Transition radiation PID with GaAs:Cr Timepix3

not silicon finally

Daniil Rastorguev

Fortnightly SiDet, 16.02.2022

TR radiator basics

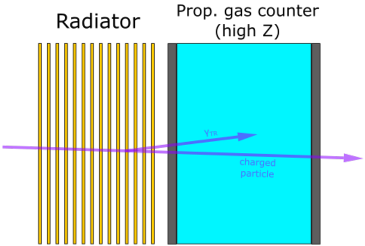


Figure: Typical TR setup

Photon energies: $E_\gamma \sim \gamma \hbar \omega_p \sim$ 10 keV

Yield: approx. 1 TR photon per particle
(for a 100-foil radiator)

Gamma factor range: $\gamma \in [10^3 \div 10^4]$

Interference due to structure periodicity:

- Radiation is suppressed for charged particles slower than a certain γ_{thr}
- Angular spectrum oscillates

Conventional TR particle identification

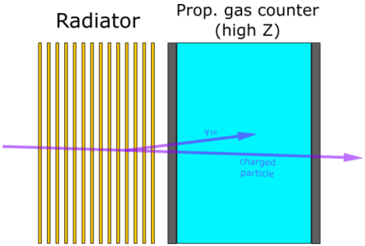


Figure: Typical TR setup

«Slow» particle, $\gamma < \gamma_{thr}$, e.g. muon

Expected energy deposit:
charged particle dE/dX (10 keV)

«Fast» particle, $\gamma > \gamma_{thr}$, e.g. electron

Expected energy deposit:
charged particle dE/dX (10 keV) +
TR photon(s) p.e. absorption (10 keV)

Position/energy sensitive TR detection

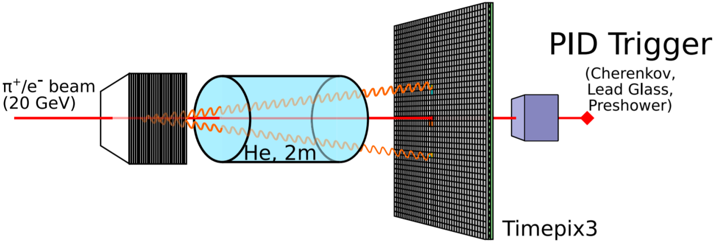


Figure: Transition Radiation Detector prototype with Timepix3
(Dachs F et al. 2020 NIMA 958 162037)

High granularity detector on some distance is able to register hits of a beam particle and TR photon events independently

Timepix3 for transition radiation

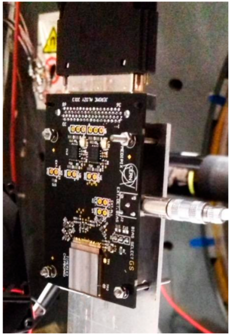
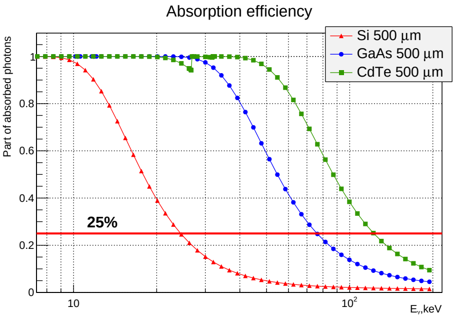


Figure: GaAs:Cr-Timepix3 on Katherine readout in the TRD prototype

Timepix3 for TR PID specs:

- Independent energy measurement and timing in each pixel
- 55 um pitch $\Rightarrow$
  Angular resolution $\sigma_\theta \sim$ 0.01 mrad
- Different sensors – 500 um Si and 500 um GaAs

Some thoughts about semiconductor sensor materials for X-rays detection



Material	Z	$K_{\alpha 1}$ [keV]	$K_{\alpha 2}$ [keV]	$d_{\alpha 1}$ [μm]	$d_{\alpha 2}$ [μm]	η[%]
Si	14	1.74	1.74	11.86	11.86	4.1
Ga	31	9.25	9.22	40.62	40.28	50.5
As	33	10.54	10.50	15.62	15.47	56.6
Cd	48	23.17	22.98	113.20	110.75	83.6
Te	52	27.47	27.20	59.32	57.85	87.3

Si

Is very technological to work with and has low fluorescent yield,
BUT is quite transparent for X-rays >25 keV

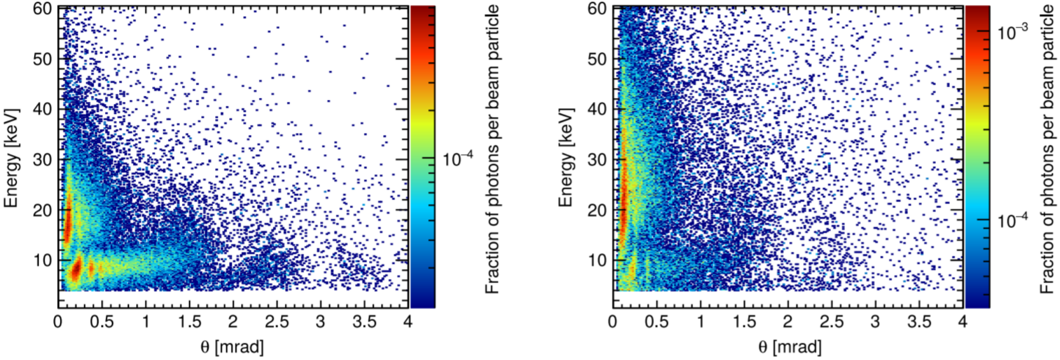
CdTe

Has very good X-rays absorption efficiency and can be up to 2 mm thick, **BUT** has strong fluorescence (and fluo photons can go far)

GaAs

Has good balance between efficiency and fluorescence. Can be up to 1 mm thick.
Is an optimal choice for X-rays of 10–60 keV

Silicon vs. GaAs



(a) Energy over angle of TR measured with a Si sensor.

(b) Energy over angle of TR measured with a GaAs sensor.

Figure: Energy-angle spectra. 20 GeV electron beam. Radiator of 30 Mylar foils (Dachs F et al. 2020 NIMA 958 162037)

What GaAs:Cr really is?

Pure GaAs: low resistivity, low electron lifetime
GaAs, Cr-compensated: high resistivity, medium electron lifetime

High resistivity bulk

No junctions, constant electric field, no need for sophisticated mobility models

Charge collection and induced signal

Limited carrier lifetime $\Rightarrow$ CCE < 100%
$\mu_h \ll \mu_e \Rightarrow$ holes don't really contribute

Charge sharing

Carrier diffusion and fluorescence may affect pixelated detector resolution

Charge carrier tracking algorithm

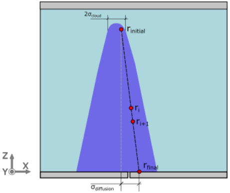


Figure: Modelling scheme

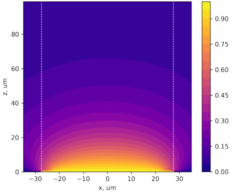


Figure: Weight potential near pixel

1. Generate initial (photo-e travel) and final (diffusion) position
2. On each step:
   - reduce charge (account for lifetime)
     $q_{i+1} = q_i \exp -\frac{(z_i - z_{i+1})d}{\mu\tau U_{bias}}$
   - add fraction to induced signal
     $\Delta Q = q_i(V(\vec{r}_{i+1}) - V(\vec{r}_i))$
3. Sum all contributions, add noise, apply threshold
4. CHEATING: add «interpixel smearing» and rescale energy

Modelling results

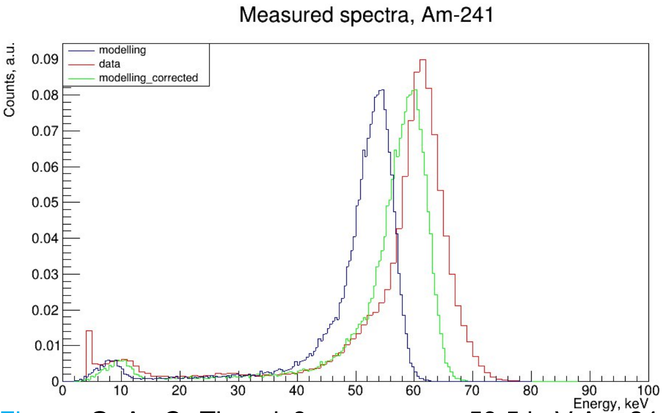


Figure: GaAs:Cr-Timepix3 response on 59.5 keV Am-241 line

Can’t really simulate measured energy without proper FE electronics model :(

Cluster type breakdown

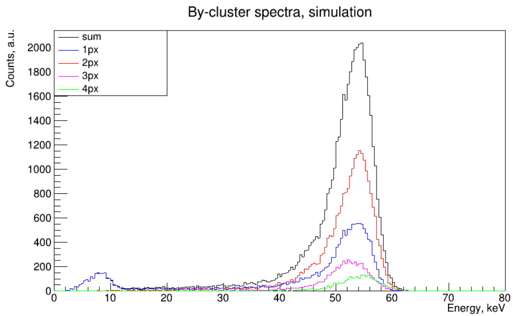


Figure: Am-241, simulation

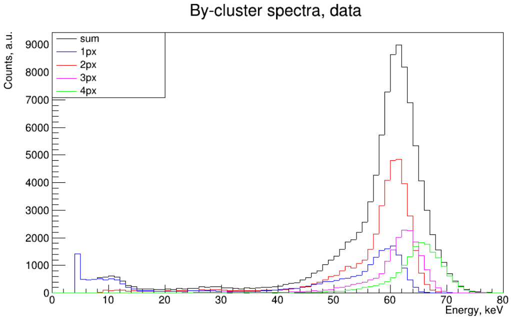


Figure: Am-241, data

Current status and what's next

Figure: A cat meme to illustrate current situation with the project

Thank you!

Contact

Deutsches Elektronen-
Synchrotron DESY

www.desy.de

Daniil Rastorguev
CMS
daniil.rastorguev@desy.de