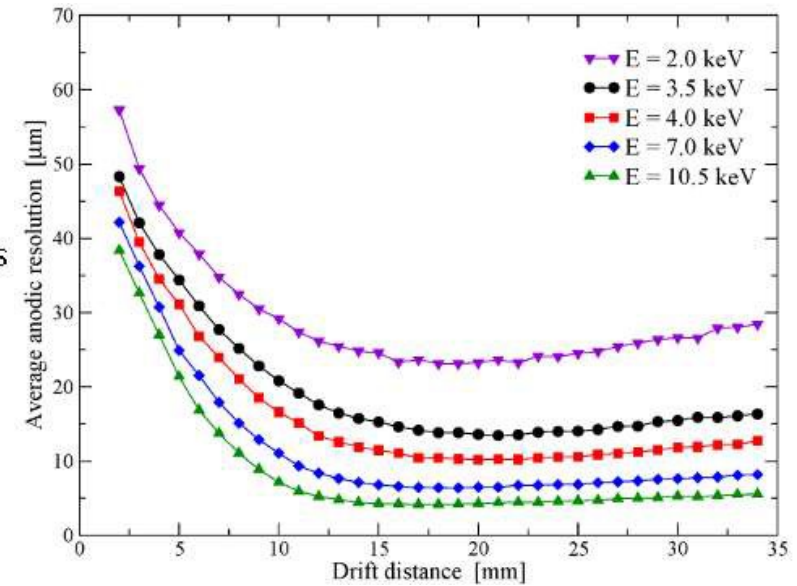
$$D = \frac{k_B T}{q} \mu \quad \text{diffusion coefficient}$$

$$v = \mu E \quad \text{drift velocity}$$

$$t = \frac{x}{v} \quad \text{drift time}$$

$$\sigma = \sqrt{2Dt + \sigma_0^2} = \sqrt{2 \cdot \frac{k_B T}{q} \mu \cdot \frac{x}{\mu E} + \sigma_0^2} = \sqrt{2 \frac{k_B T}{qE} x + \sigma_0^2}$$

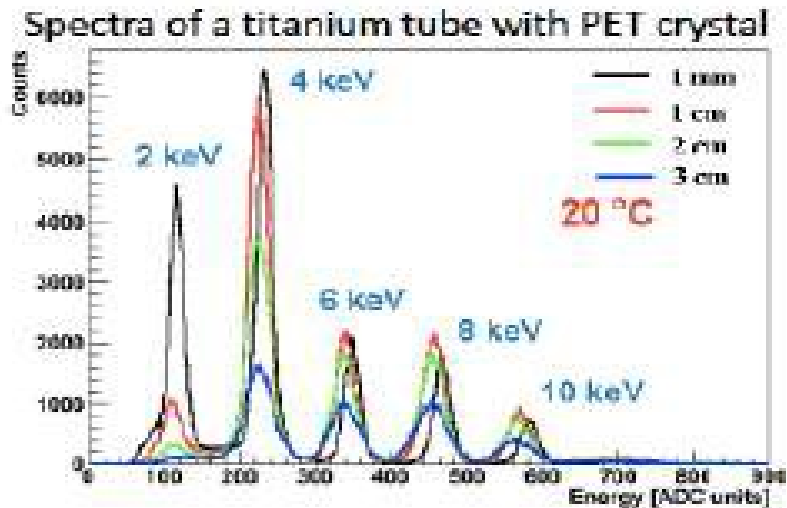
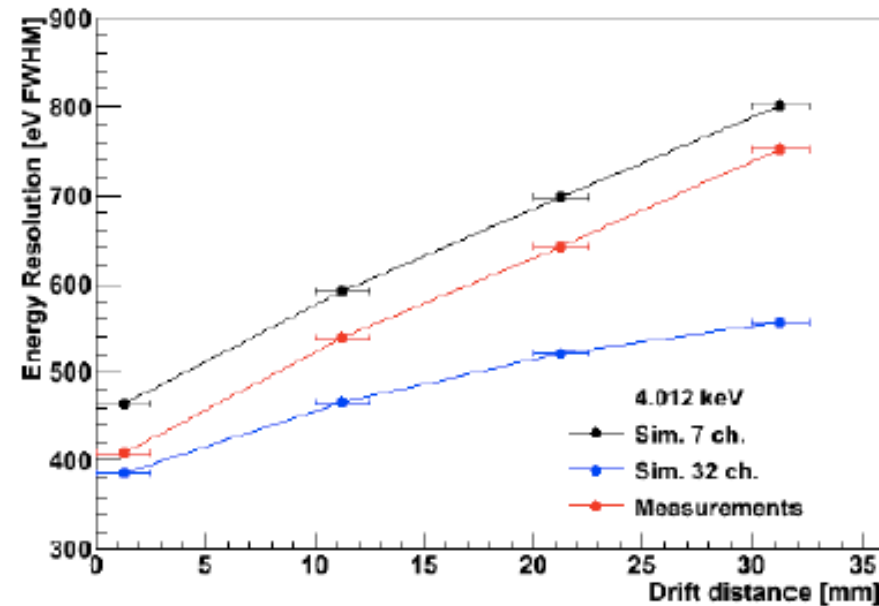
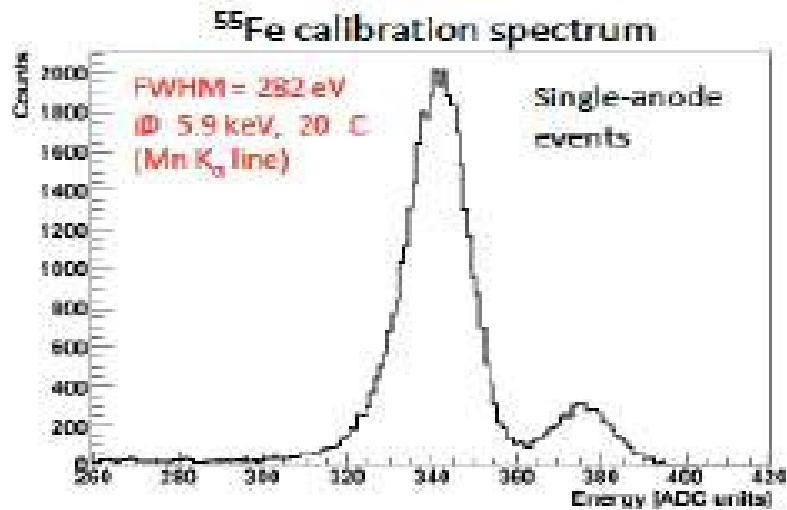
For low energy X-ray photons it is possible to take $\sigma_0 \approx 0$



Compromesso segmentazione anodi

- Per aumentare la risoluzione in energia a scopi spettrografici: vorrei che la carica fosse divisa al massimo tra 2 anodi (la risoluzione dipende da $\sqrt{N_{\text{anodi}}}$ tra cui e' divisa la carica)
- Per aumentare la precisione spaziale a scopi di imaging: vorrei che l'anodo fosse segmentato di piu' per sfruttare condivisione di carica, a scapito della risoluzione energetica (anche se mitigate da capacita' e corrente di leakage piu' basse)

Room temperature spectroscopic performance of the ALICE SDD



- Very good noise performance: ENC = 25 e⁻ rms @ +20 °C using a sub-optimal front-end electronics, only 2× worse than the best commercial SDDs operated below -20°C
- Good energy resolution for such area: < 570 eV FWHM @ 20 °C with a full instrumented ASIC read-out (realistic simulation)

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 \rightarrow FZ

GEOMETRIC AREA (filling factor): 5" \rightarrow 6" wafer <100>

RESISTIVITY: 4 k Ω cm \rightarrow 9 k Ω cm

THICKNESS (QE): 300 μ m \rightarrow 450 μ m

DESIGN OPTIMIZATION FOR X-RAY DETECTION AND SPACE APP.

VOTLAGE DIVIDER: reduced power

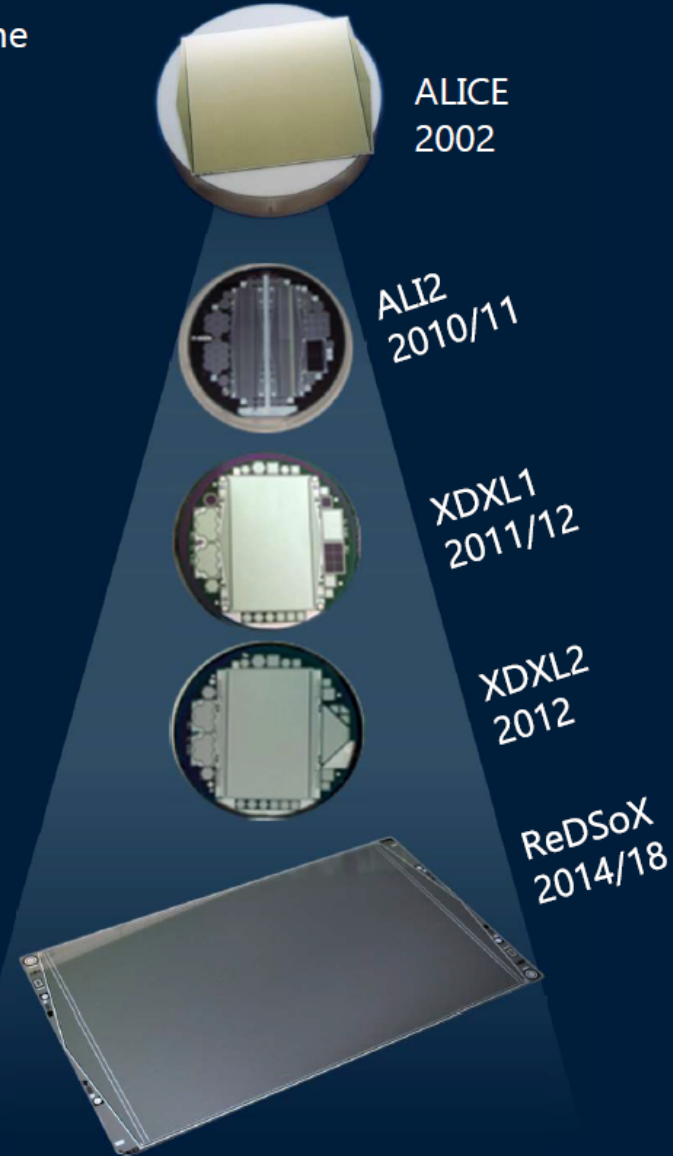
SURFACE CURRENT: minimization

Si-SiO₂ INTERFACE GAP: minimization

FIELD PLATE: optimization for minimal surface current

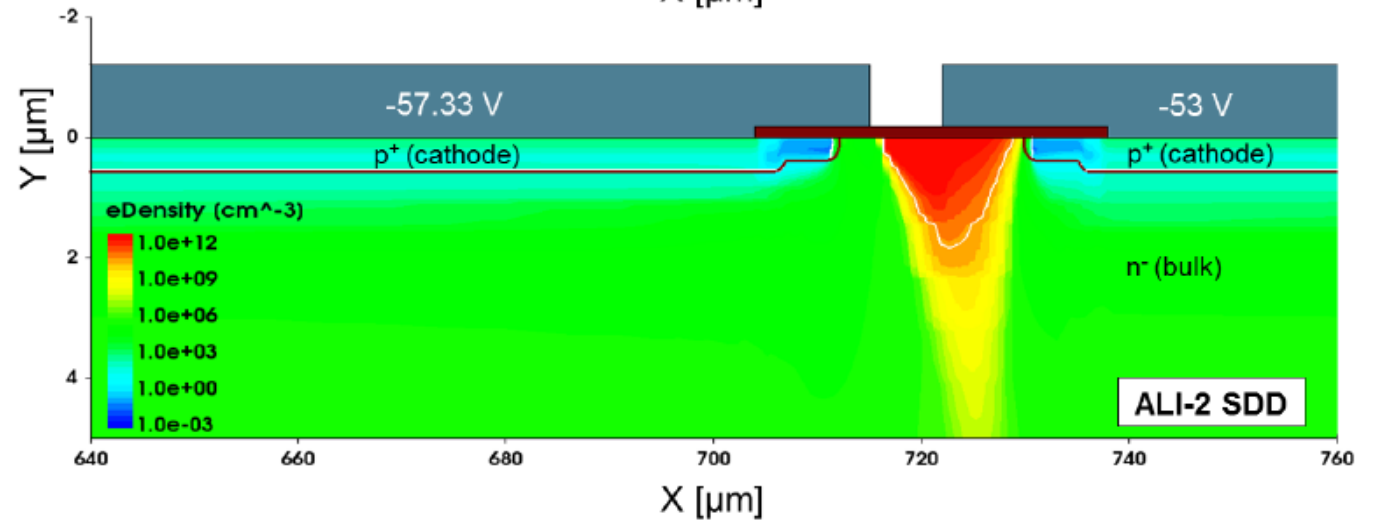
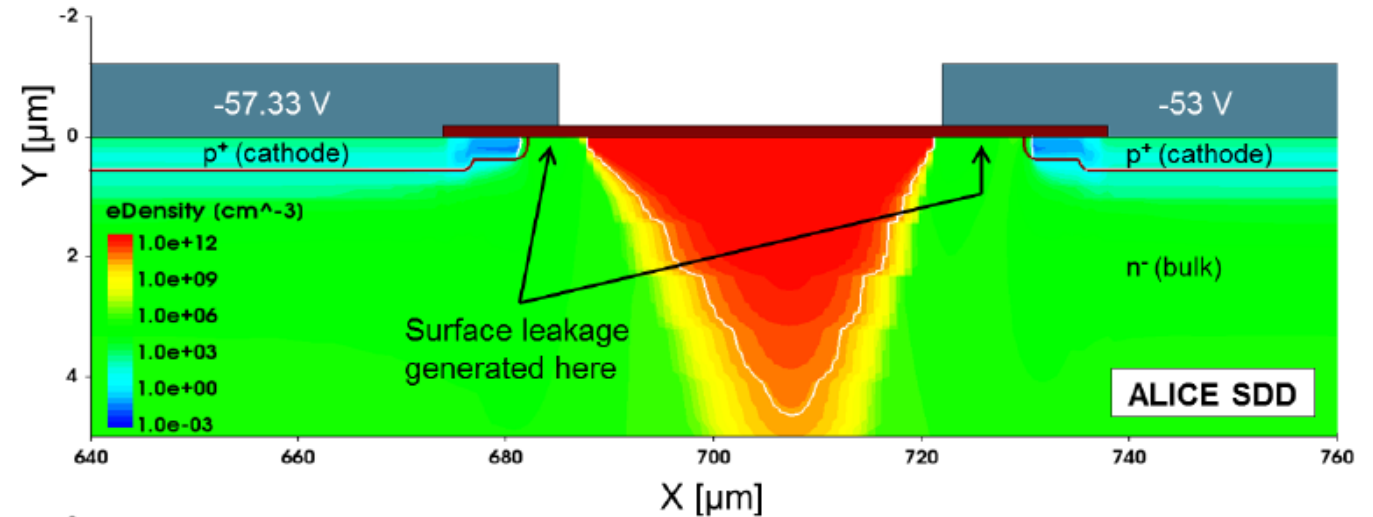
QUANTUM EFFICIENCY: optimization for low E_{ph}

ANODE PITCH: opt. for spectral-timing & imaging



Restringimento gap tra p⁺ vicine

- Densita' di elettroni in rosso
- Corrente di leakage di superficie avviene tra SiO e bulk
- Per restringere la zona non svuotata basta aumentare il rapporto tra area degli impianti e area del gap.
- Anche la zona svuotata sotto l'ossido si restringe



E_XTP SDD

LOT OF MODIFICATIONS TO IMPROVE LOW ENERGY X-RAY DETECTION

- Active area: $53 \text{ cm}^2 \rightarrow 76 \text{ cm}^2$, increment of 43%
- Power consumption at 1300 V: 350 mW
- $\rightarrow 37 \text{ mW}$, reduction of a factor ~ 9
- Average QE media increased of $\sim 27\%$ at 4.5 keV



eXTP SDD typical parameters (HV=1300V)

The drift time is about $5 \mu\text{s}$ when the photon is absorbed close to the top of the 35 mm long drift channel (corresponding to the central line of the Silicon tile).

The charge cloud reaches a maximum size of about 1 mm,