

Quentin ARNAUD



EDELWEISS Dark Matter Search

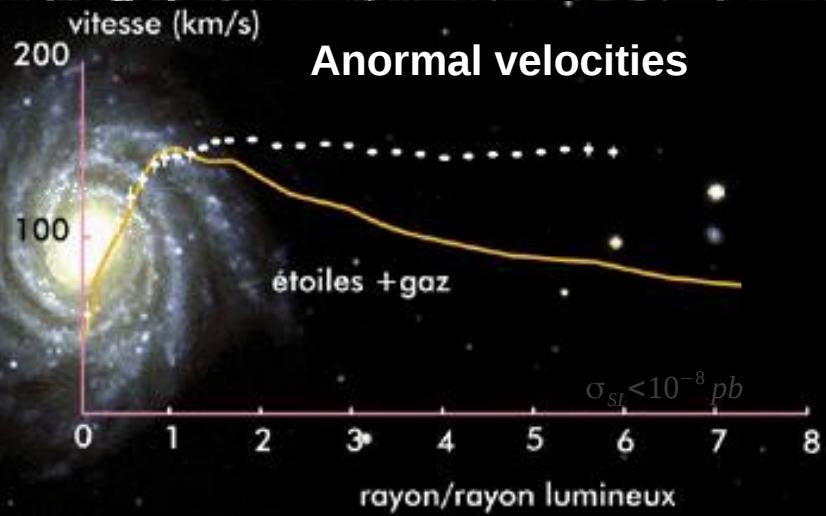
Study of trapping effects in FID detectors

Journées de rencontre des Jeunes Chercheurs

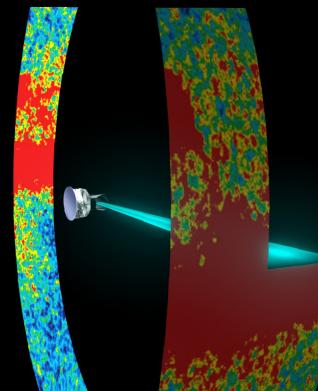
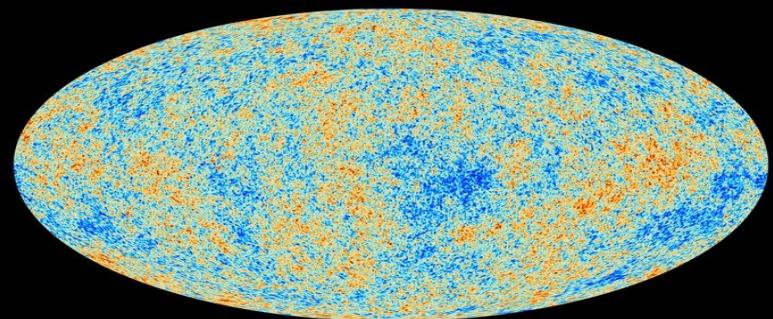
05/12/2013



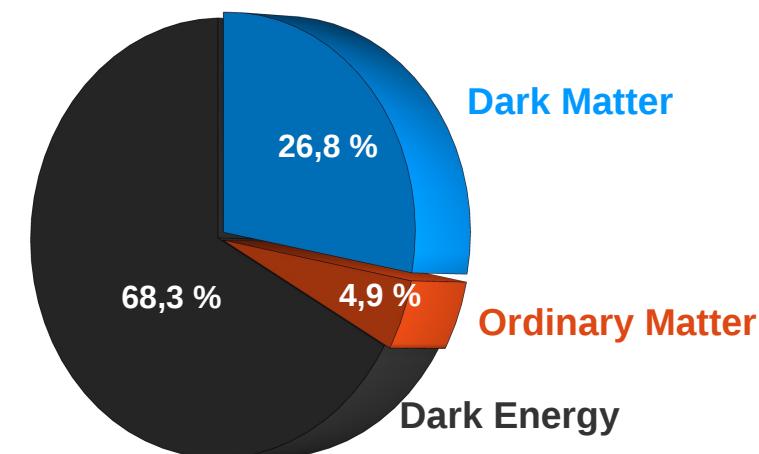
Galaxy Clusters & gravitational lensing



Cosmic Microwave Background anisotropies



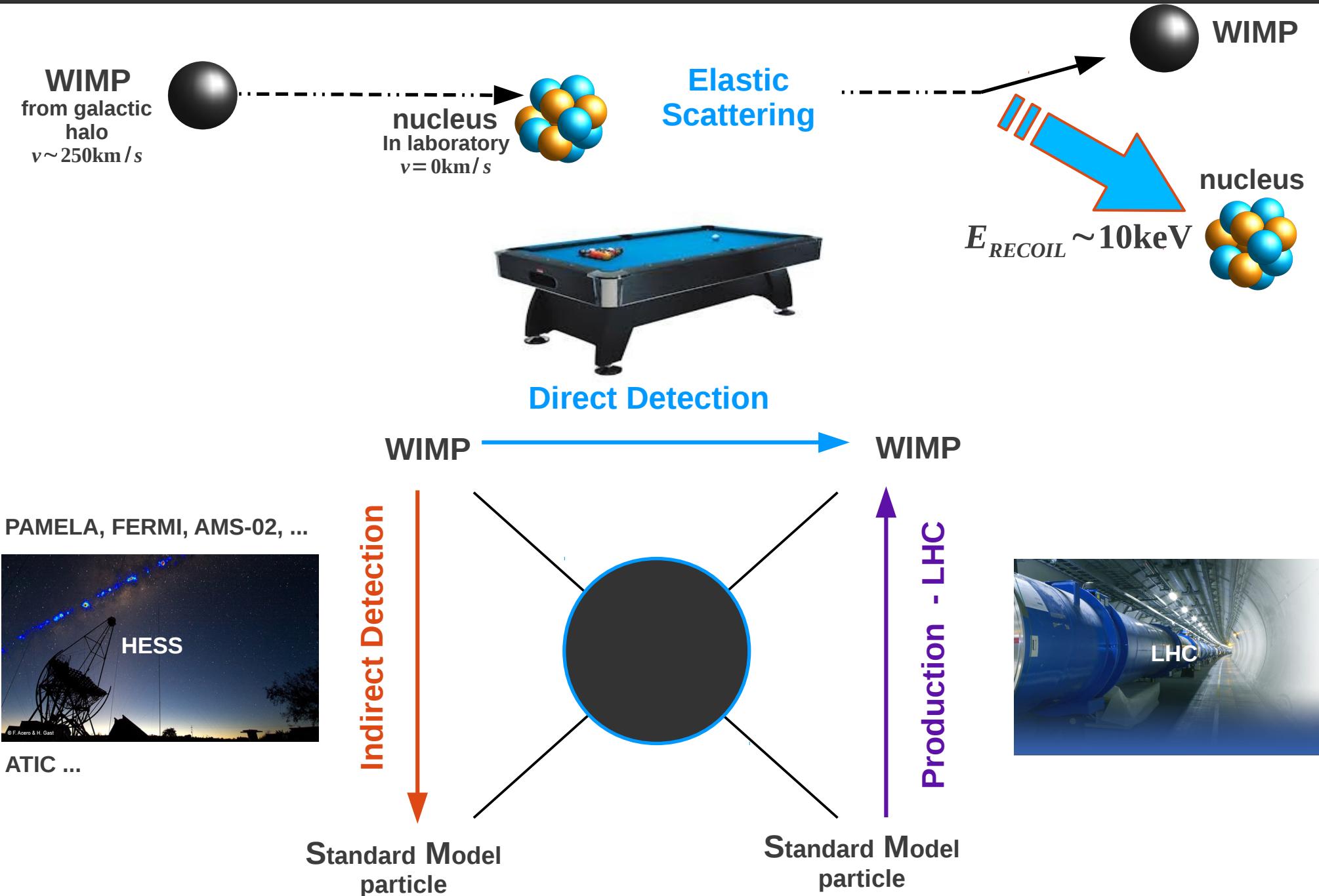
from Planck last results :

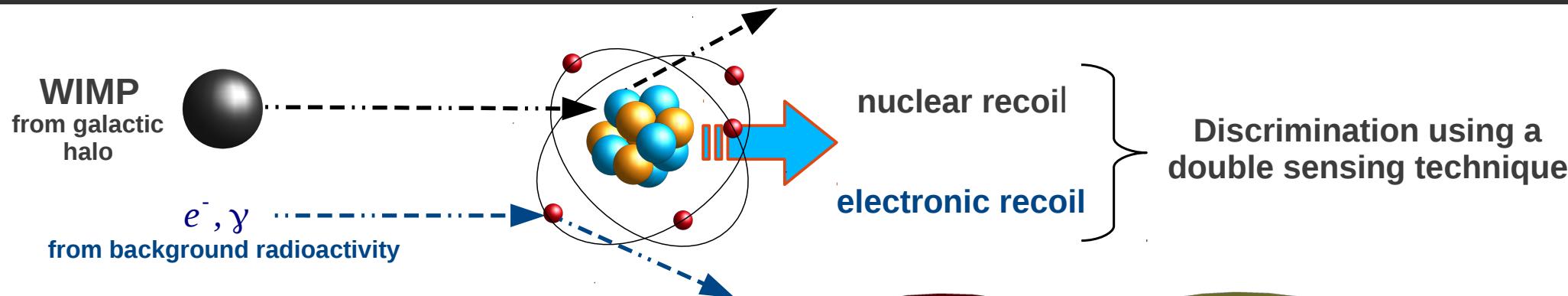


Most widely accepted explanation of these gravitational effects :

Dark Matter might be composed of Weakly Interactive Massive Particles

- Neutral (electric charge and color)
- Massive $1\text{GeV} < M_{WIMP} < 10^4\text{GeV}$
- Extremely Low interaction cross section with ordinary matter $\sigma_{SI} < 10^{-8}\text{ pb}$





A real Challenge :

Background radioactivity

- Shieldings
- Underground-laboratories
- Clean Materials
- Discrimination Power

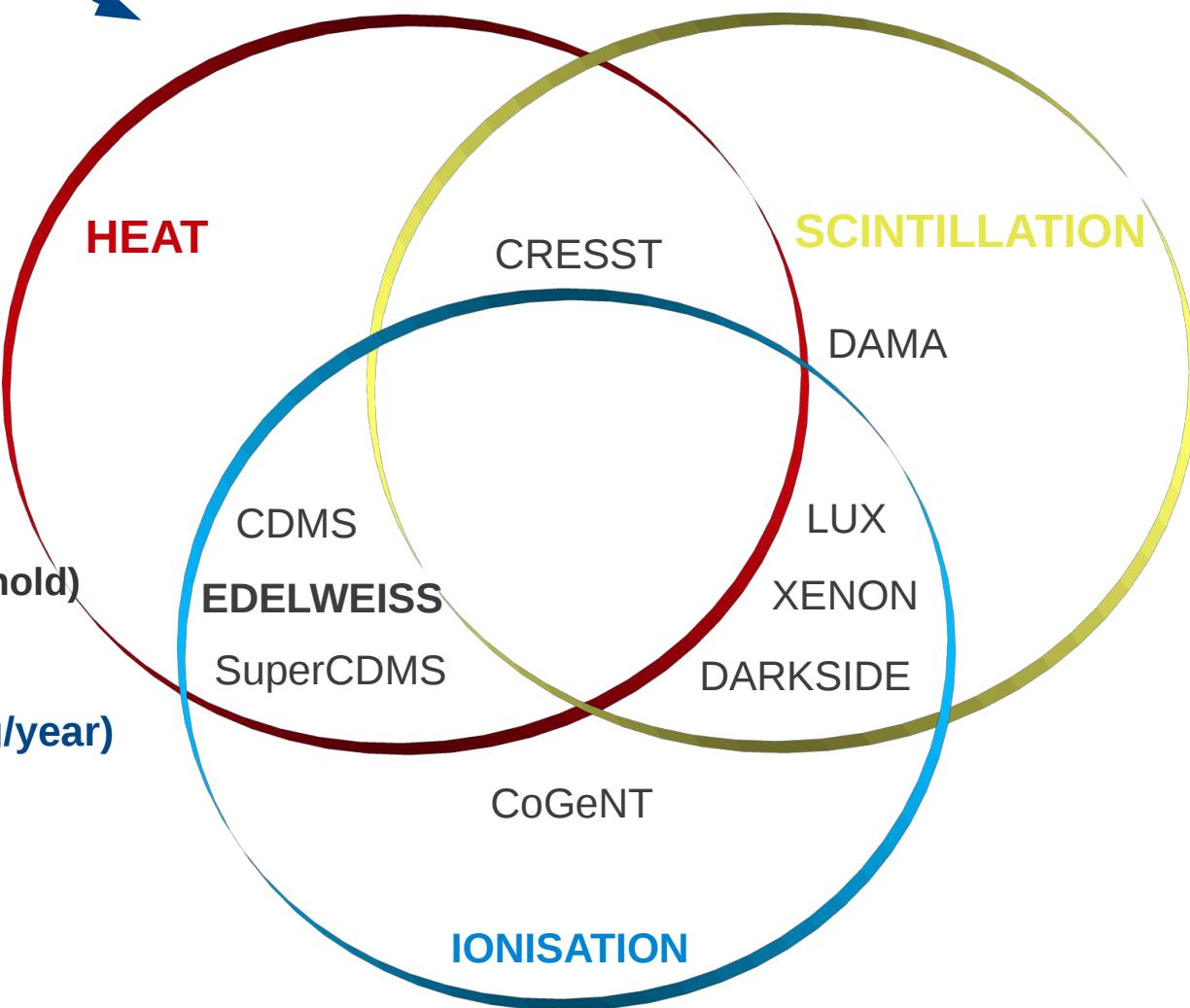
Low energy recoils (few 10keV)

- High precision electronic (low threshold)
- Cryogenic temperatures

Extremely low event rate (< 10events/kg/year)

- Long exposures
- Large masses

Neutrons mimic WIMPs !!!



Rare event experiment < 10events/Kg/year → Necessity to protect detectors from background radioactivity

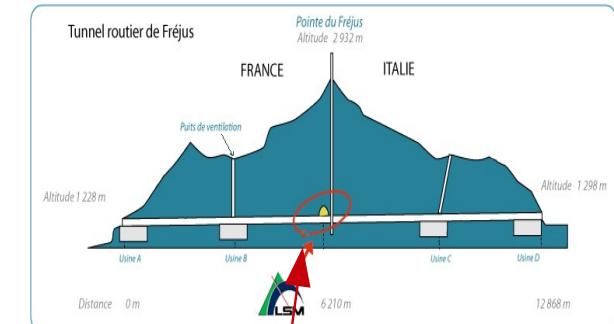
Experiment located at the **LSM** (Laboratoire Sous-terrain de Modane)

Natural shielding of **1700m** of roach :

-allows to reduce the flux of **cosmic muons** by a factor **10⁷** !

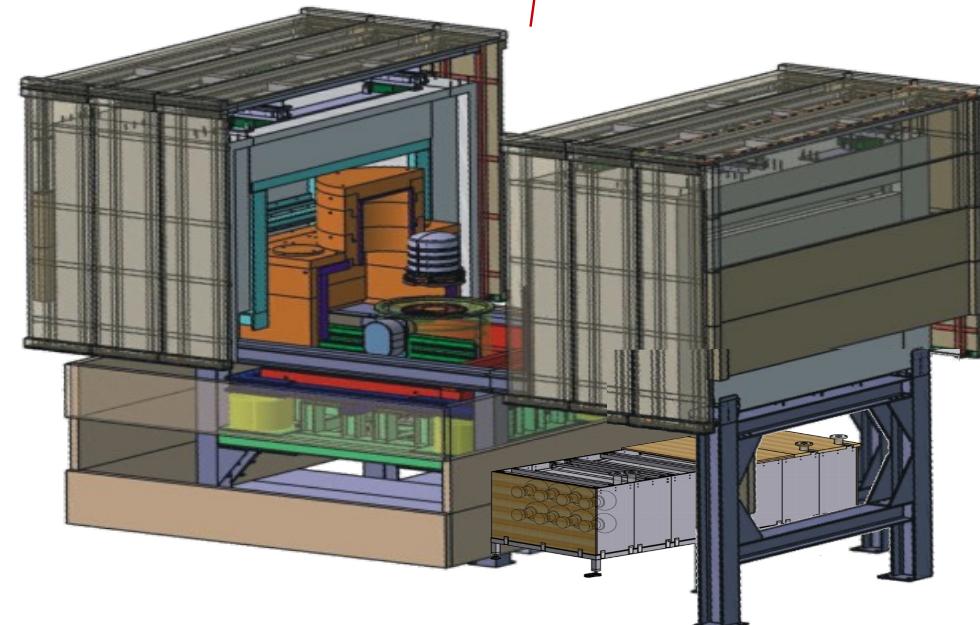
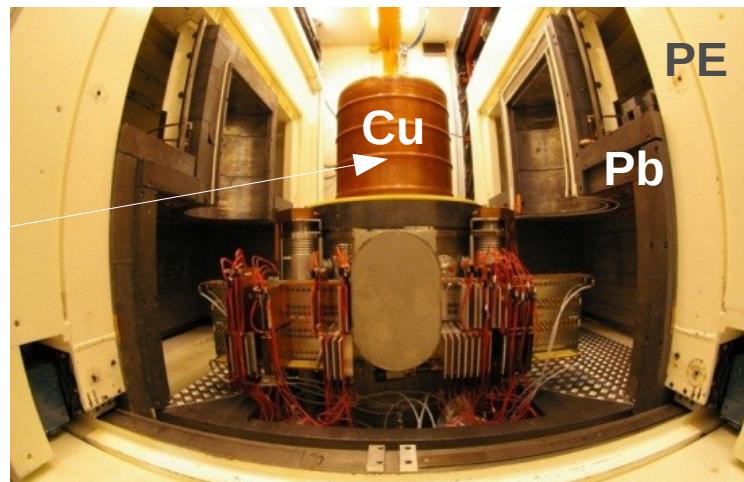
Multiple shields : **lead (Pb)**, **polyéthylène (PE)**, **copper (Cu)** of the cryostat

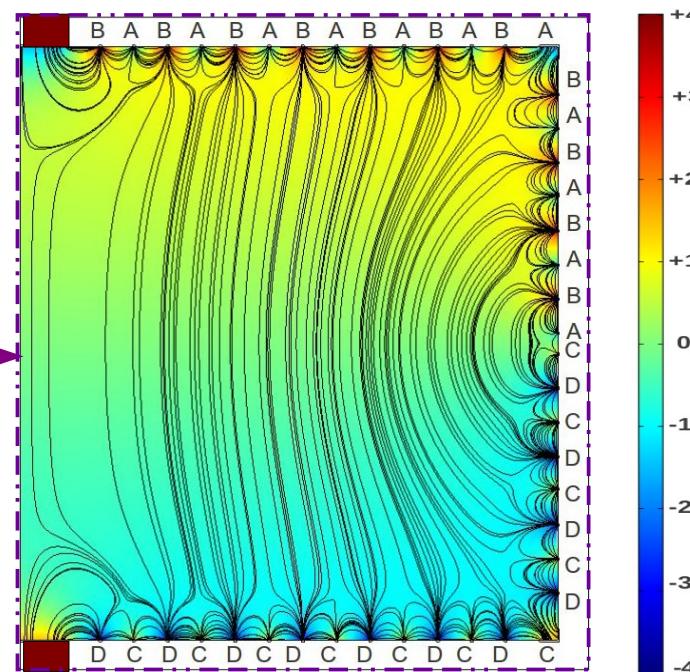
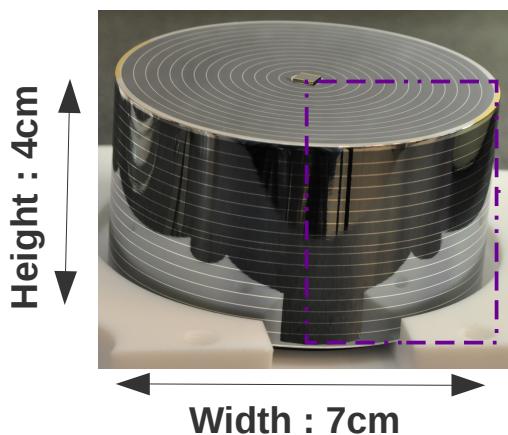
Muon Veto : used to tag muon-induced neutrons (previous talk by **C. Kefelian**)



...In the end, residual radioactivity mostly comes from the shields itselfs !

How to Deal with it ?



Full Inter-Digitized 800g**Detector****4 Ionisation channels****Electrode Biases :**

Veto A = -1.5V

Fiducial B = +4V

Veto C = +1.5V

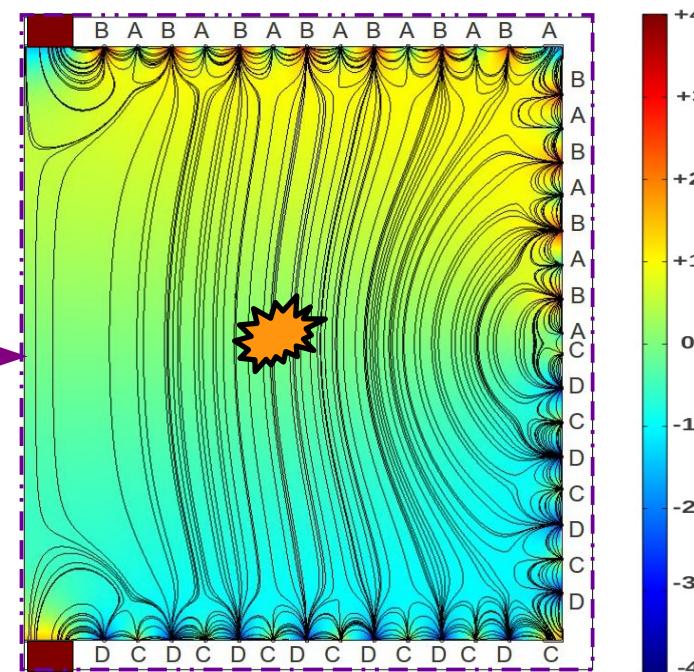
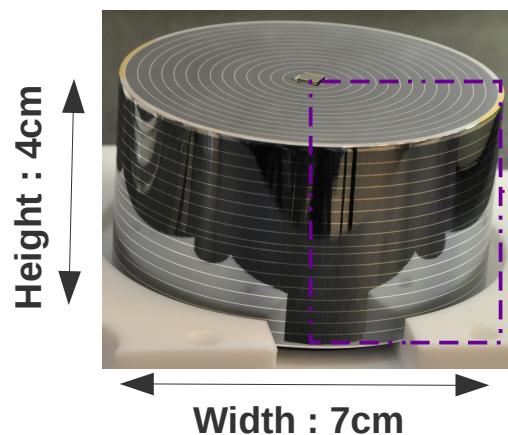
Fiducial D = -4V

2 Heat Channels**Neutron Transmutation Doped (Thermistor)**

**Discrimination of the residual radioactivity β/γ by the double measurement :
Ionization/Heat**

Full Inter-Digitized 800g

Detector



4 Ionisation channels

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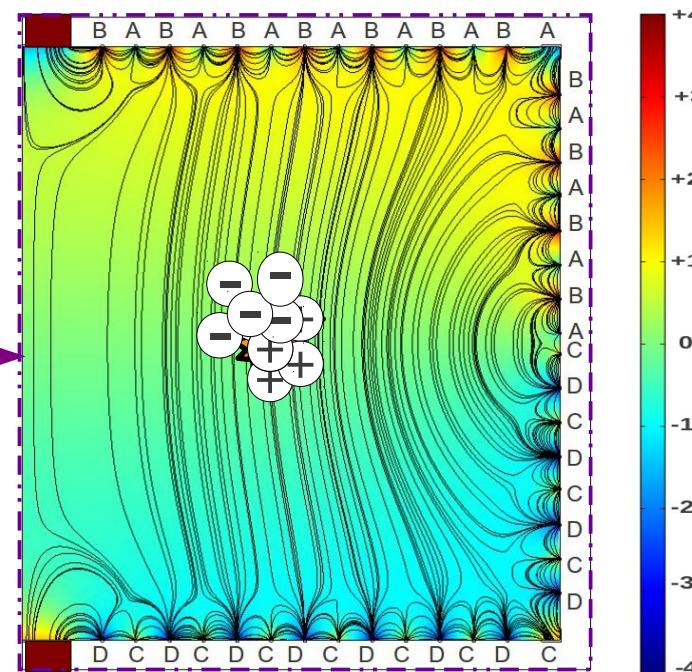
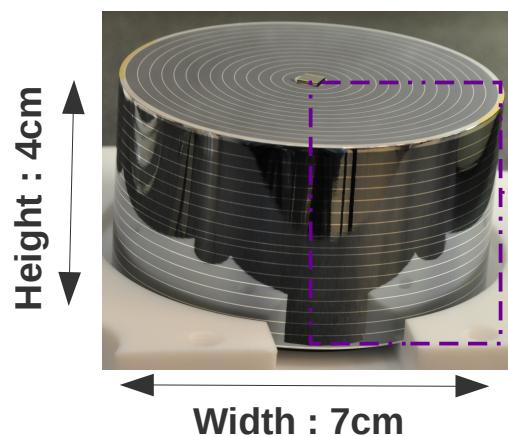
2 Heat Channels

Neutron Transmutation Doped (Thermistor)

Discrimination of the residual radioactivity β/γ by the double measurement :
Ionization/Heat

Energy Deposit

γ : 356keV

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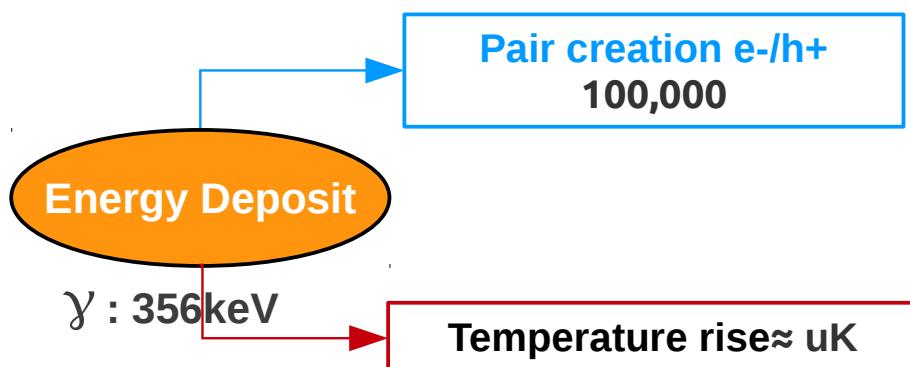
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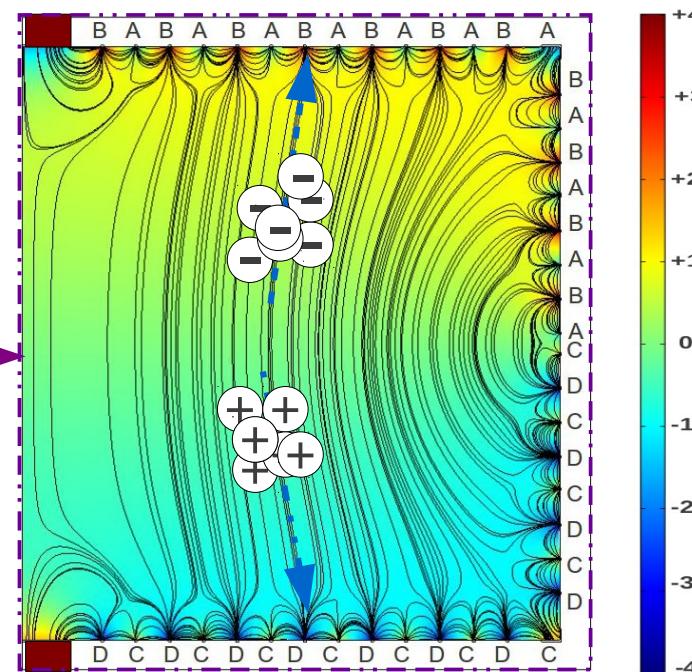
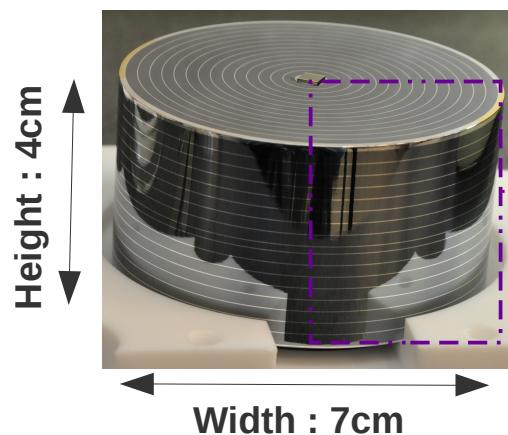
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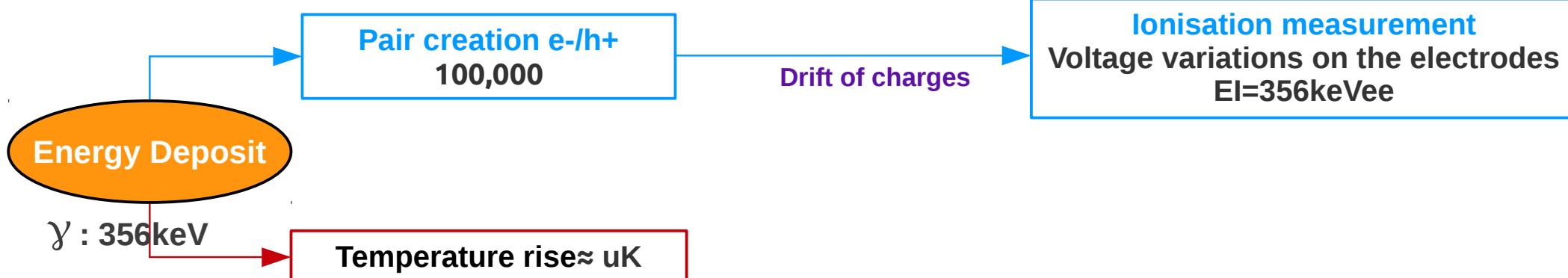
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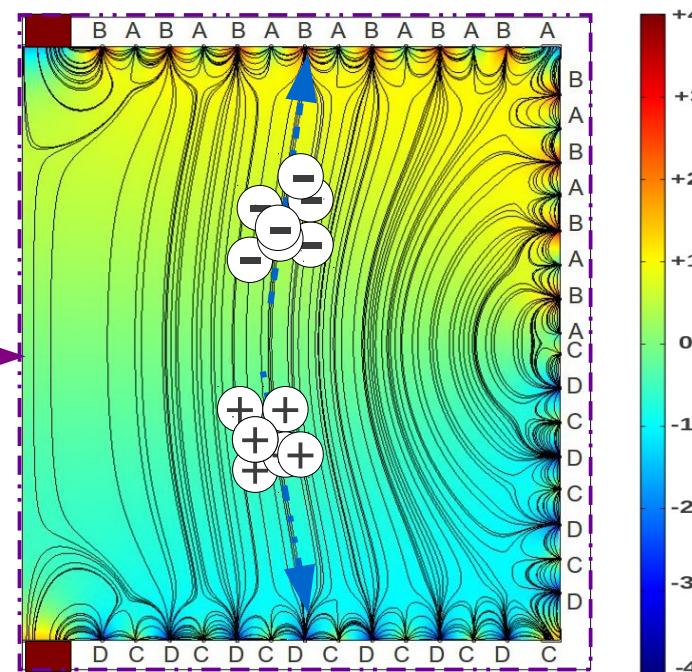
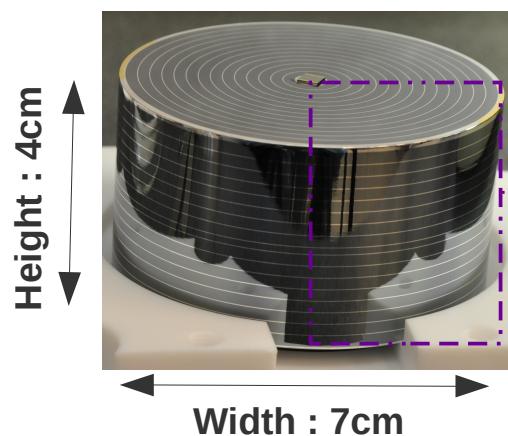
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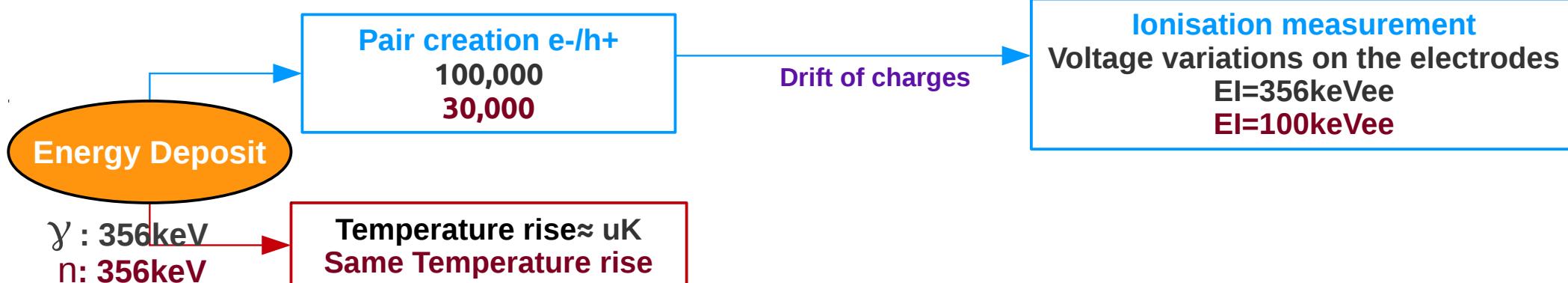
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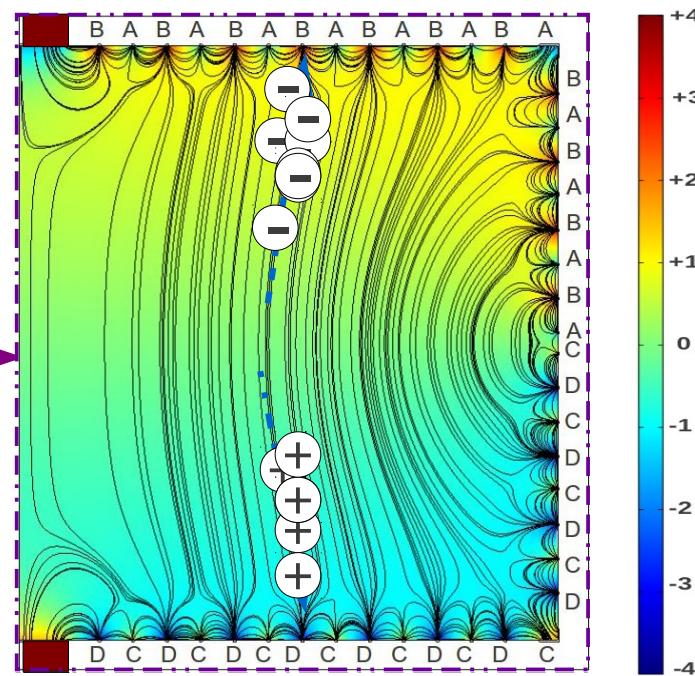
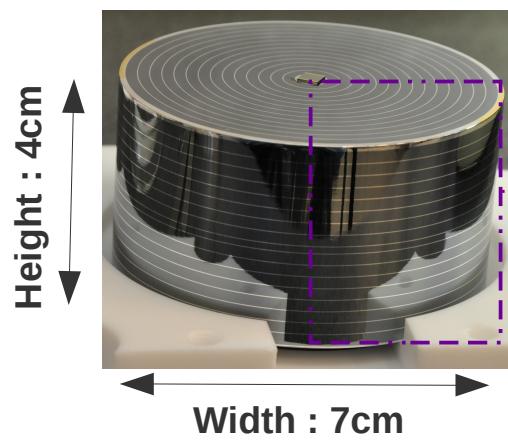
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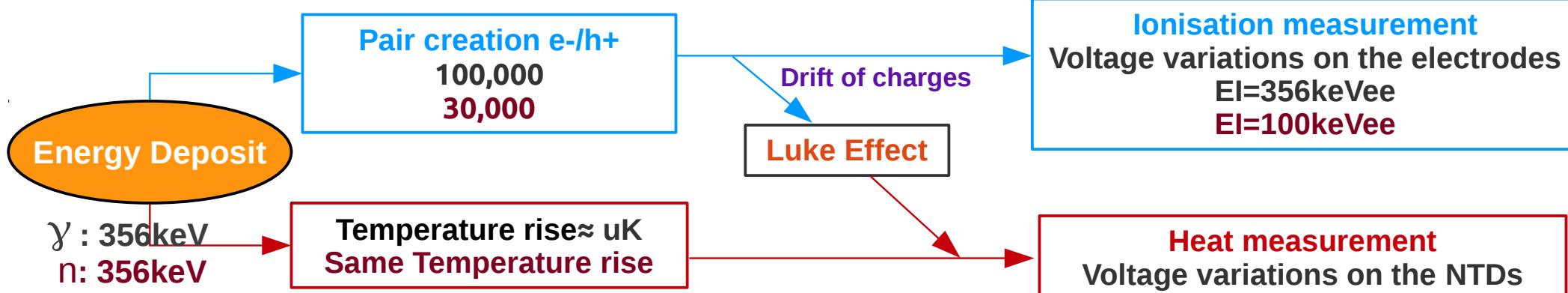
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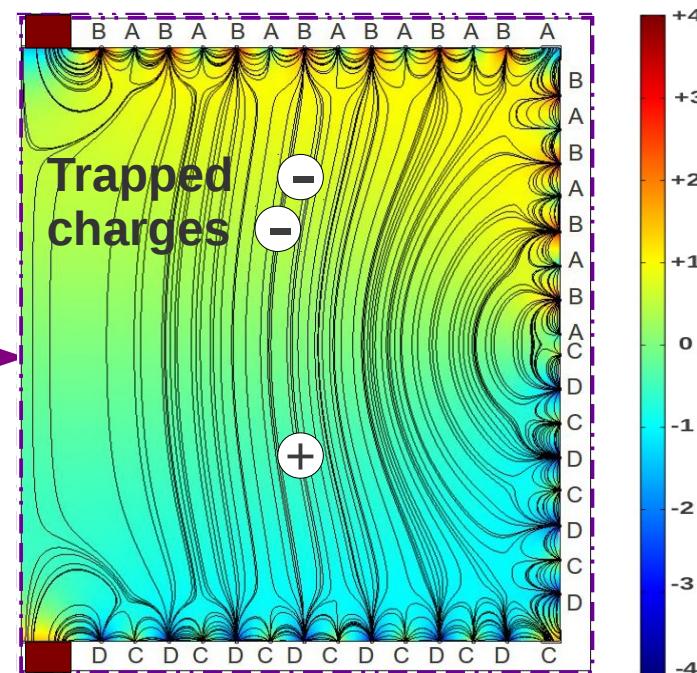
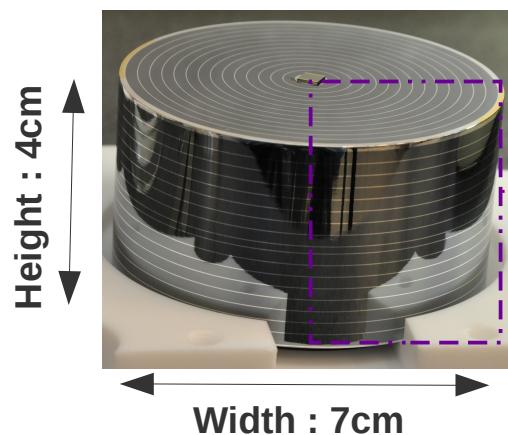
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2 Heat Channels**Neutron Transmutation Doped (Thermistor)**

**Discrimination of the residual radioactivity β / γ by the double measurement :
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$$\text{Deposited energy : } E_{\text{Recoil}} = E_{\text{Heat}} - E_{\text{Luke}}$$

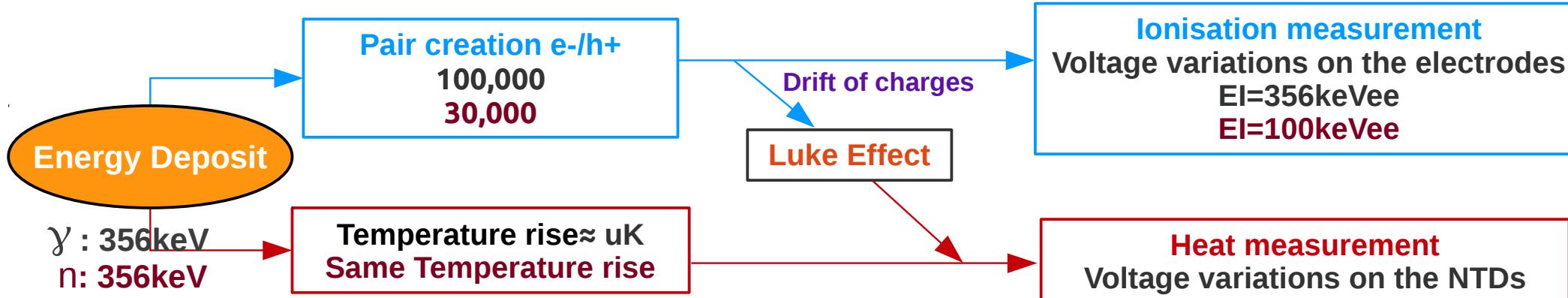
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2 Heat Channels**Neutron Transmutation Doped (Thermistor)**

Luke effect : proportionnal to the **nb of charges** and to the **biases applied**

Low voltages to avoid an enhancement of **Luke effect** resulting in charge trapping



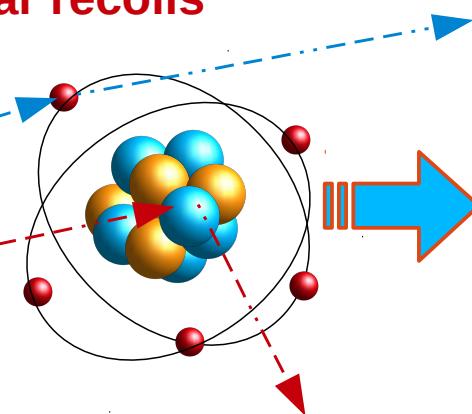
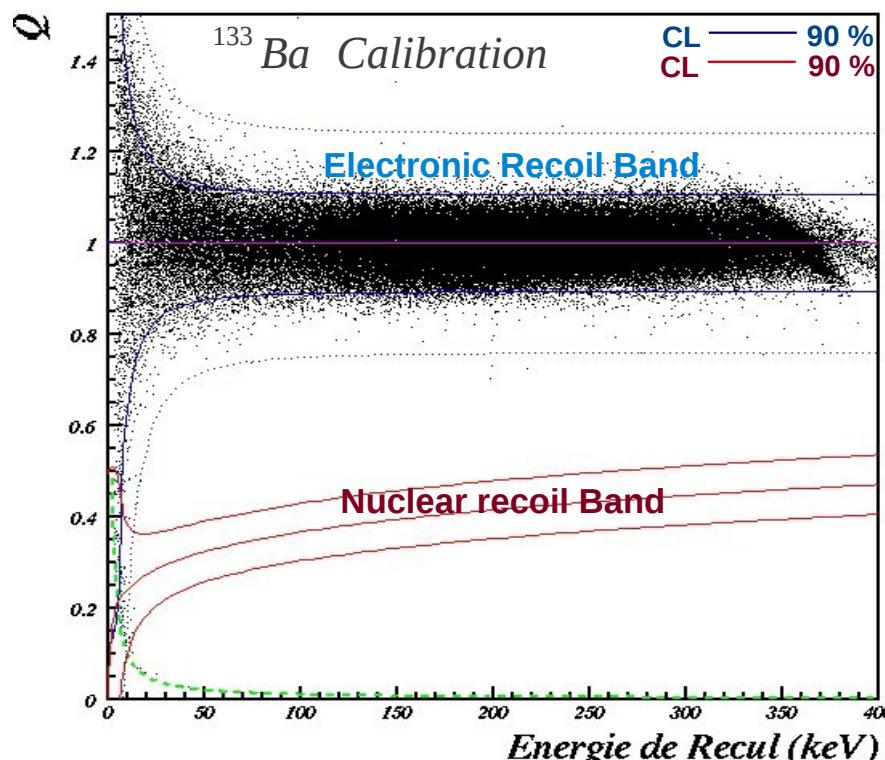
Capability to reject electronic recoils from nuclear recoils

Ionization yield Q defined as : Ionization / Recoil Energy

Q normalized to 1 for electronic recoils : e^-, γ

$Q = 0.16 E_R^{0.18}$ for nuclear recoils : WIMP, n

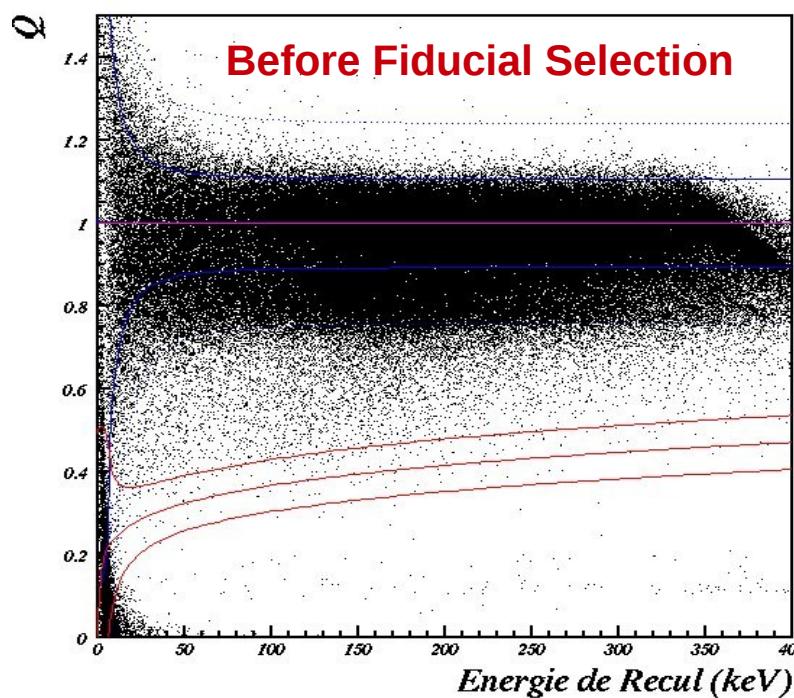
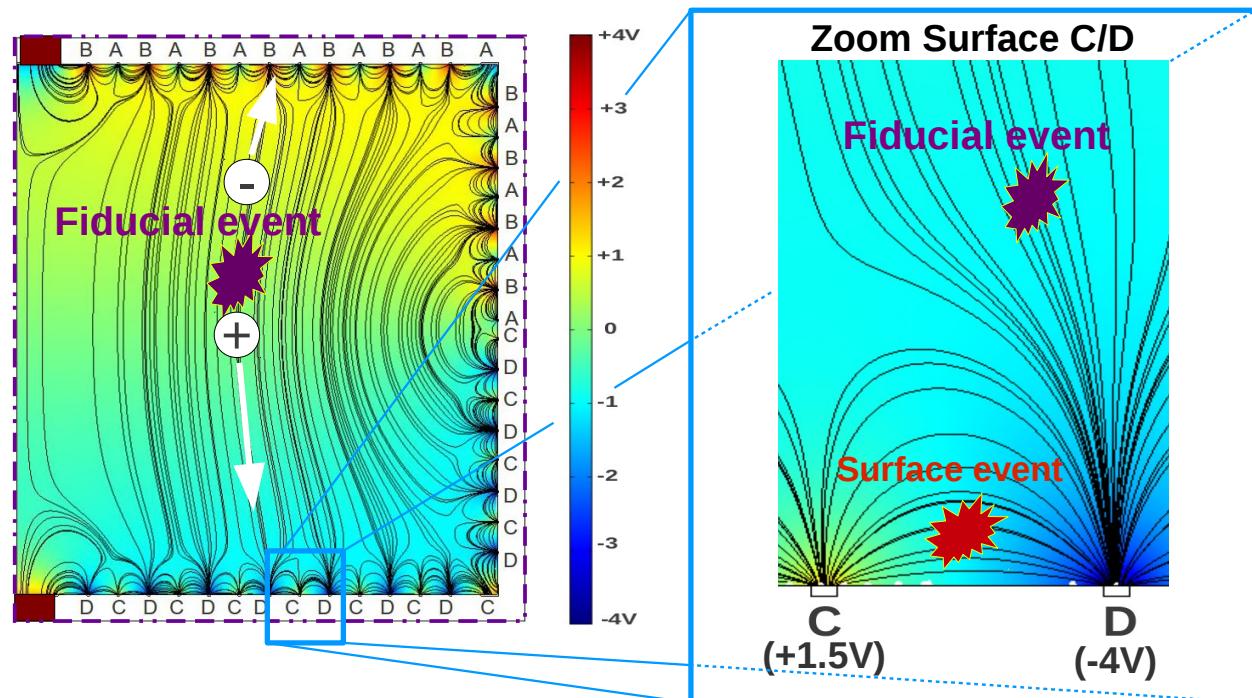
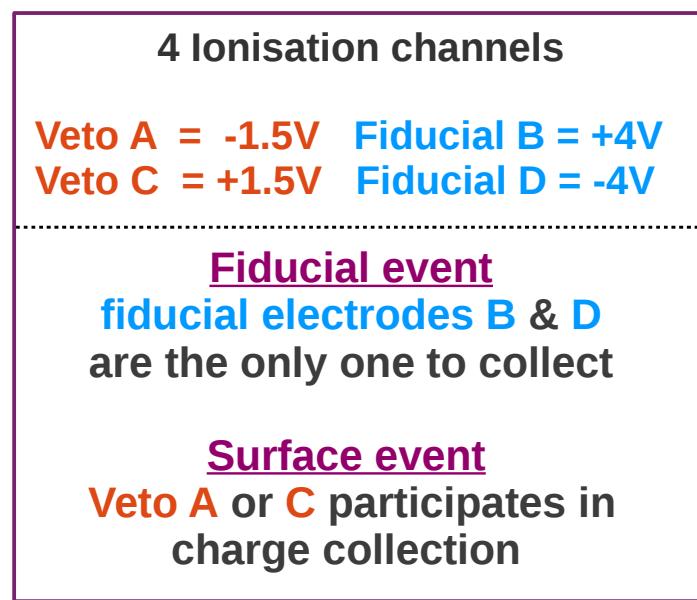
The recoil energy E_R is deduced from the Ionization and Heat measurements.



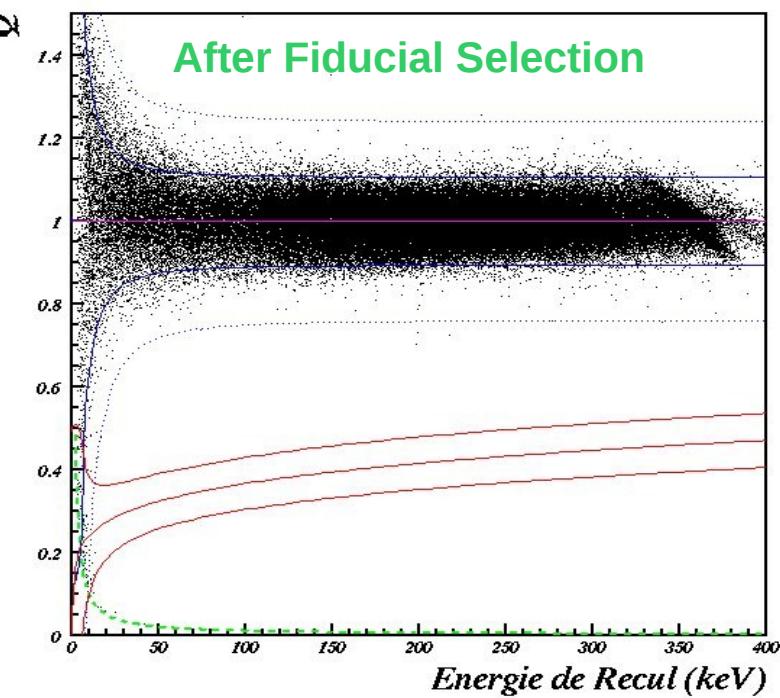
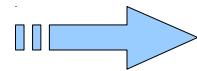
Gamma rejection better than 10^5 for Er above 20keV

Confidence levels are determined both by baseline resolutions on Heat and Ionization channels, voltages and resolutions at high energies.

Any resolution improvement is of major importance for the discrimination of radioactivity from background origin.



Rejection of
Surface events



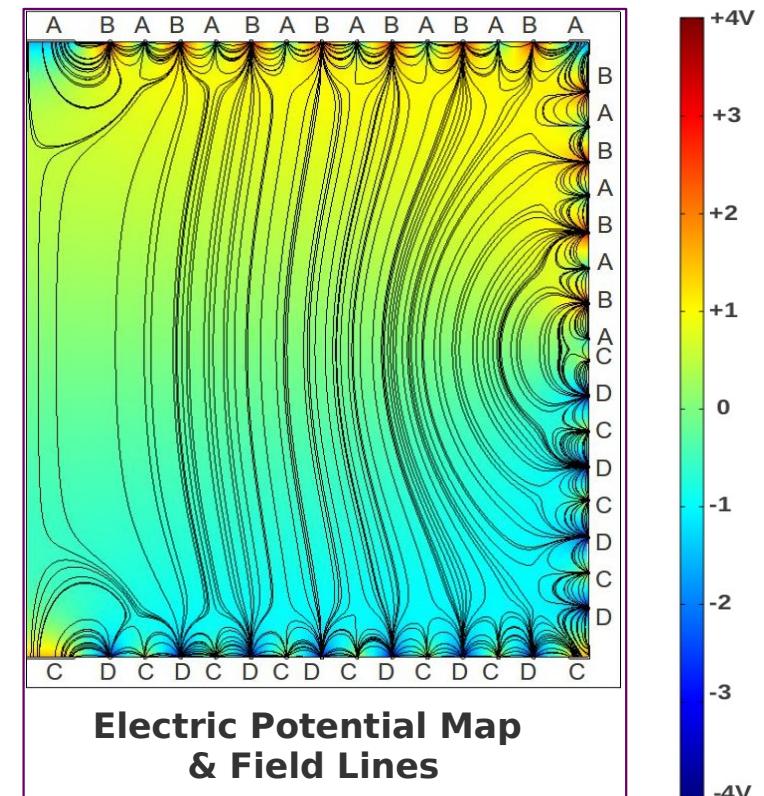
In semiconductors for one pair e-/h+

$$Q_K = -e \left(\Phi_K(\vec{r}_{hF}) - \Phi_K(\vec{r}_{eF}) \right)$$

Induced charge on electrode K
(Signal)

Weighting potentiels at final positions of charges

On dira Potentiels de Ramo



In semiconductors for one pair e-/h+

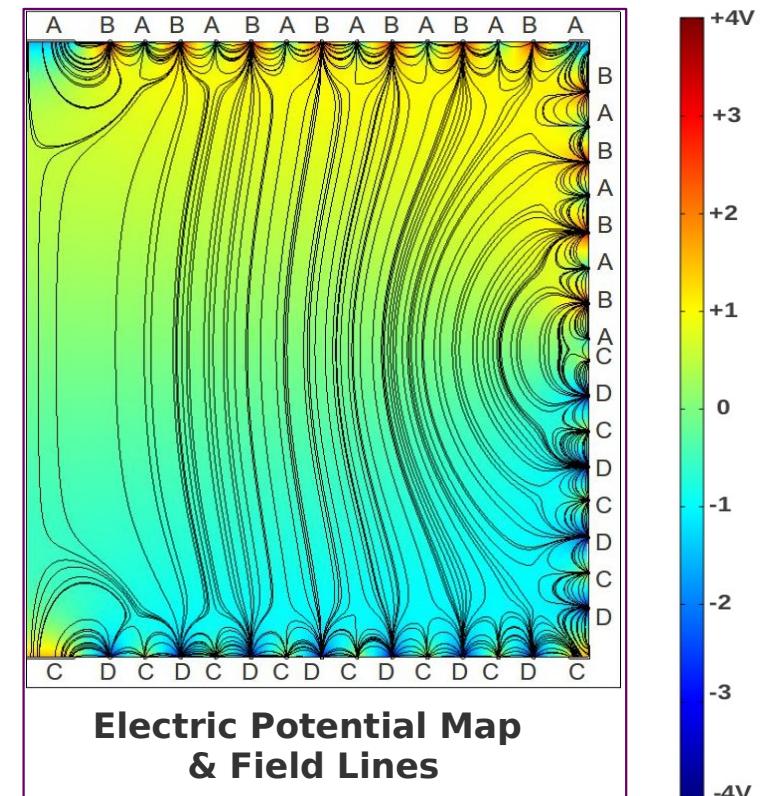
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Weighting potentials are associated to a given set of electrodes : A,B,C or D



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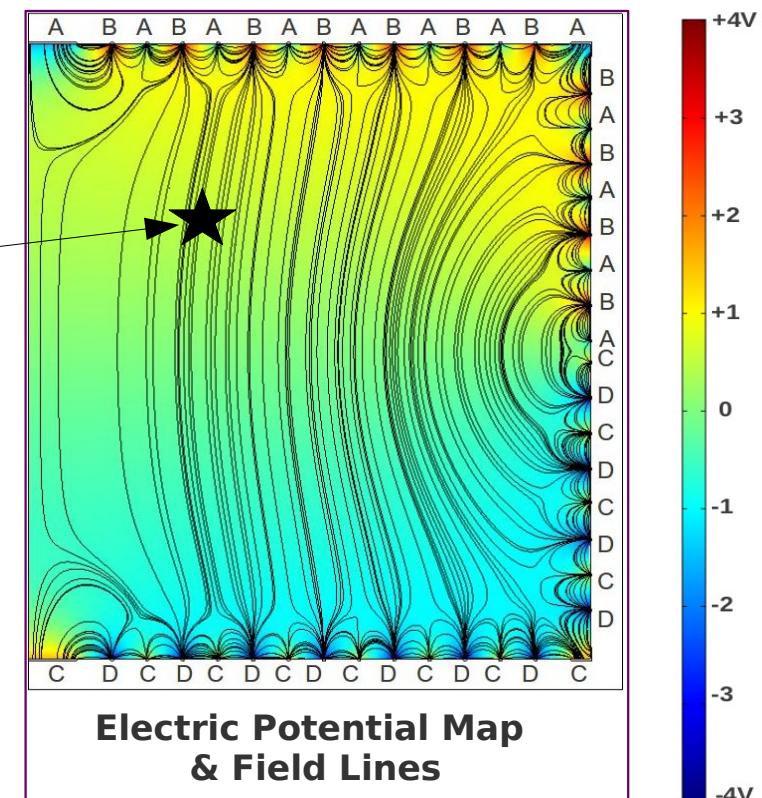
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Simply obtained by setting to one Volt the
considered electrode....
... and grounding all the other ones

Ex : $\Phi_C(\vec{r}_{star})$?



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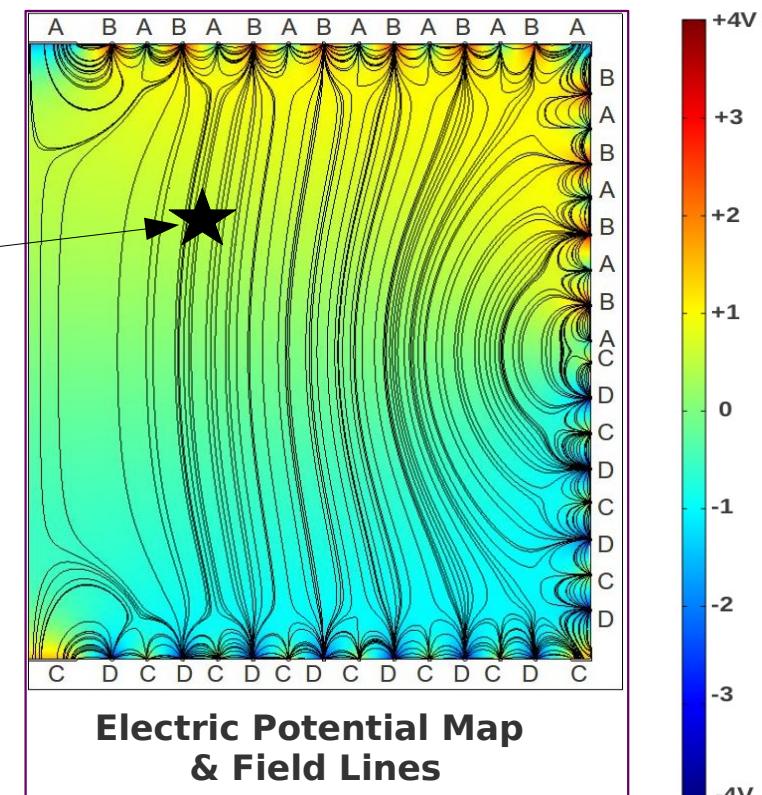
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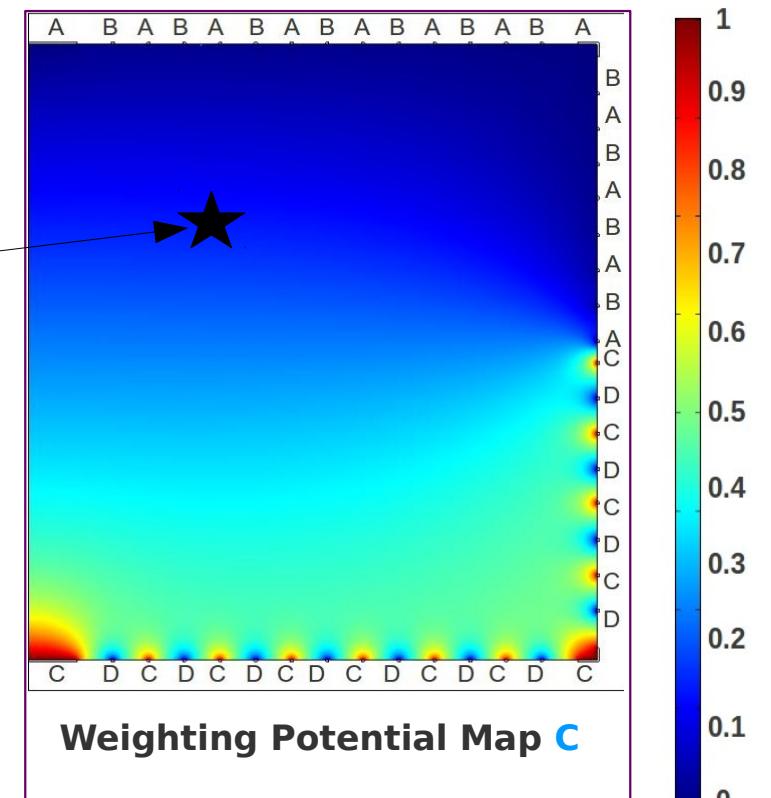
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Ex : $\Phi_C(\vec{r}_{star}) = 0.1$



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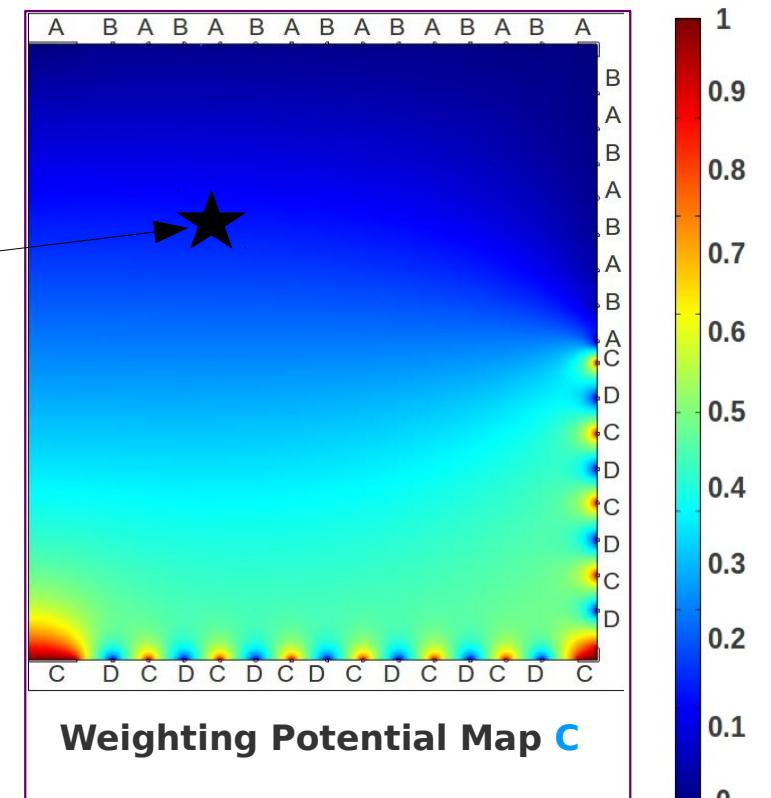
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$\Phi_A(\vec{r}_{star}) ?$



In semiconductors for one pair e-/h+

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Weighting potentials at final positions of charges

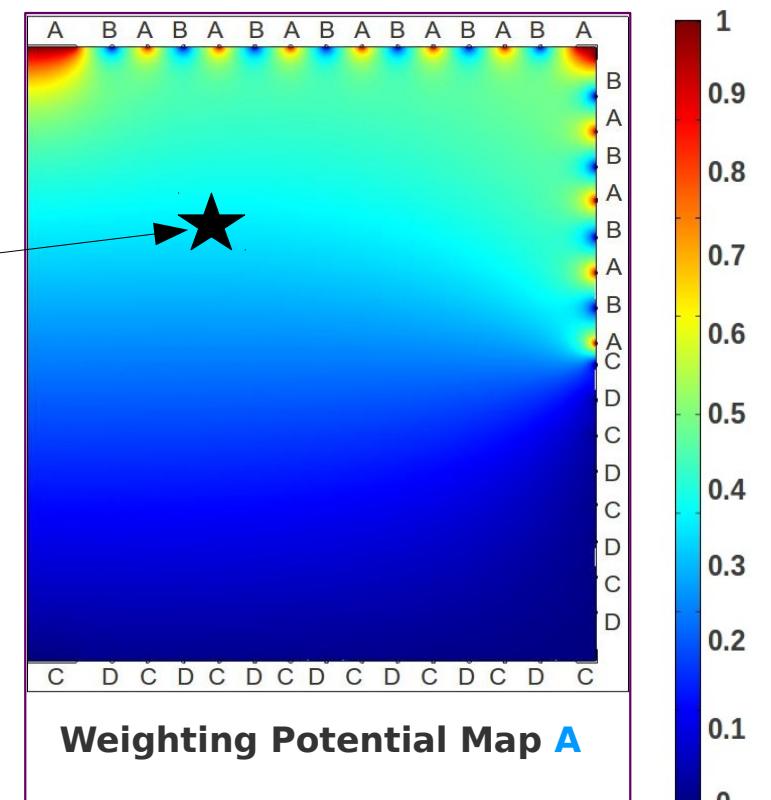
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Ex : $\Phi_C(\vec{r}_{star}) = 0.1$

$$\Phi_A(\vec{r}_{star}) = 0.4$$



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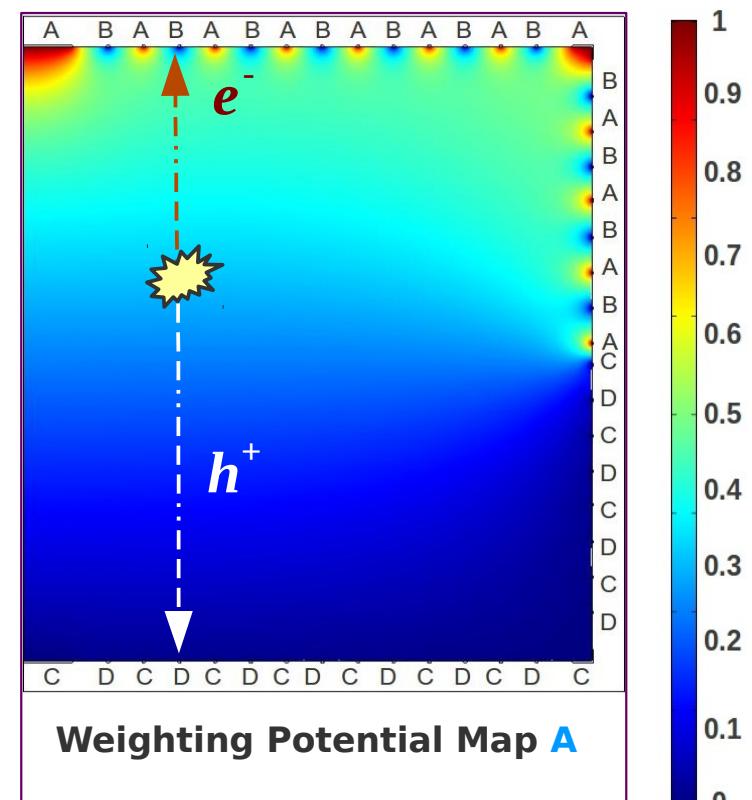
On dira Potentiels de Ramo

Simple example of one pair e-/h+

Ex: hole collected on D & electron collected on B

$$Q_A = -e \left(\Phi_A(\vec{r}_{hF}) - \Phi_A(\vec{r}_{eF}) \right) = 0$$

$$= 0 \qquad \qquad = 0$$



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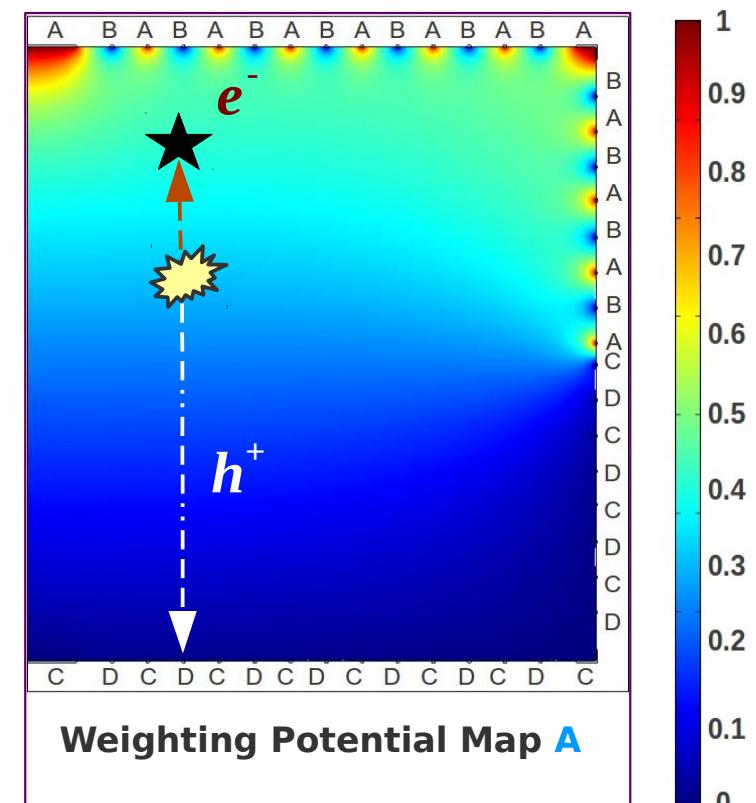
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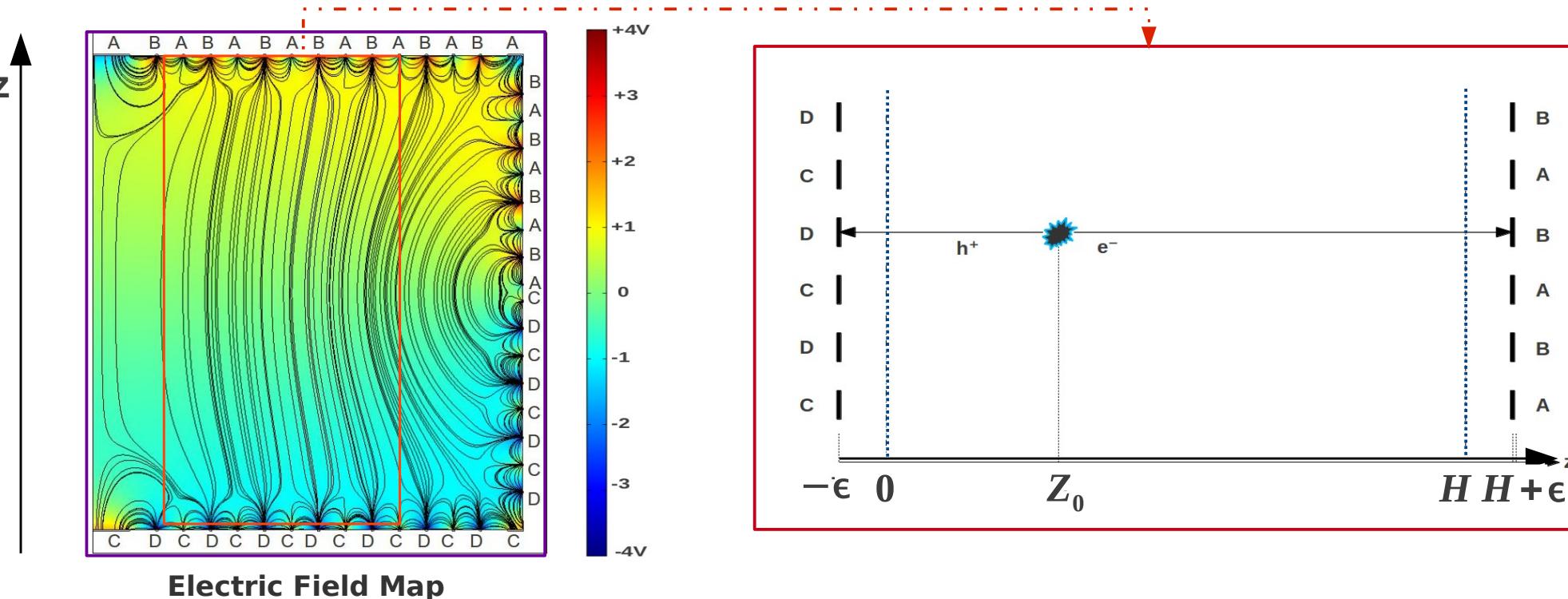
Ex: hole collected on D & electron trapped

$$Q_A = -e(\Phi_A(\vec{r}_{hF}) - \Phi_A(\vec{r}_{eF})) = e\Phi_A(\vec{r}_{eF}) = 0.4e$$

$$= 0$$

Veto signals are expected even for fiducial events
due to charge carrier trapping





Drift of charge carriers along z
with mean trapping lengths

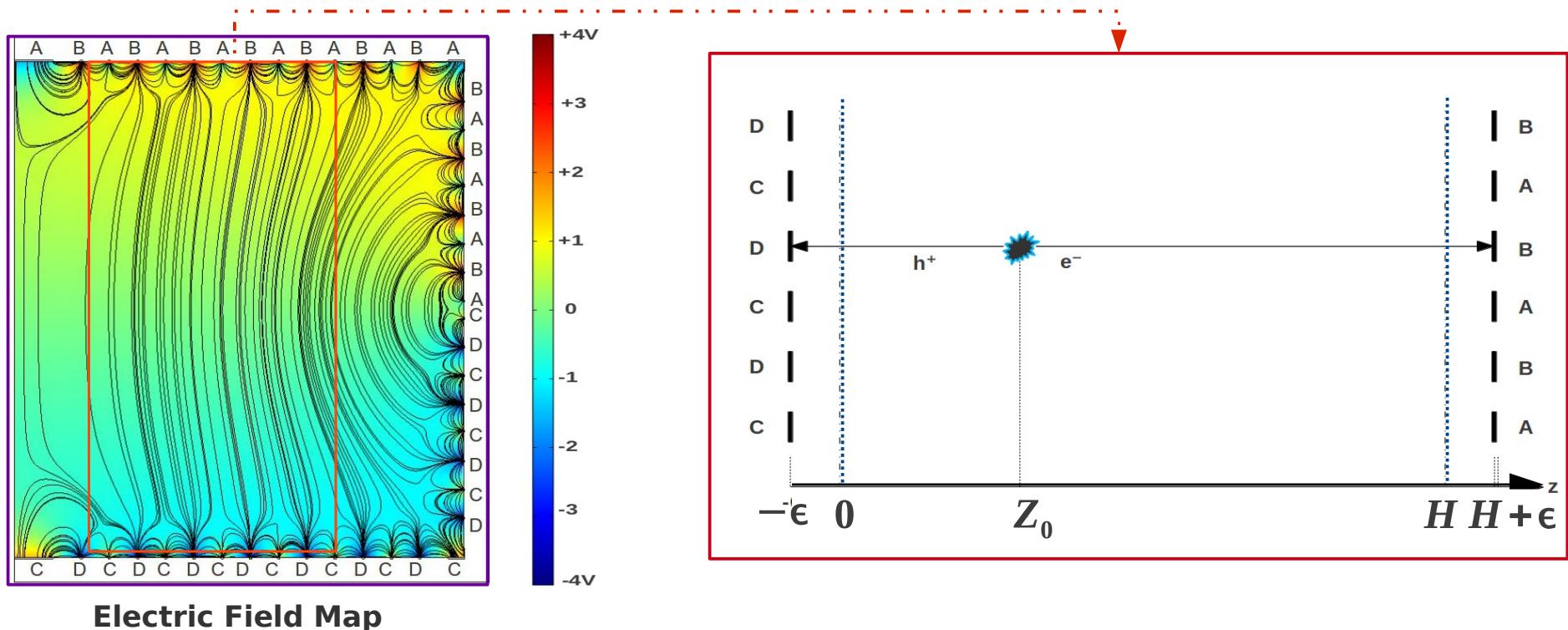
Approximation of homogenous electric field

For N_p pairs created at $z = Z_0$:

$$N_e(z) = N_p e^{-\mu_e(z - Z_0)} \quad N_h(z) = N_p e^{\mu_h(z - Z_0)}$$

Trapping outside the bulk is neglected

Higher electric field at the near-surface region



$$Q_K = \sum_{N_p} -e (\Phi_K(\vec{r}_{hF}) - \Phi_K(\vec{r}_{eF}))_n$$

Charge induced by trapping on veto electrodes

$$Q_{(A,C)}(Z_0) = -e \left(\int_{z=0}^{Z_0} \mu_h N_p e^{\mu_h(z-Z_0)} \Phi_{(A,C)}(z) dz - \int_{z=Z_0}^H \mu_e N_p e^{-\mu_e(z-Z_0)} \Phi_{(A,C)}(z) dz \right)$$

Trapped holes (z) Trapped electrons (z)

With a first order extrapolation :

$$EIA - EIC = \frac{eN_p}{2} ((\mu_e + \mu_h) Z_0 - \mu_e H)$$

$$EIA + EIC = \frac{eN_p}{2(H + 2\epsilon)} (\mu_e + \mu_h) (Z_0^2 - Z_0 H)$$

$$EIA - EIC \propto Z_0$$

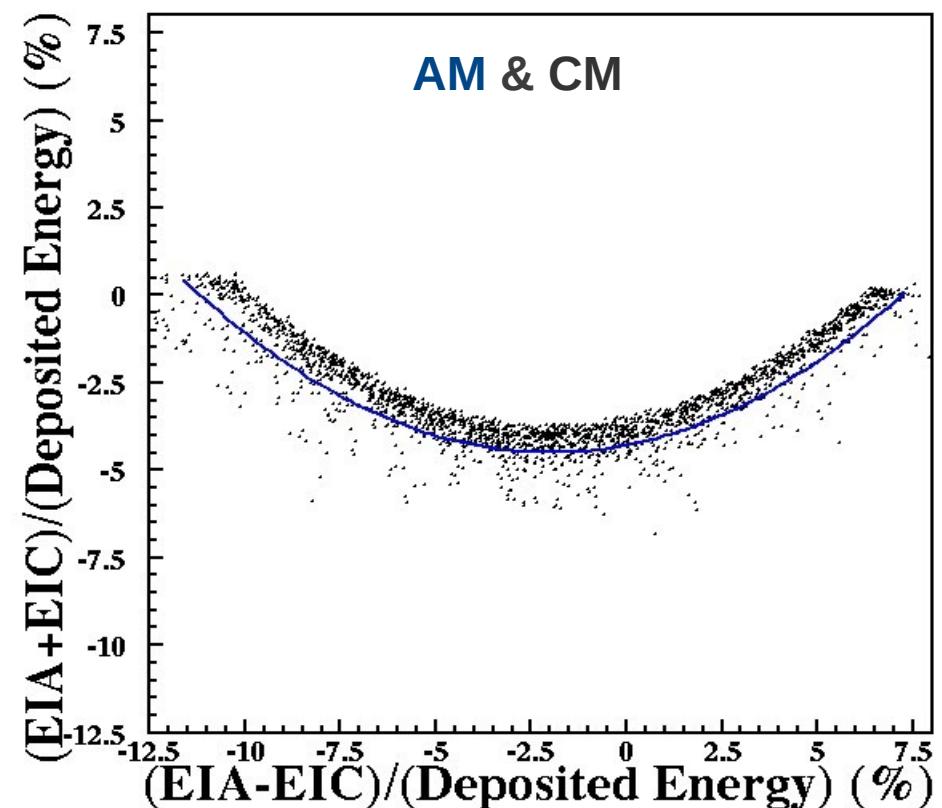
EIA+EIC vs EIA-EIC : parabola shape

CM : Drift of charges along field lines

AM : Drift of charges along z axis

CM : Surface region is taken into account.

AM : Trapping neglected out of the bulk

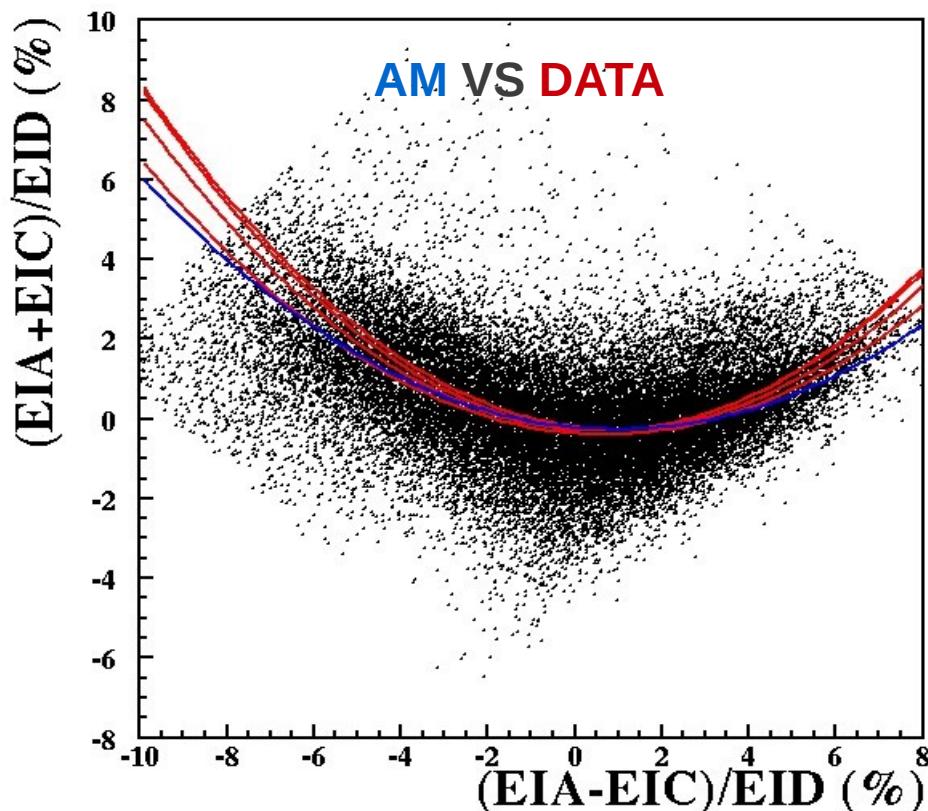


Black markers : computational model
Blue line : AM function

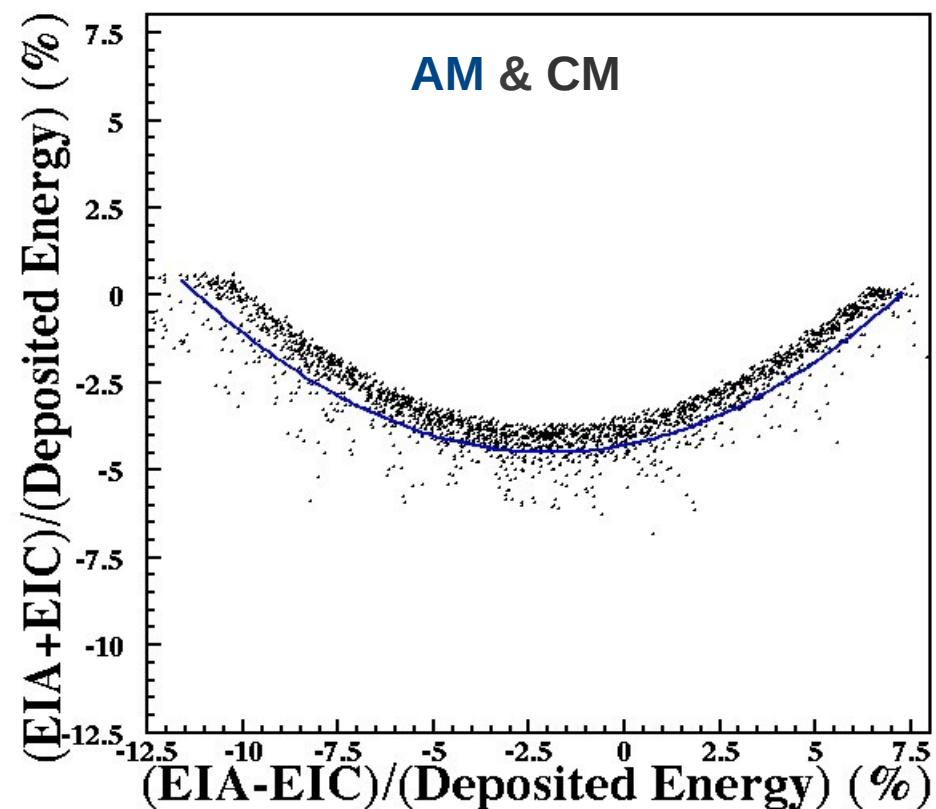
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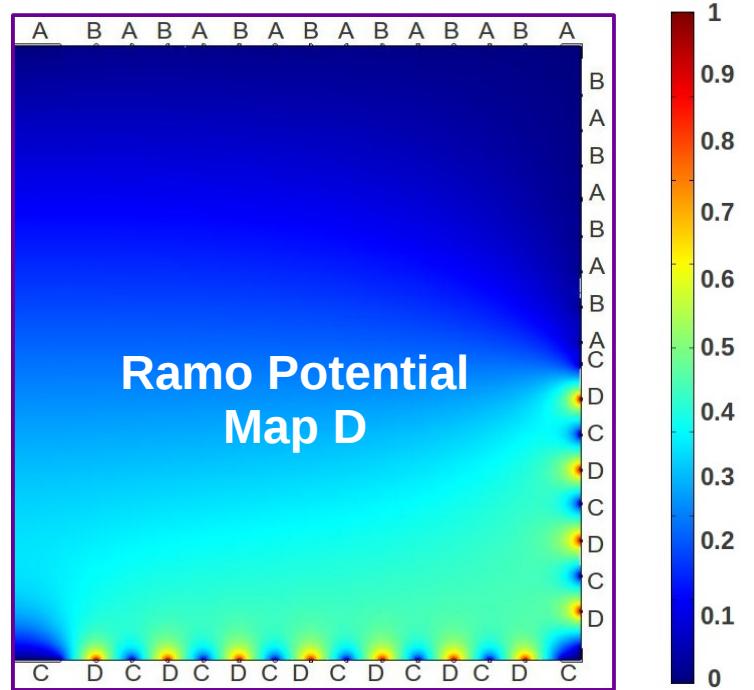
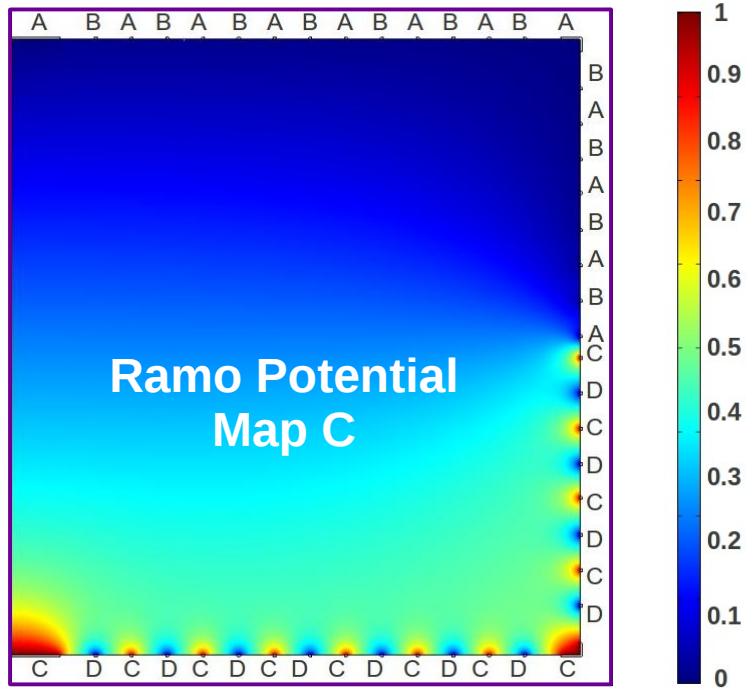
$$EIA + EIC = \frac{eN_p}{2(H + 2\epsilon)} (\mu_e + \mu_h) (Z_0^2 - Z_0 H)$$



Black markers : events of one detector
Red lines : fits on various detector data
Blue line : AM function centered at zero



Black markers : computational model
Blue line : AM function



Induced charge due to Trapping

1

Charge collection

2

Total Induced Charge

$$\Phi_C(Z_0) = \Phi_D(Z_0) \text{ In the bulk region } 0 < z < H$$

Induced charge on D = induced charge on C

$$Q_D(Z_0) = eN_p e^{-\mu_h Z_0}$$

Holes reaching Z=0 (and thus D)

$$Q_D(Z_0) = Q_C(Z_0) - eN_p e^{-\mu_h Z_0}$$

**A collected charge induces the
opposite of its charge**

Energy loss on EID $\propto Z_0$

EIA - EIC $\propto Z_0$

Energy loss on EID $\propto EIA - EIC$

Z_0 : energy deposit depth

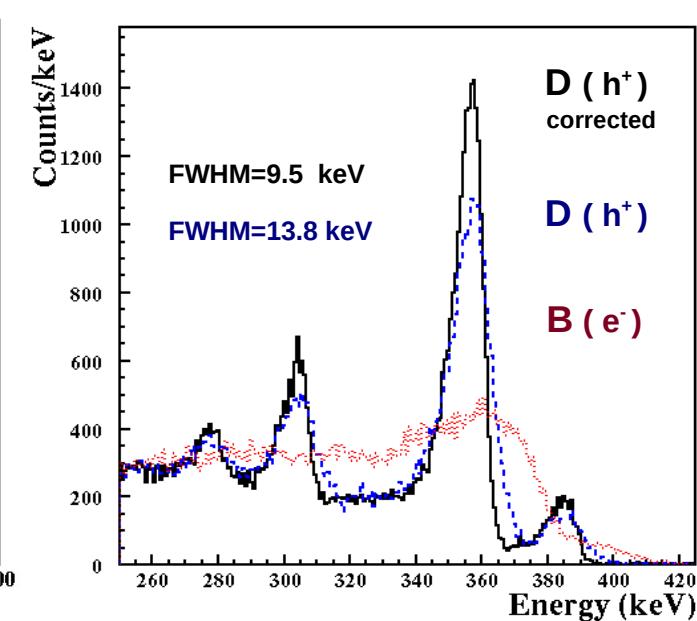
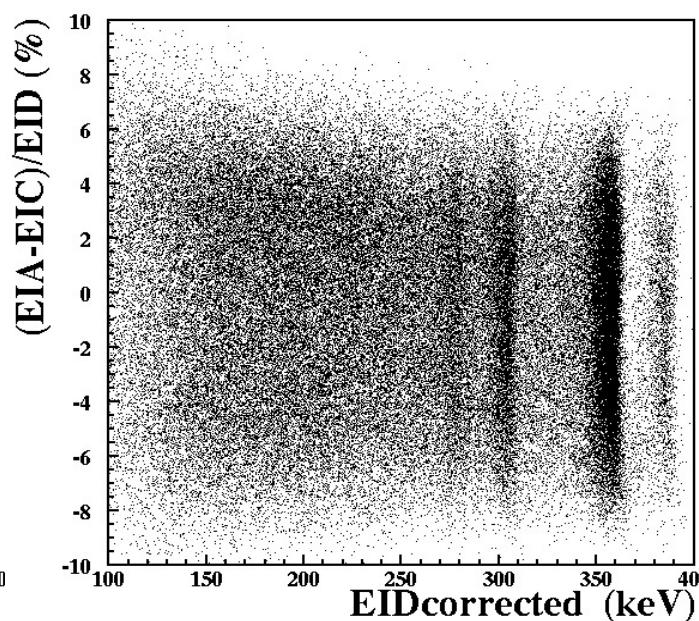
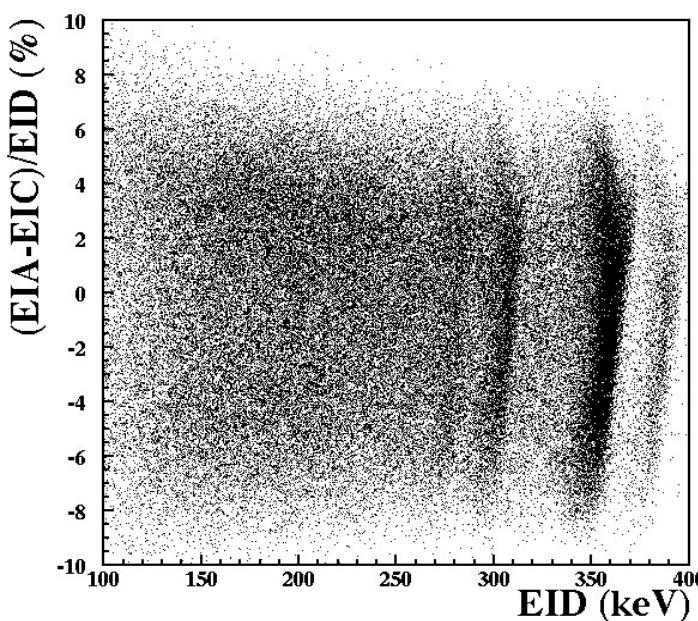
EIA : energy veto A

EIC : energy veto C

Before correction

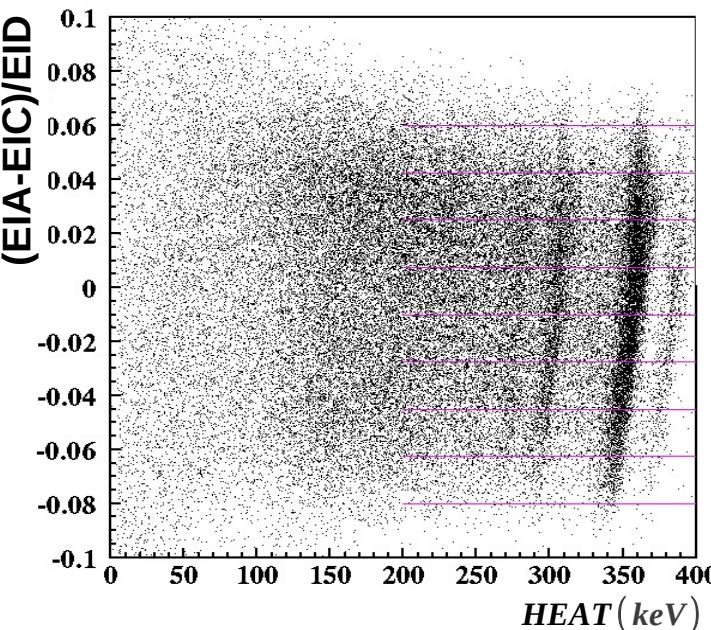
After correction

¹³³Ba Calibration FID 804 Run 15

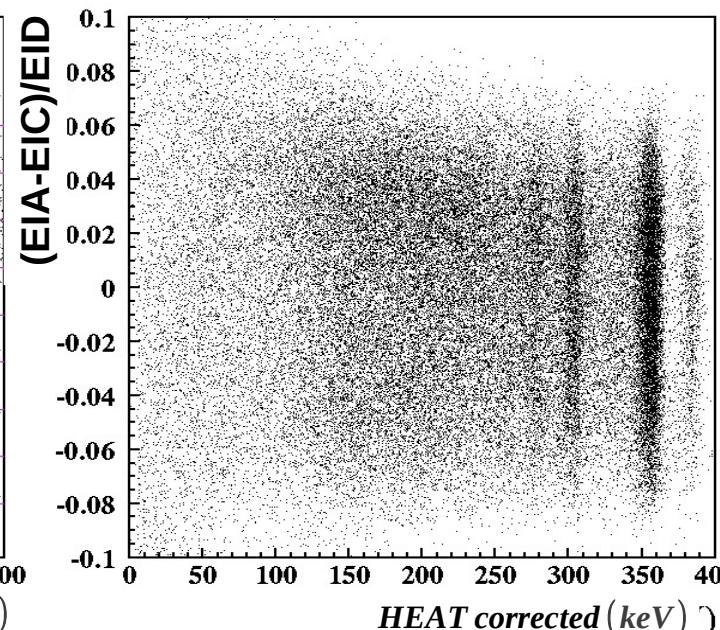


30 % improvement of the resolution at 356 keV

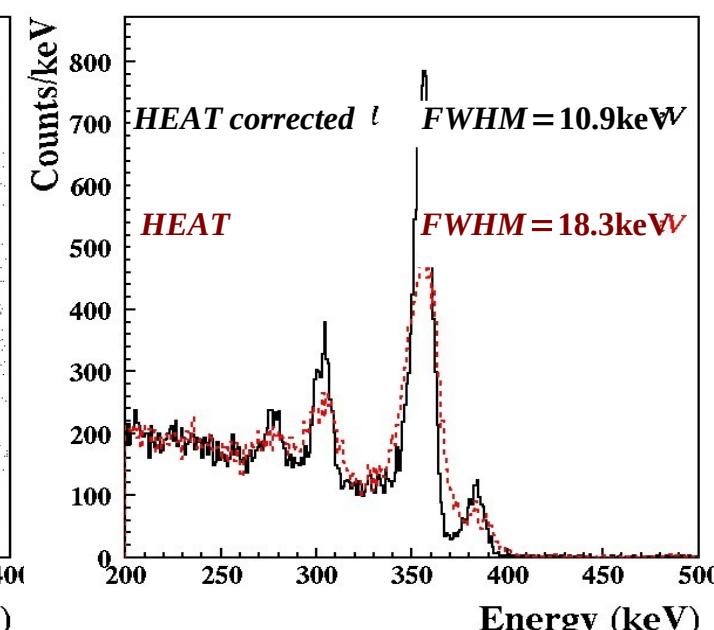
Before correction



After correction



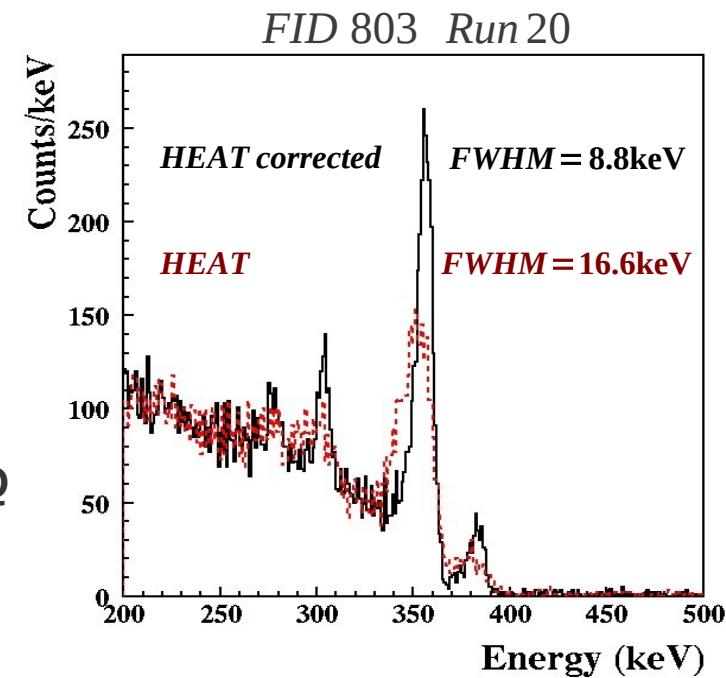
FID 804 Run 15



40 to 45% improvement of the Heat resolution at 356 keV

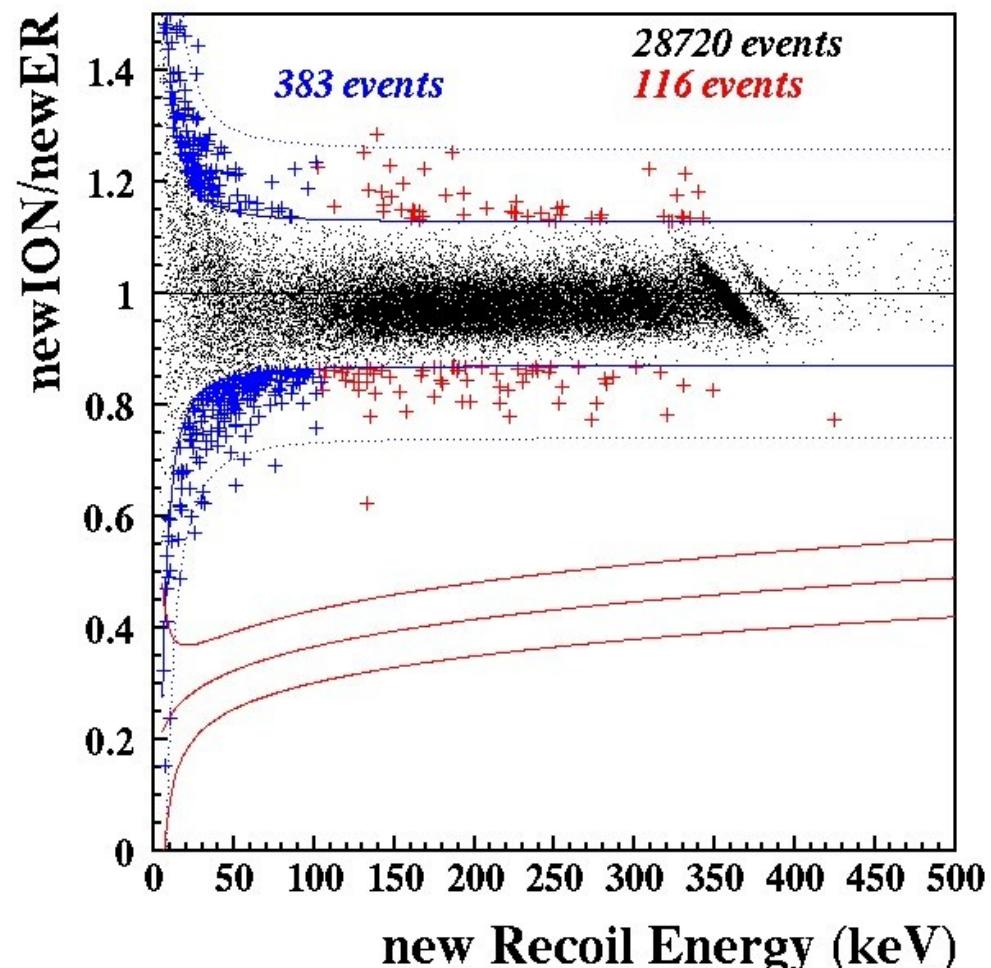
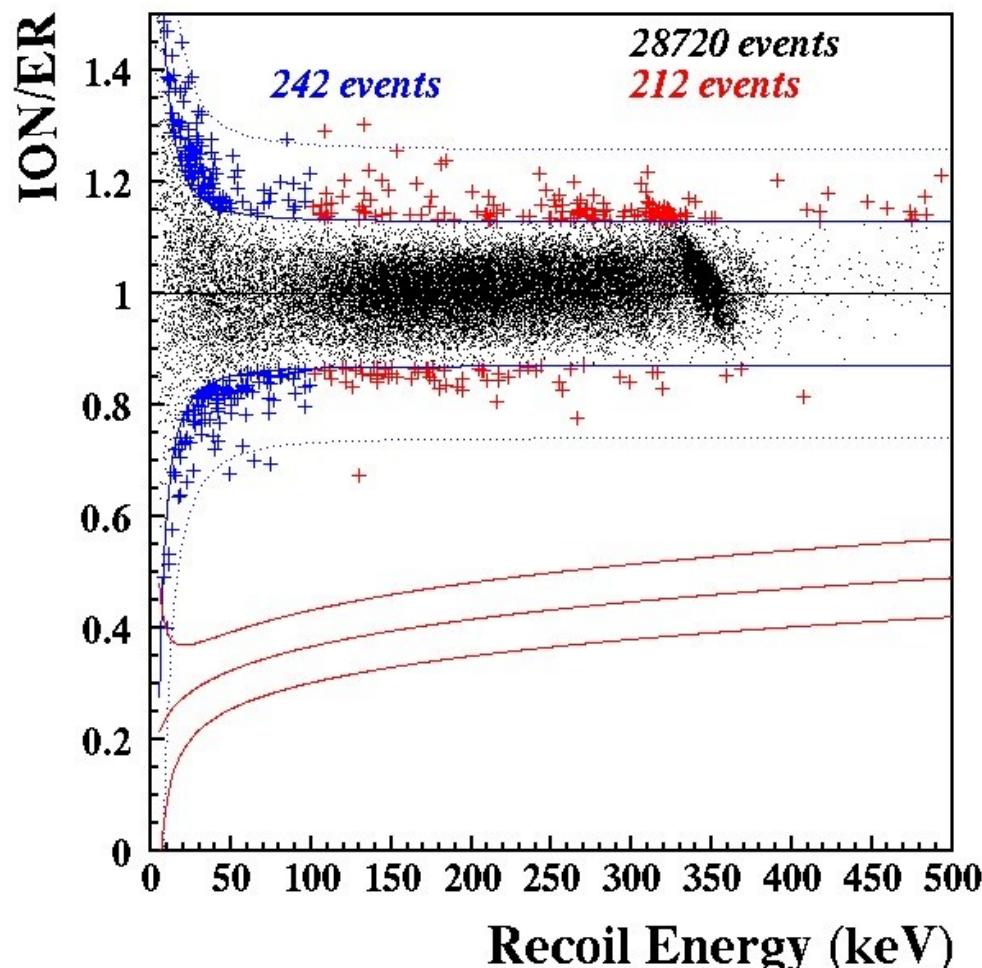
$$E_{\text{Heat}} = E_{\text{Recoil}} + E_{\text{Luke}}$$

Heat correction : depends on Z0 but also on the ionization yield Q



Before correction

FID 803 Run 20

After correction**Efficient correction above 100keV****Degradation of the Qplot below 100keV as expected**

Conclusion

Ionization : Analytical Model, improvement of the resolution (30 % at 356 keV)

Heat : Analytical Model, improvement of the resolution (40-45 % at 356 keV)

Also an improvement of the rejection at high energy

Perspectives

Necessity define a unique measurement of the ionization

-Using both fiducial anode B and cathode D at low energy
Resolution mostly limited by the noise (win a factor $\sqrt{2}$)

-Using corrected ionization at high energy
Resolution mostly limited by trapping

And this with a smooth transition from one energy regime to the other

Also working on defining new fiducial cuts taking into account veto correlations induced by trapping...

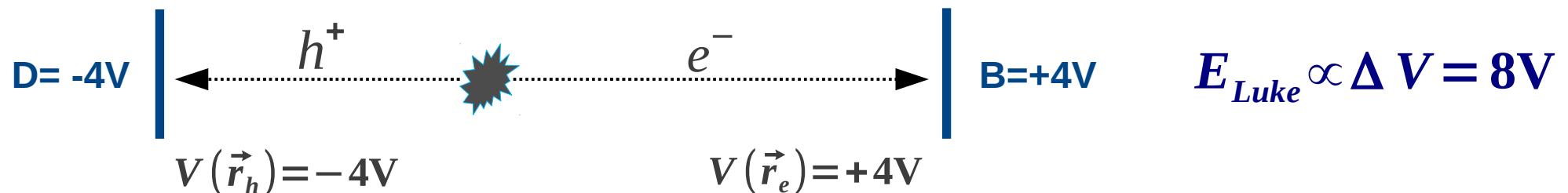
} IDEM for Heat

Au cas où

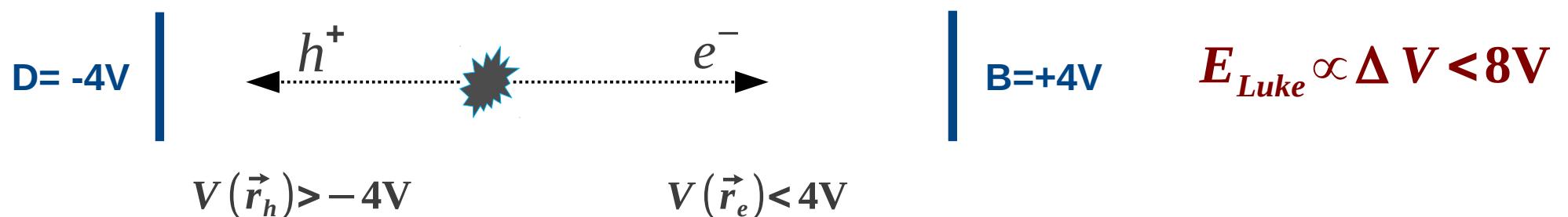
Trapping effect on Heat signals

$$E_{Luke} \propto (V(\vec{r}_e) - V(\vec{r}_h))$$

Non trapping case



Trapping case



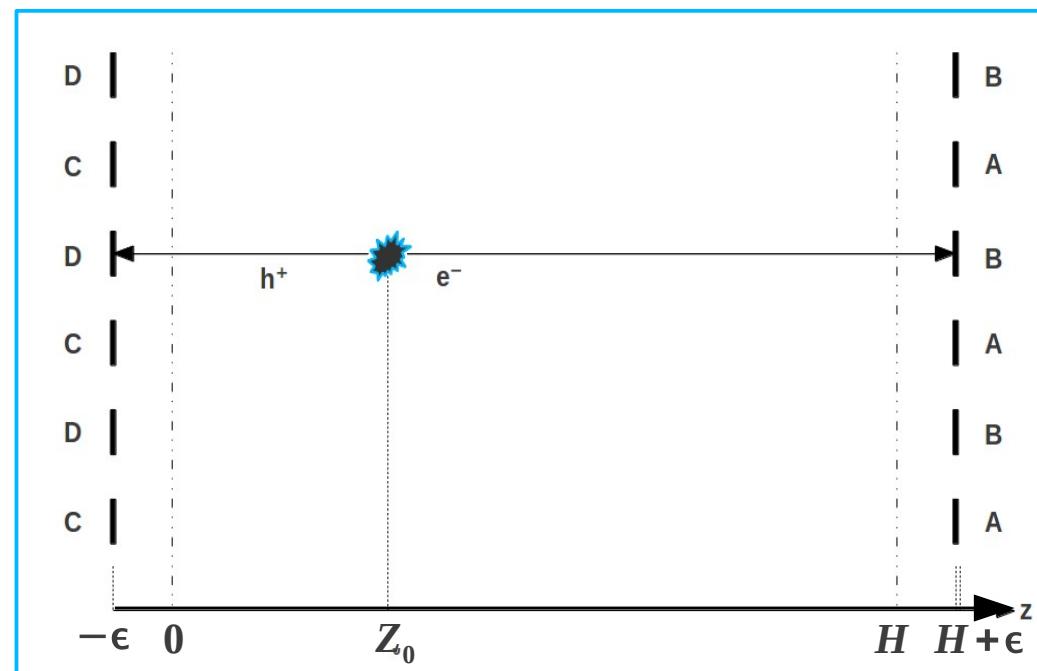
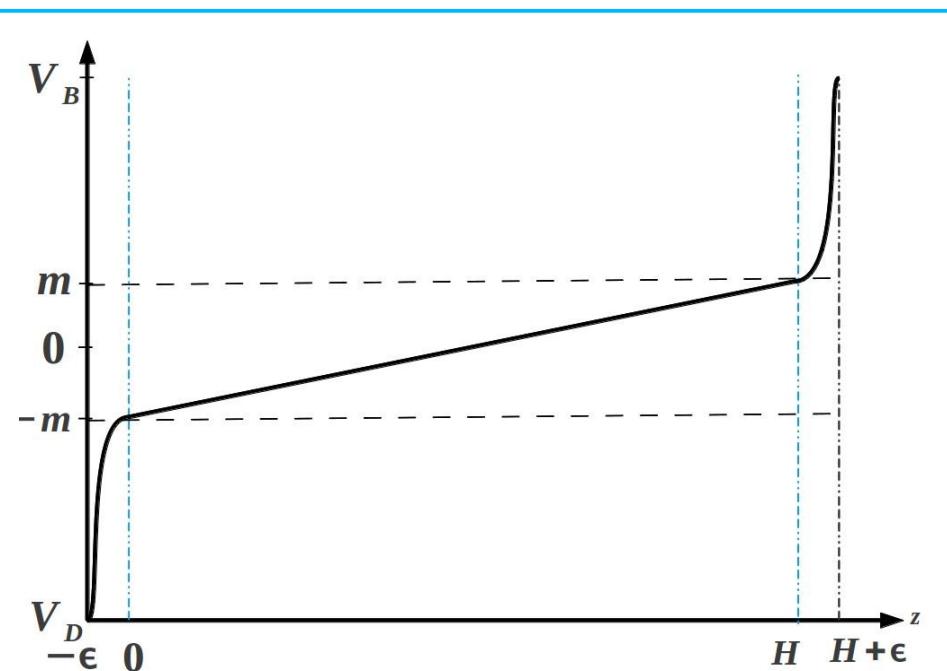
Luke Effect and therefore Heat lowered by charge carrier trapping

Analytical Model

$$E_{Luke} = e \sum_{i=1}^N (V(\vec{r}_e) - V(\vec{r}_h))_i$$

$$E_{Luke} = e N_p \left(\int_{z=Z_0}^H \mu_e e^{-\mu_e(z-Z_0)} V(z) dz - \int_{z=0}^{Z_0} \mu_h e^{\mu_h(z-Z_0)} V(z) dz + e^{-\mu_e(H-Z_0)} V_B - e^{-\mu_h Z_0} V_D \right)$$

electrons holes electrons holes
Trapped **Collected**



Direct Detection of Dark Matter 2/2

How to distinguish a neutron from a Wimp ?

non-exhaustive list :

- * Neutrons can induce multiple interactions, WIMPs can't !

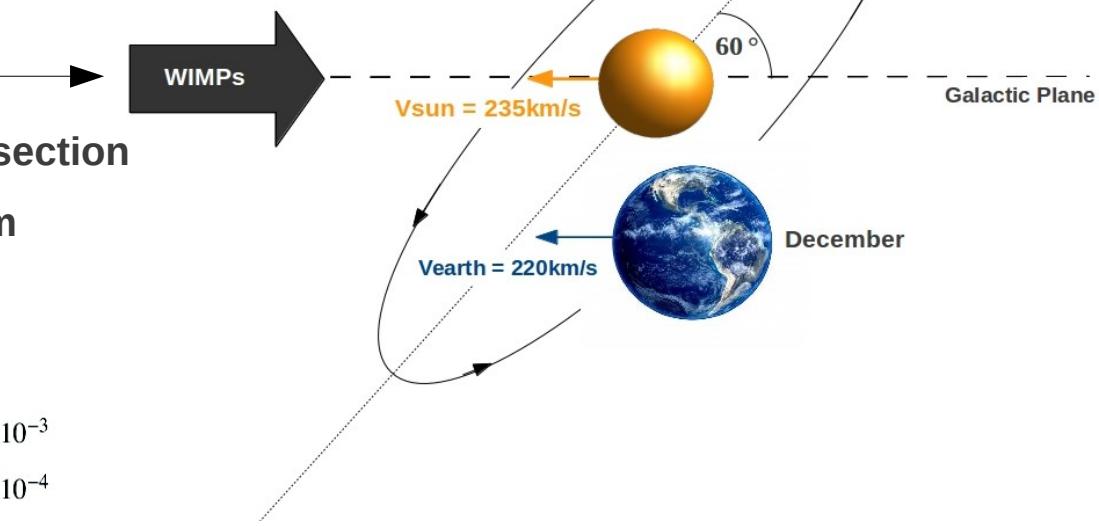
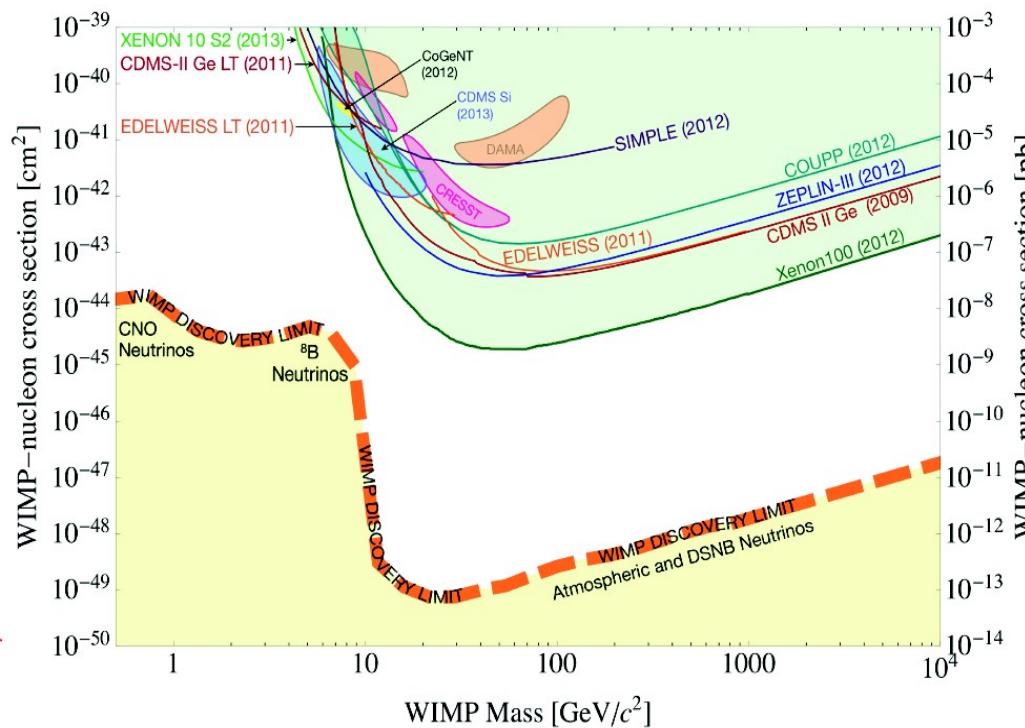
If coincidence between 2 detectors → neutron

- * Annual modulation of WIMPs flux of a few %

- * A^2 dependance of the Spin independent cross section

- * Exponential form of the Recoil energy spectrum

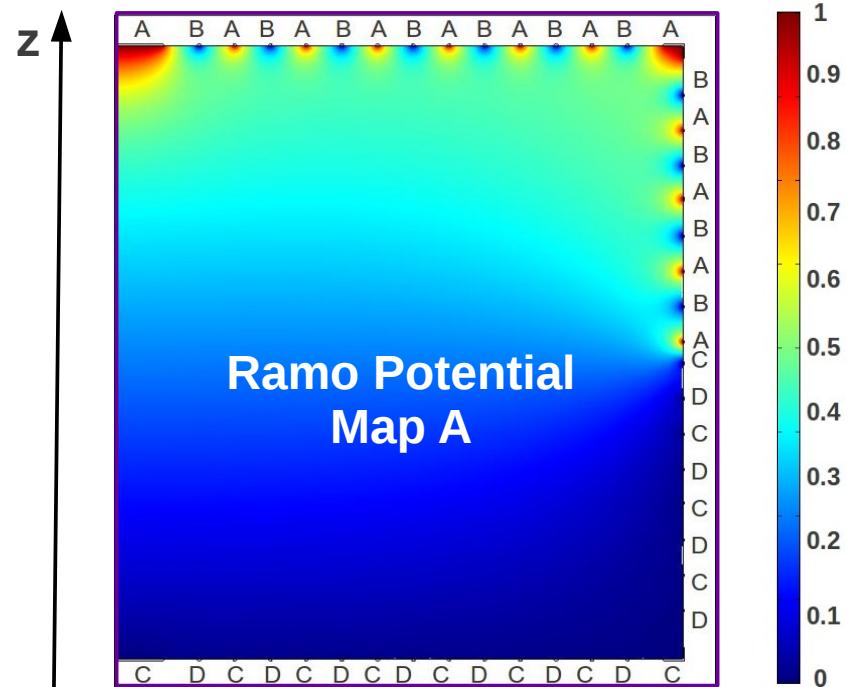
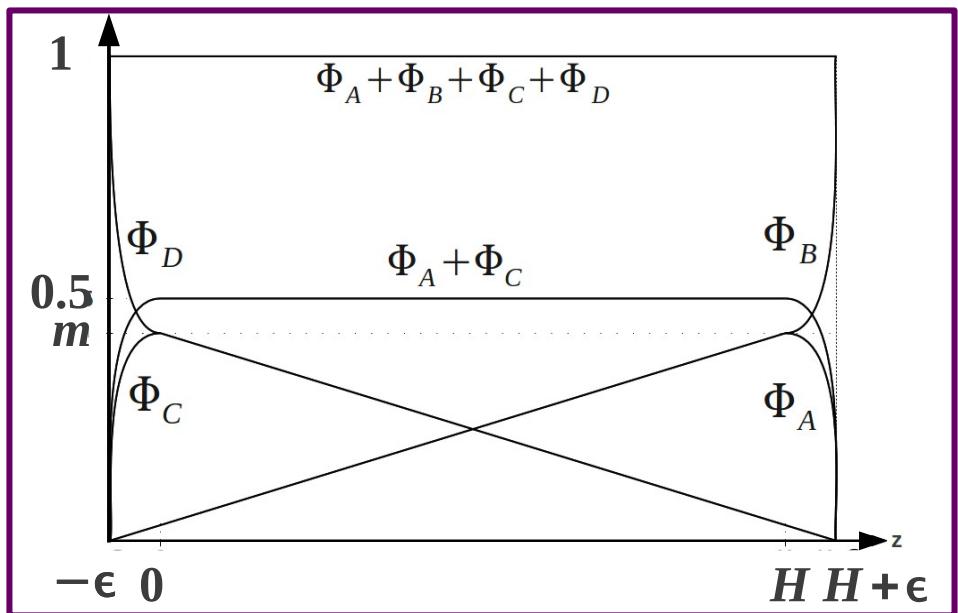
Need Statistics and variety of experiments



No signal doesn't mean No results

No Wimp signal with a certain exposure (Kg.days) gives a higher limit on the interaction cross section

Analytical Model



$$z \in [0, H]$$

$$\Phi_A(z) = \Phi_B(z) = \frac{z + e}{2(H + 2e)}$$

$$\Phi_C(z) = \Phi_D(z) = \frac{-z + H + e}{2(H + 2e)}$$

Charge induced by trapping on veto electrodes

$$Q_{(A,C)}(Z_0) = -e \left(\int_{z=0}^{Z_0} \mu_h N_p e^{\mu_h(z-Z_0)} \Phi_{(A,C)}(z) dz - \int_{z=Z_0}^H \mu_e N_p e^{-\mu_e(z-Z_0)} \Phi_{(A,C)}(z) dz \right)$$

Trapped holes (z) Trapped electrons (z)