# Development of a **Gaseous Proton-Recoil Detector** for neutron flux measurements between 0.2 and 2 MeV neutron energy

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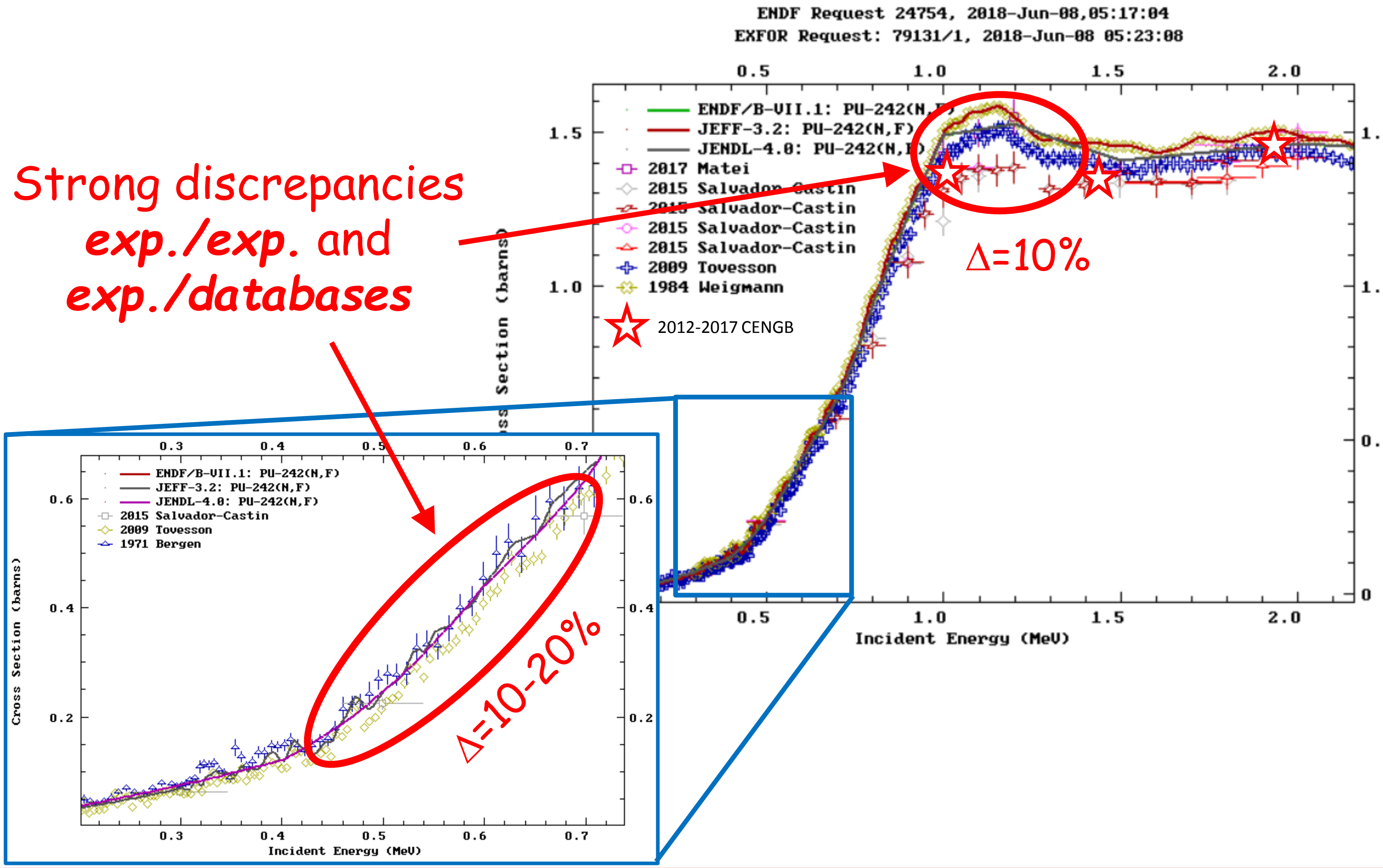
## Cross section measurement

$^{242}$Pu(n,f) measurement in the [200 keV ; 2 MeV] energy range



## Neutron flux measurement

Useful to normalize the cross section measurement (as well as for neutron beam line characterization, or dosimetry investigations…)

Usually, standard reactions are used : $^{235}U(n,f)$, $^{238}U(n,f)$, $^{237}Np(n,f)$

These standards are known with an accuracy of few % (from 0.5% to 10%)

## An independent measurement

Evaluators require independent measurements

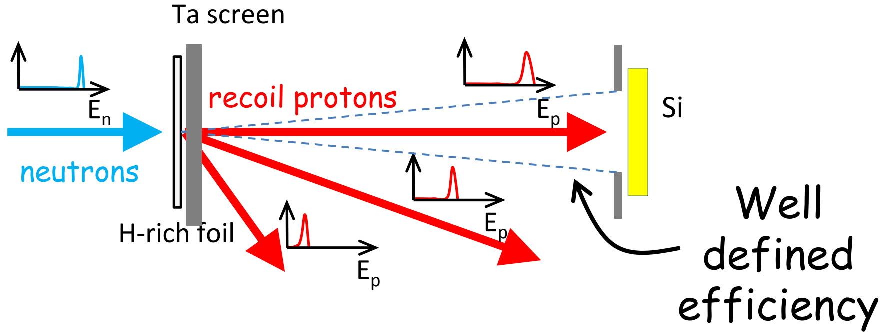
$^{1}H(n,p)$ reaction is a primary standard known with an accuracy around 0.2% in the MeV region

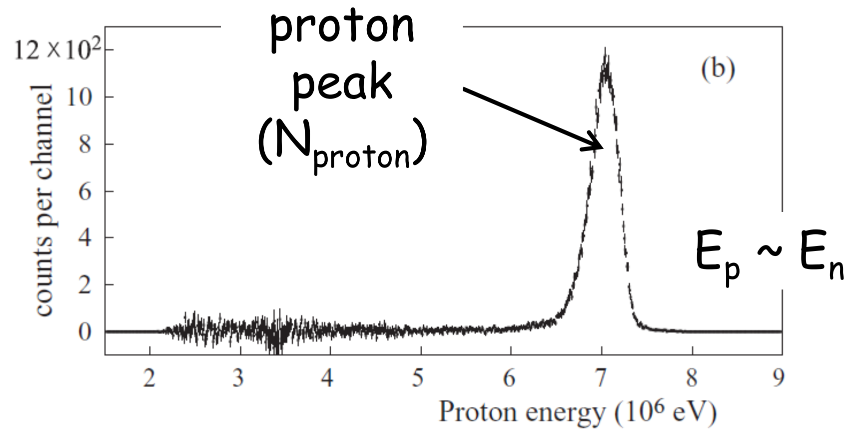
Especially, its application and detection are **completely different** from the other standards
(e.g. recoil proton detection VS fission fragments detection)

→ A real improvement in term of independence

# Principle

## Experimental setup :




**Si spectrum after usual background subtraction**

## Usual background :

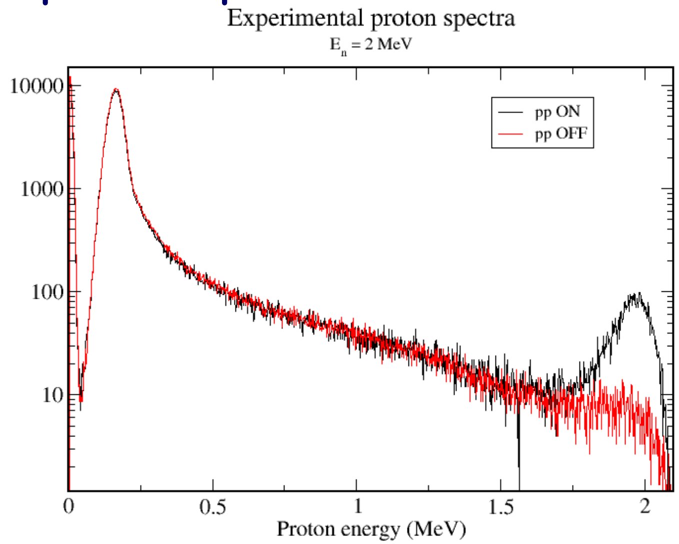
The Si detector may see other signals which have to be subtracted

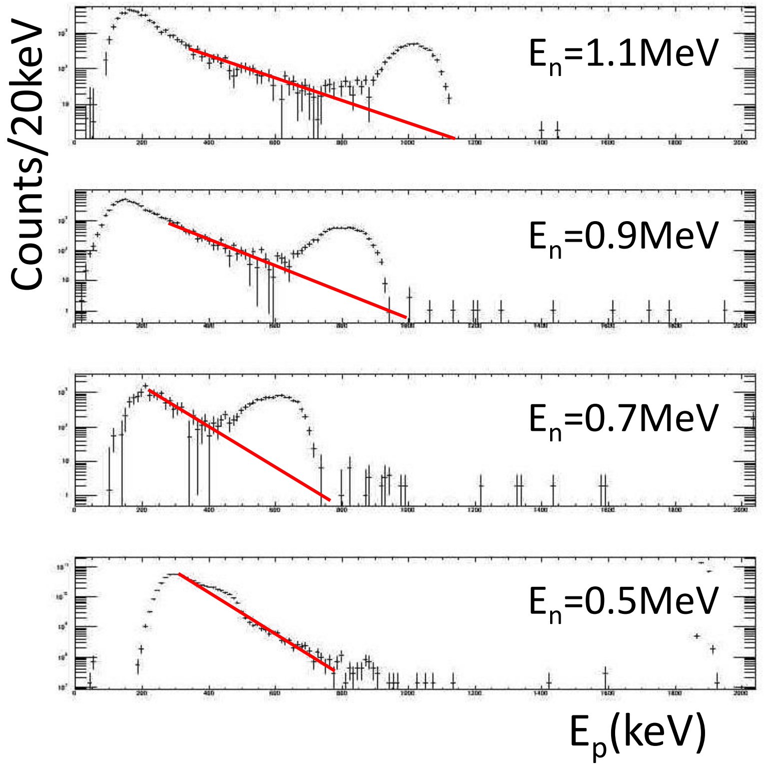
➡ Need for a background measurement (masking H-rich foil)

To obtain a precise neutron flux ($\Delta N_{proton}$~1%), the background has to be small enough

# A tremendous background

At low energy, the background is **hundred times** higher than the proton peak




*P. Marini et al., Nucl. Instr. and Meth. A, 841 (2017)*

**Non-ideal** background subtraction

➡ Remaining background

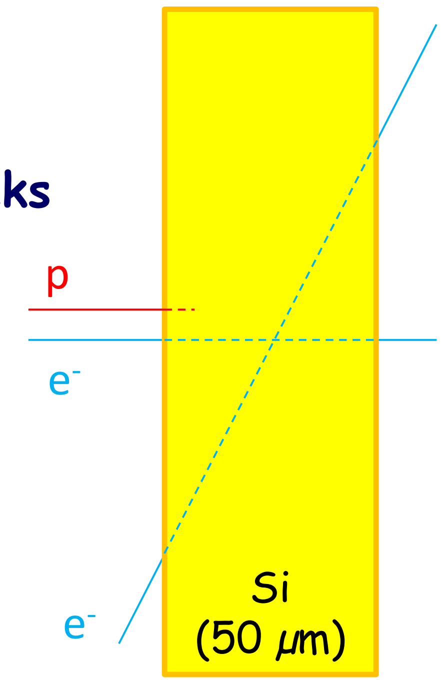
**Impossible to determine $N_{proton}$ better than 1% below 1 MeV**

# Background source

An experiment was carried out @AIFIRA to investigate this background :

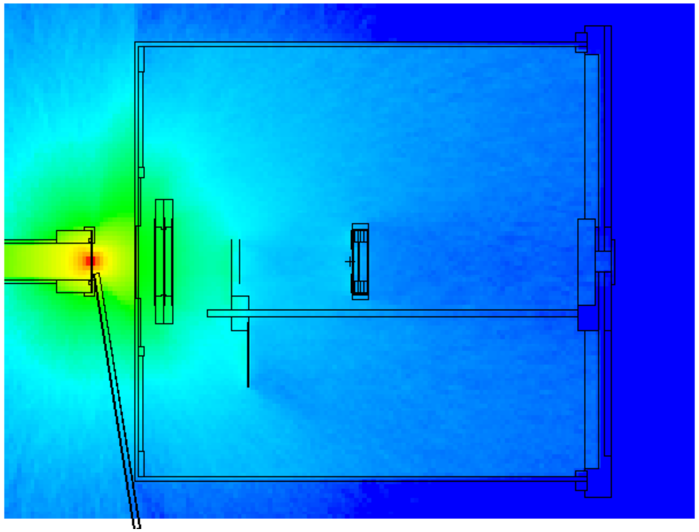
- present as soon as the beam is ON
- present even when the Si detector is masked

<u>electrons</u>
less 'MeV/µm' but :
. **whole Si depth** used
. possible **tangent tracks**
. more **multiple** events




Very high signal at few 100 keV (quickly decreasing with E)

Emitted by gamma-ray interaction



$e^-$ flux for a 1 MeV gamma-ray source (MCNP simulations)

# Background source

An experiment was carried out @AIFIRA to investigate this background :

- present as soon as the beam is ON
- present even when the Si detector is masked

<u>electrons</u>
less 'MeV/$\mu$m' but :
. **whole Si depth** used
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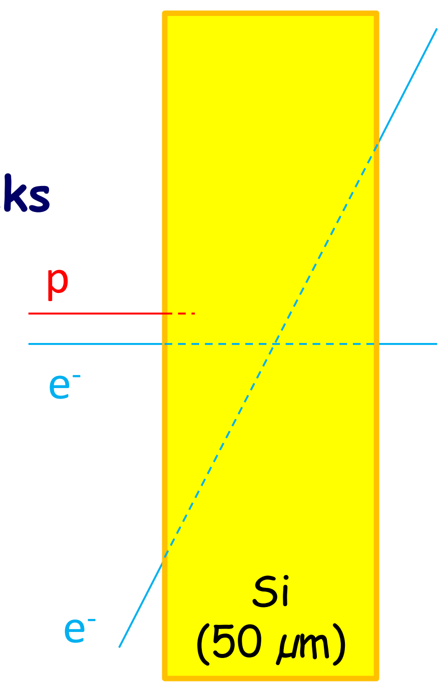



Emitted by gamma-ray interaction

These gamma-rays are mainly produced by (n,$\gamma$) reaction on the neutron source material

Very high signal at few 100 keV (quickly decreasing with E)

**They cannot be avoided**

# Main features

**Low sensitivity to electrons:** thickness adapted to proton range

Thinner Si detectors:
- need to be changed for each energy
- sensitive to irradiation
- more difficult to calibrate

Gaseous detector:
- gas pressure adapted to proton range
- much more complex

**Background events rejection**

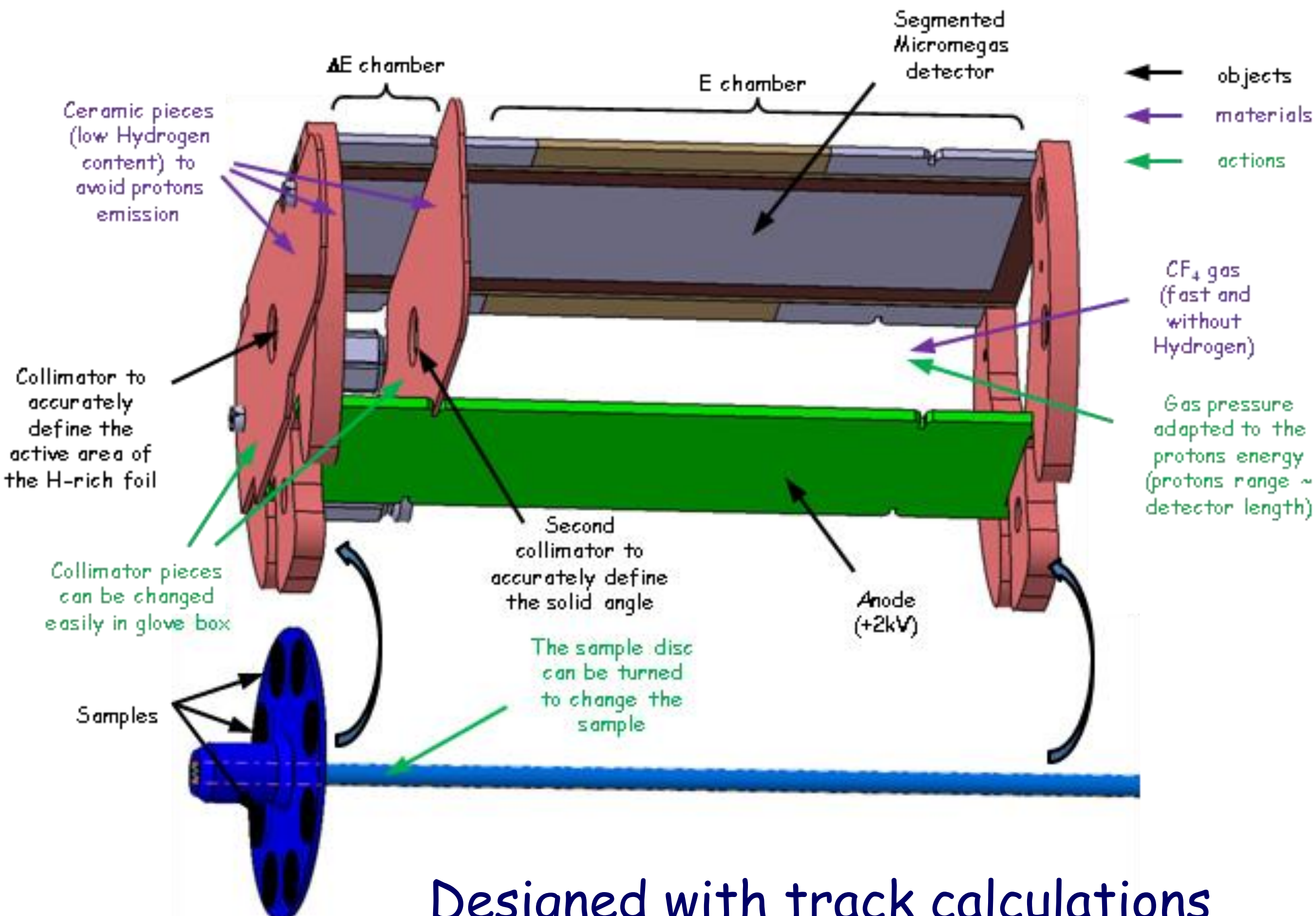
segmented detector to perform track analysis

**Well defined efficiency**

a collimator is placed inside the detector => two chambers

100% efficiency required for good tracks ("no missed event")

# The Gaseous Proton Recoil Detector (GPRD)




**Constraint :**

as low material as possible to avoid interference with cross section measurement (e.g fission)

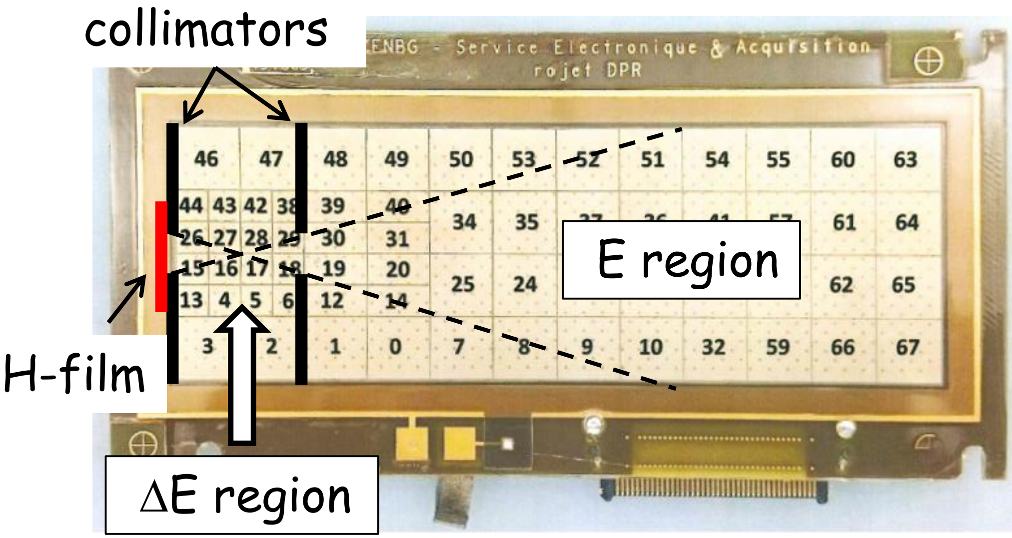
Designed with track calculations

(nbr $e^-$ generated, different $E_n$, different $P_{gas}$)

# III- A new detector, phase I

## The Gaseous Proton Recoil Detector (GPRD)

### Segmented detector (CEA/Irfu)



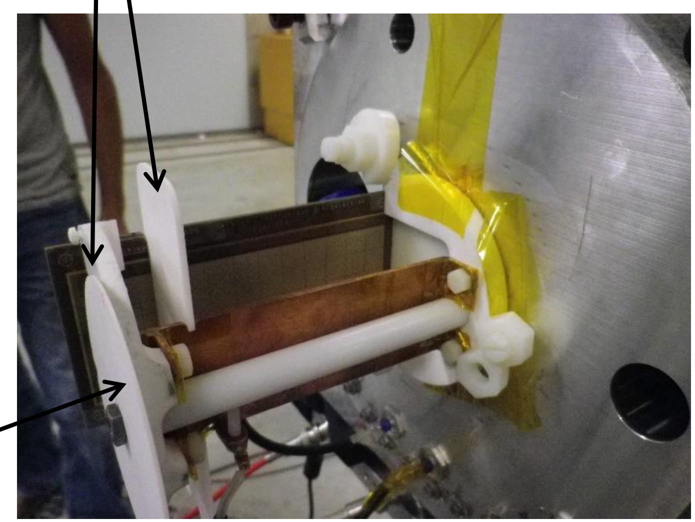

64 pads

divided in two chambers: ΔE-E

smaller pads in ΔE region
(lower e- generation)

well defined efficiency (collimated sample)

**Picture of the GPRD prototype**
(test experiment)



# Energy calibration

- **signal amplitude:**

$$E_{proton} = \sum_{pad\ i} E^i_{deposited}$$

$$E^i_{deposited} = \frac{A^i}{\varepsilon^i_{collection} * \eta^i_{gain}}$$

Signal amplitude

f(exp.conditions,xyz)

f(gap, gas, U)

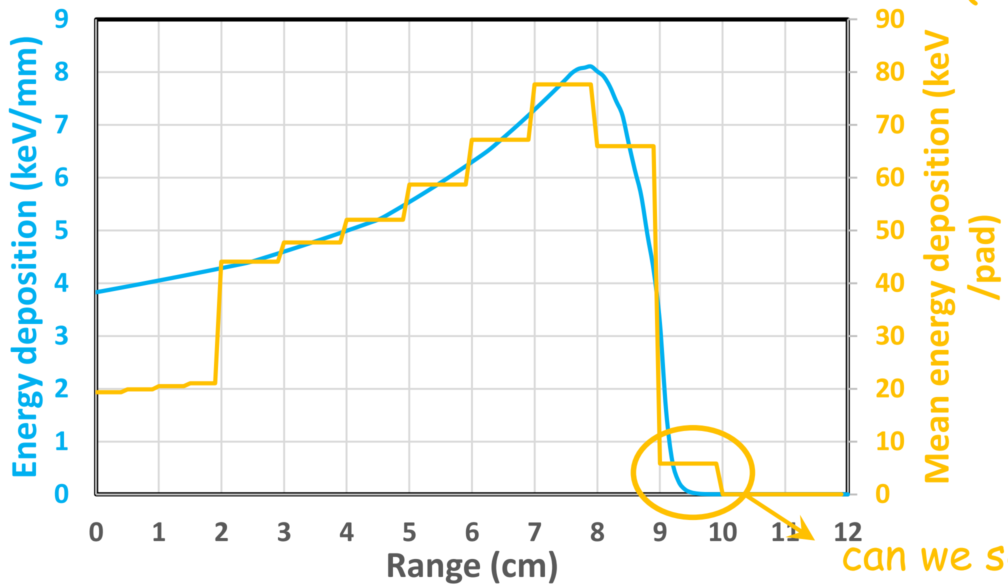
Due to $\varepsilon_{collection}$, it is **very hard** to determine the proton energy via the signal amplitude

# Energy calibration

- track length:

obtained thanks to the segmentation ➡ proton energy

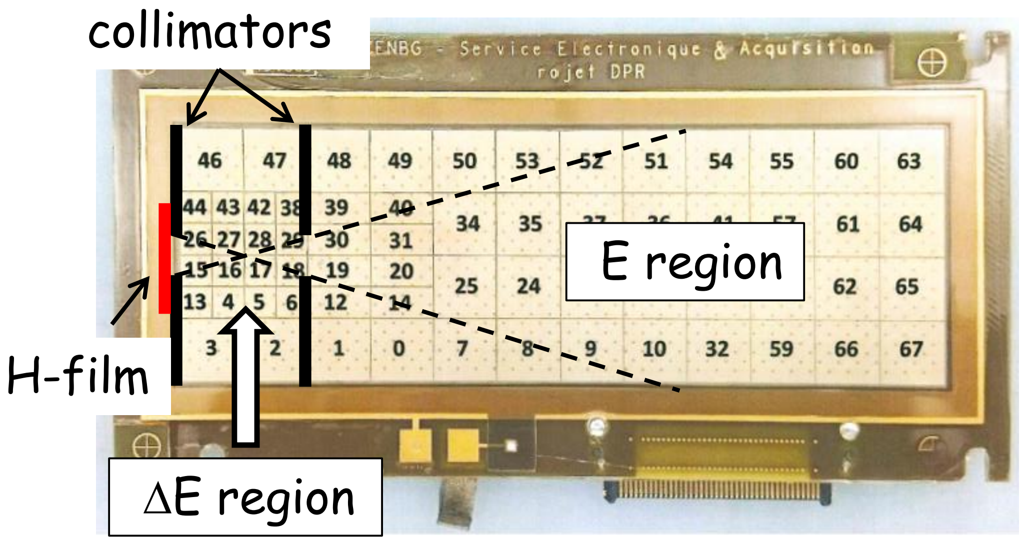
Issue: smooth end-of-track ➡ energy deposition reconstruction (thanks to constant $\eta_{gain}$, despite $\varepsilon_{collection}$)




can we see this ?

Issue: no information on the z-axis ➡ very poor energy resolution

# Efficiency




$$\varepsilon = \varepsilon_{geom}(E_n) * \varepsilon_{intr.}$$

Calculation (simulation)

100 % ? not yet proven

- **detector dead time:**

  a high counting rate could lead to missed events

  . the recoil proton counting rate is usually quite low

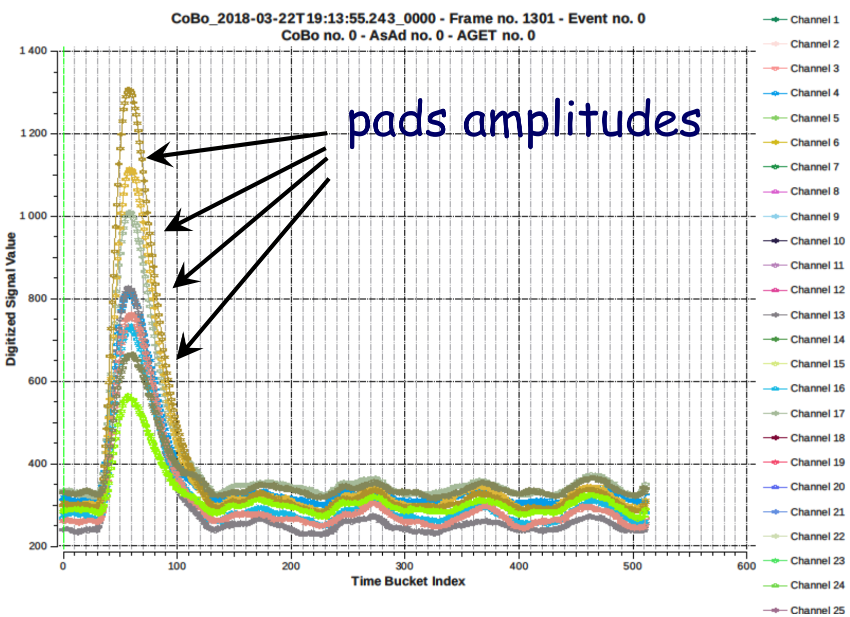
  . OK if there is not a lot of background events

## Test experiment on the AIFIRA facility in 2016

- irradiation with neutrons ($E_n$ down to 300 keV)
- same conditions than previous experiments (distance, reaction)

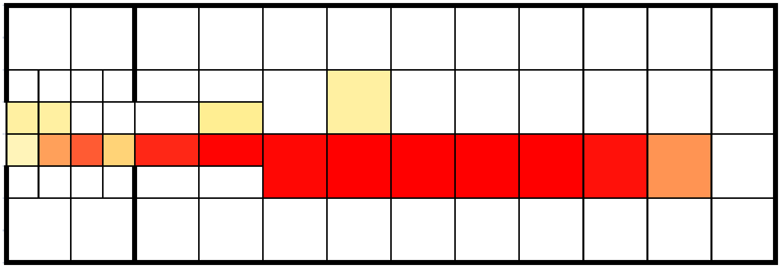
# Validations

- track measurement ✓




« straight » tracks using the whole length of the GPRD

**track for $E_n$ = 1 MeV**



# III- A new detector, phase I

**Test experiment on the AIFIRA facility in 2016**

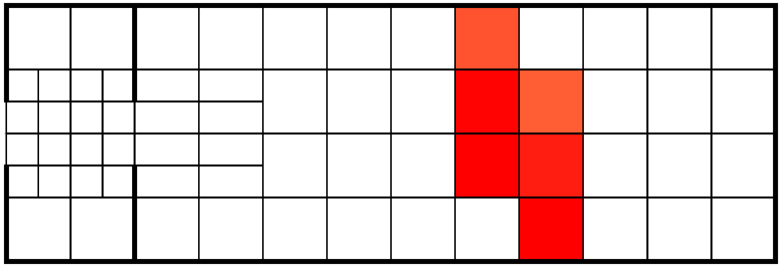
- irradiation with neutrons ($E_n$ down to 300 keV)
- same conditions than previous experiments (distance, reaction)

## Validations

- track measurement ✓
- very low sensitivity to e- or $\gamma$ ✓

test without H-film **gives no signal**
(each pad is not sensitive enough to see
signal from background electrons)

only few cosmic rays seen



**Test experiment on the AIFIRA facility in 2016**

- irradiation with neutrons ($E_n$ down to 300 keV)
- same conditions than previous experiments (distance, reaction)

# Validations

- track measurement ✓
- very low sensitivity to e- or $\gamma$ ✓
- discrimination between direct and scattered neutrons ✓

shorter "ΔE-E" tracks rejected
(protons from neutrons with lower energy / higher angle)

# III- A new detector, phase I

**Test experiment on the AIFIRA facility in 2016**

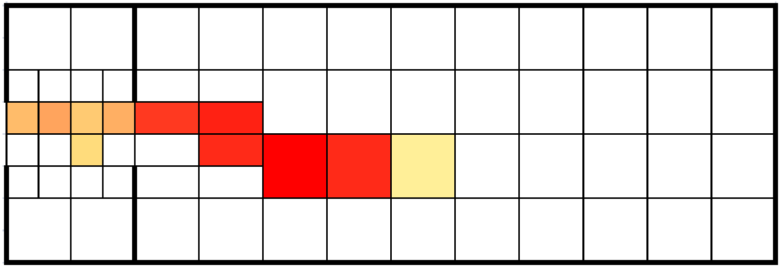
- irradiation with neutrons ($E_n$ down to 300 keV)
- same conditions than previous experiments (distance, reaction)

## Validations

- track measurement ✓
- very low sensitivity to e- or $\gamma$ ✓
- discrimination between direct and scattered neutrons ✓
- low detection energy limit: 300 keV (at least) ✓

**track for $E_n$ = 300 keV**

no test carried out below 300 keV



# III- A new detector, phase I

**Test experiment on the AIFIRA facility in 2016**

- irradiation with neutrons ($E_n$ down to 300 keV)
- same conditions than previous experiments (distance, reaction)

# Validations

- track measurement ✓
- very low sensitivity to e- or $\gamma$ ✓
- discrimination between direct and scattered neutrons ✓
- low detection energy limit: 300 keV (at least) ✓
- general functioning (electronics, acquisition, gas regulation, rotating disk...) ✓
- $\varepsilon_{intr}$ = 100% not proven ✗

need a quantitative and accurate experiment

# Issues

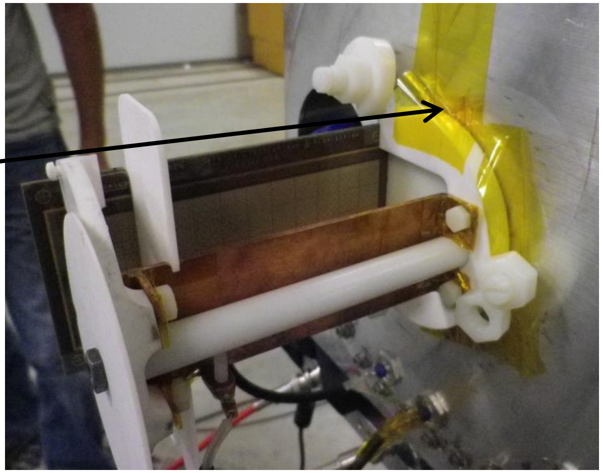
## - Static sparks

$CF_4$ gas at few 10 mbars => Paschen regime

=> drop of the breakdown voltage

➡ removal of some conductive pieces

hence the adhesive !



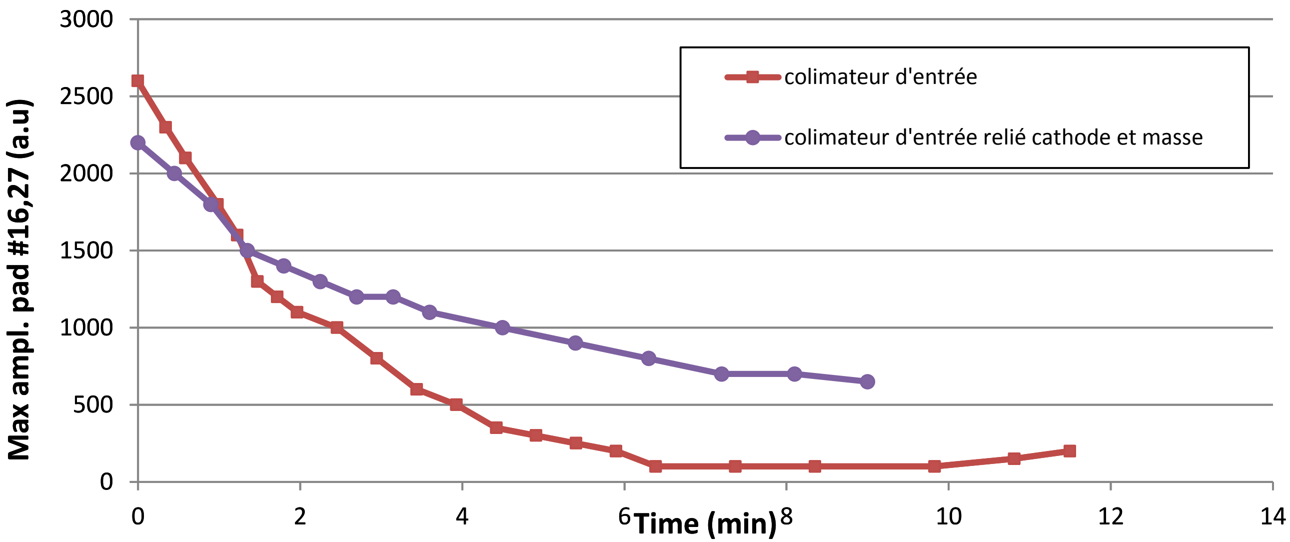
## - Non homogeneous electric field

Weak signal on the side pads
+ perturbation due to the collimator

➡ future addition of a field cage to constraint the electric field

# Issues

- Signal loss after few minutes of irradiation



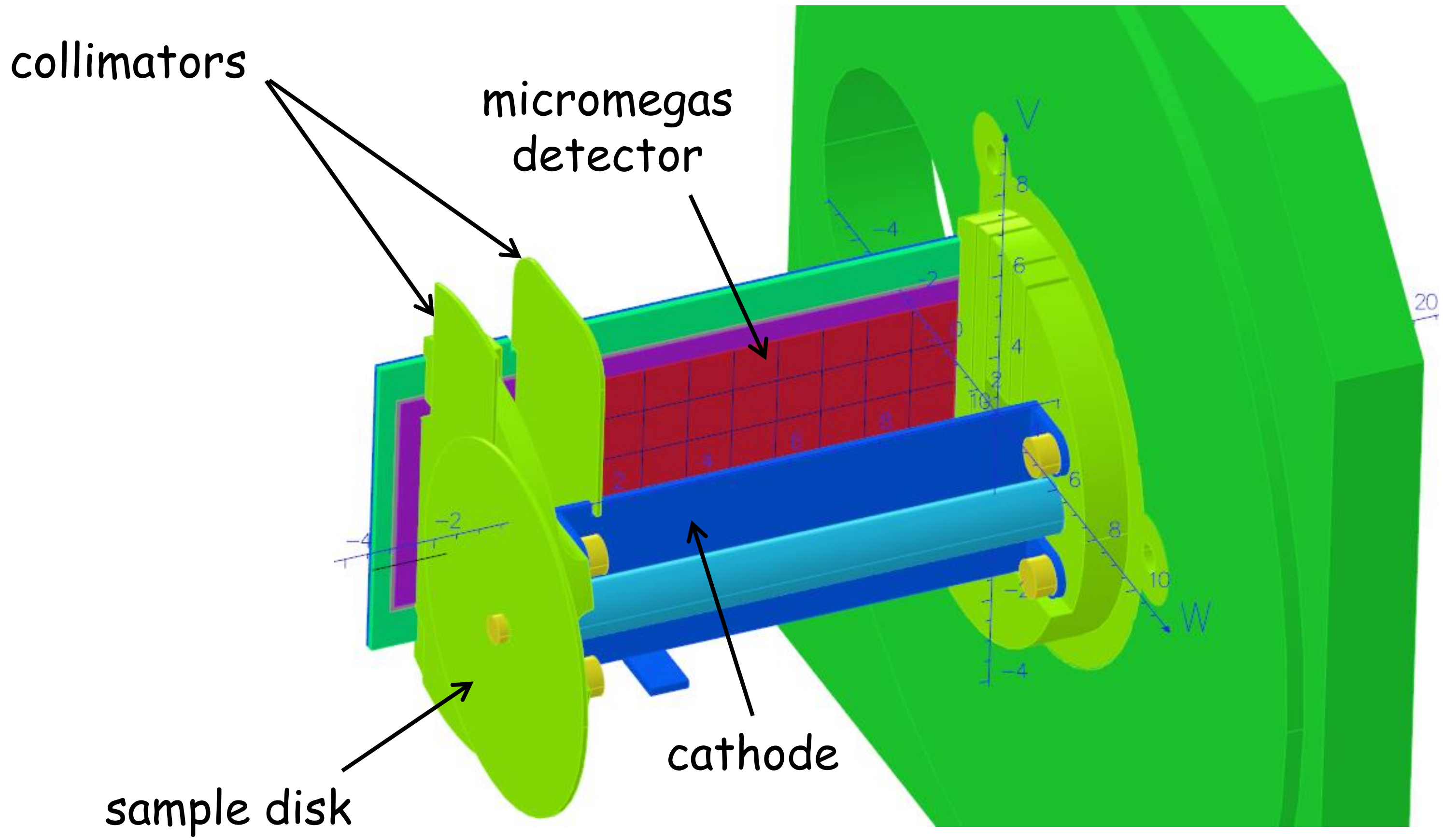

grounding some mechanical elements reduce the issue

**Charge accumulation** on insulators
(from e- coming « from » the beam) => electric field distortion

➡ future addition of a field cage to constraint the electric field

# Electric field simulations

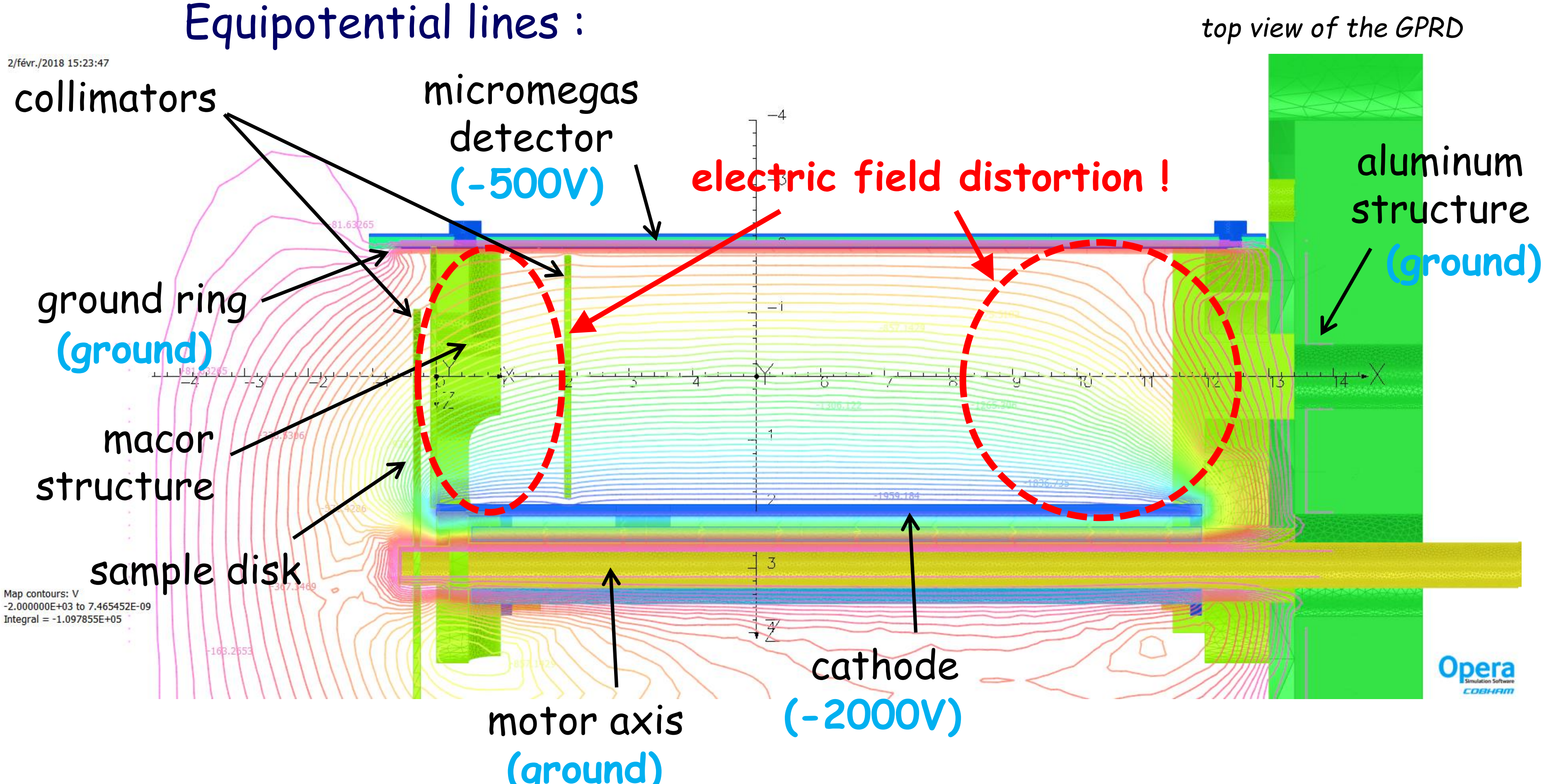
## With the OPERA code (ex-Tosca)



# Electric field simulations

## With the OPERA code (ex-Tosca)

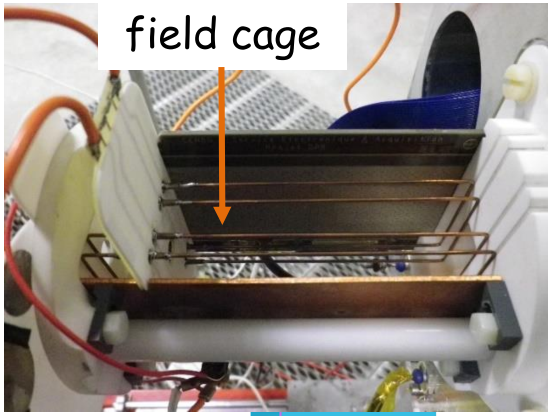
Equipotential lines :

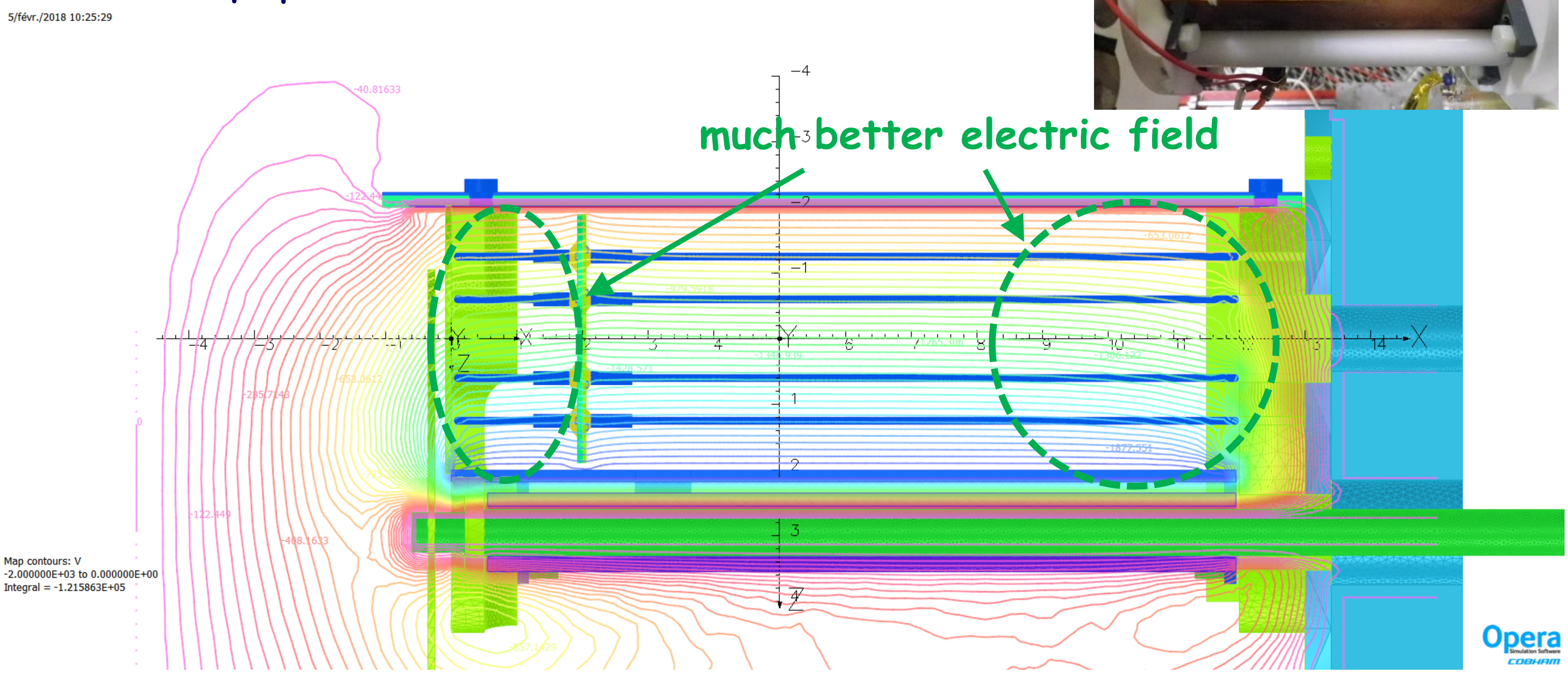


# Electric field simulations

## With the OPERA code (ex-Tosca)

Equipotential lines :

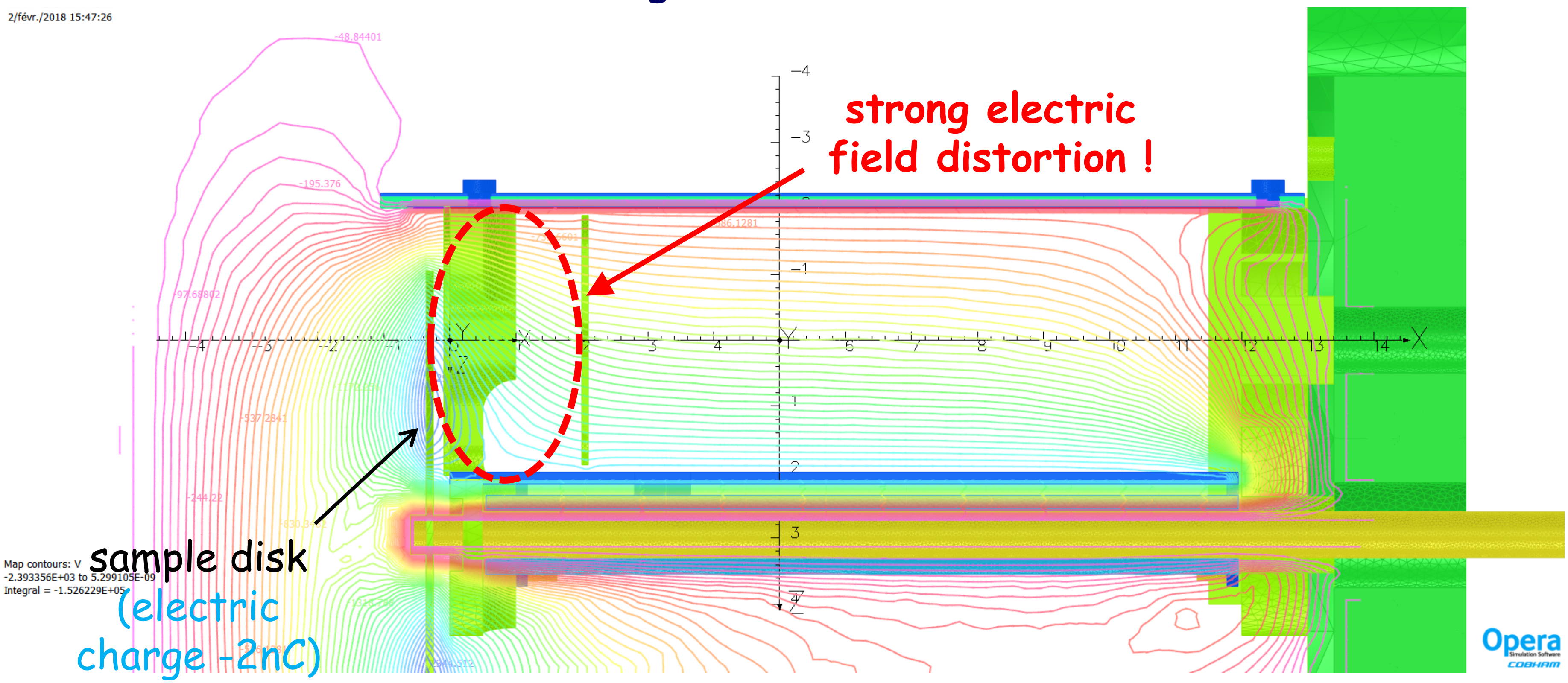


# Electric field simulations

## With the OPERA code (ex-Tosca)

A static electric charge can be added

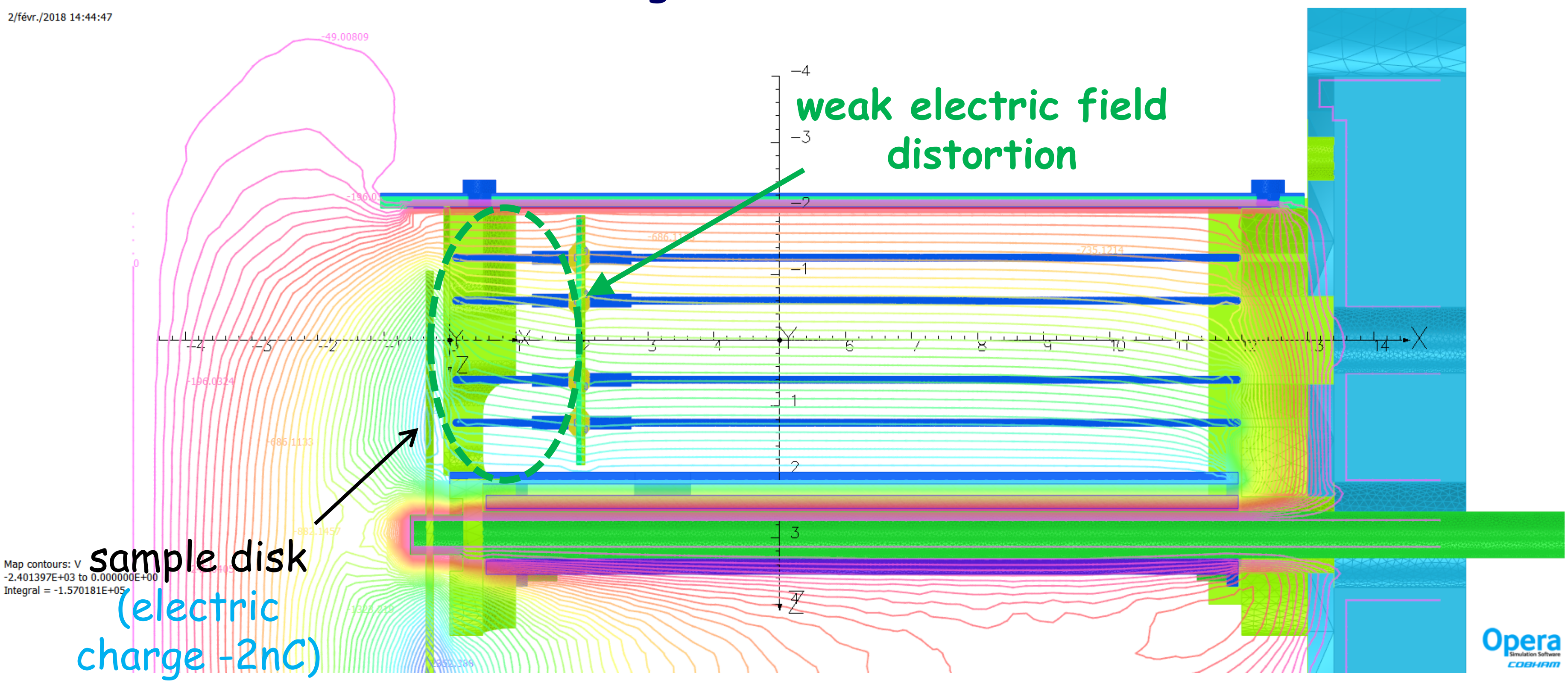


# Electric field simulations

## With the OPERA code (ex-Tosca)

A static electric charge can be added

top view of the GPRD



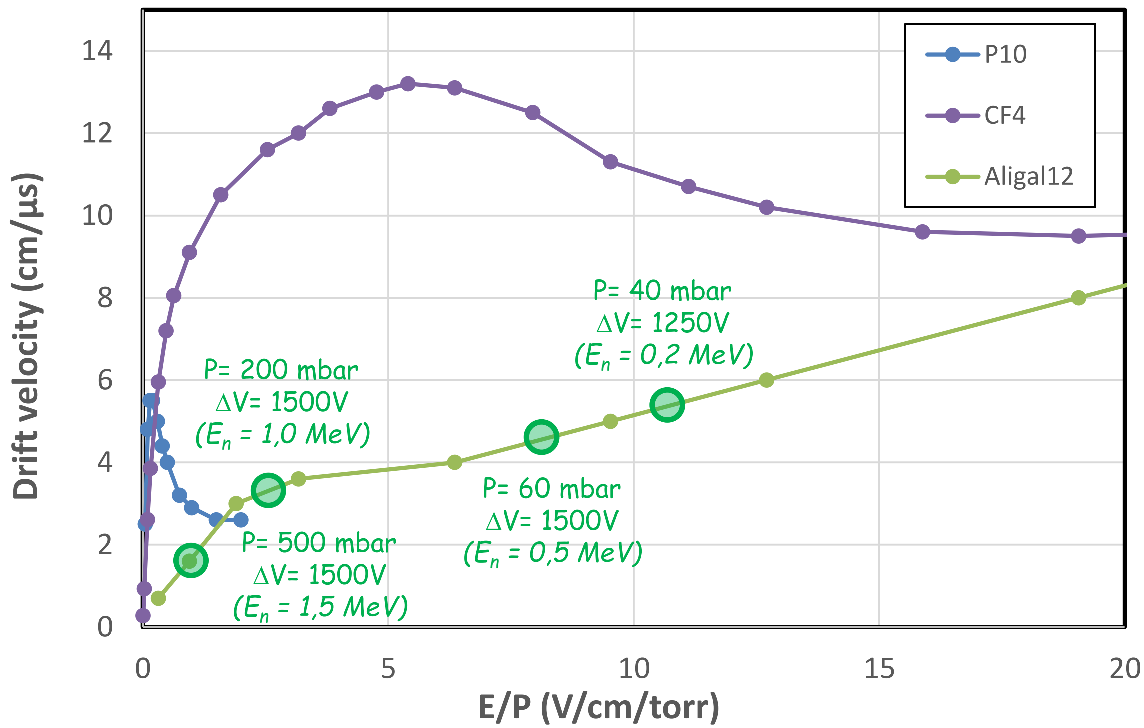
# A different gas

**With very good insulating properties: 70% $N_2$ – 30% $CO_2$**

- used in accelerator tank (as is $SF_6$)
- very cheap

**Much slower than $CF_4$:**

no background events
=> a fast gas is not
mandatory anymore



**Test experiments on the AIFIRA facility in 2018**

- irradiation with neutrons ($E_n$ down to 200 keV)
- same conditions than usual experiments (distance, reaction)

# Validations

- good static electric field behavior ✓

no more electron leakage on the side pads (except the last raw)

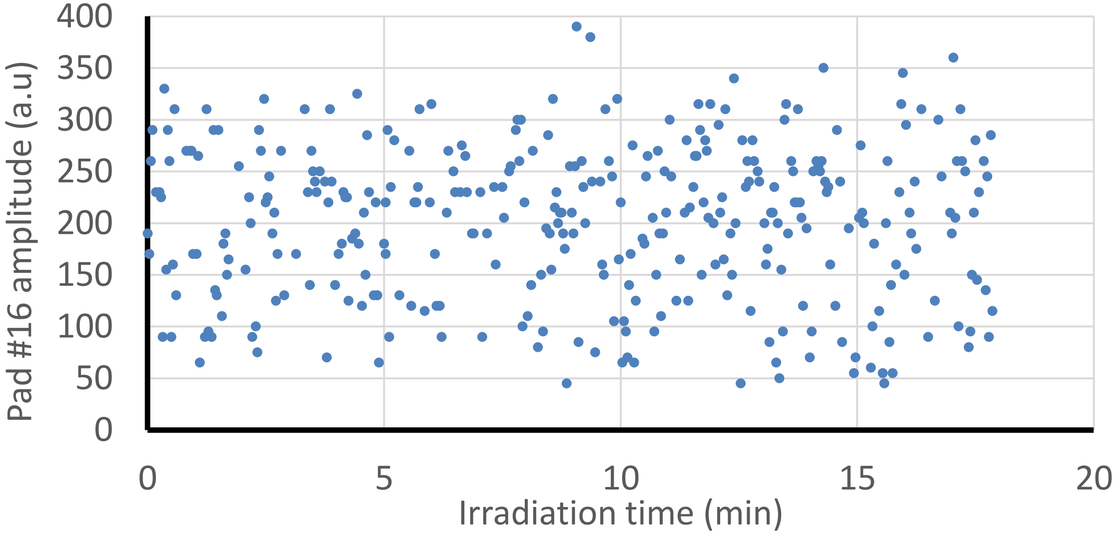
**Test experiments on the AIFIRA facility in 2018**

- irradiation with neutrons ($E_n$ down to 200 keV)
- same conditions than usual experiments (distance, reaction)

# Validations

- good static electric field behavior ✓
- good electric field behavior under irradiation ✓

no loss of signal amplitude with irradiation !



## Test experiments on the AIFIRA facility in 2018

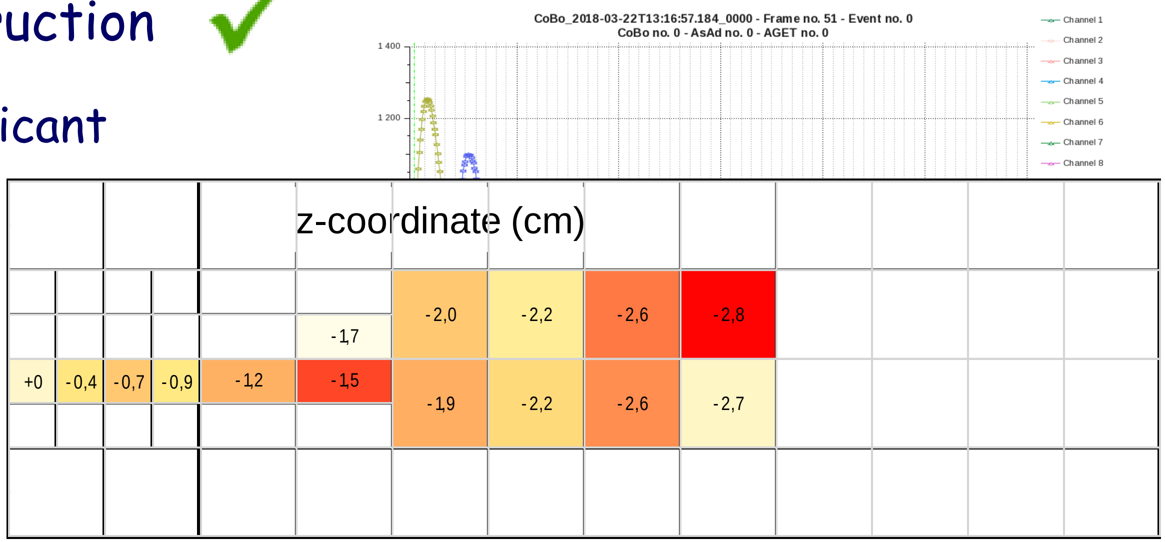
- irradiation with neutrons ($E_n$ down to 200 keV)
- same conditions than usual experiments (distance, reaction)

# Validations

- good static electric field behavior ✓
- good electric field behavior under irradiation ✓
- 3D tracks reconstruction ✓

lower drift velocity => significant time difference depending on z-axis

➡ improvement of $E_{res}$ via track length determination



# IV- A new detector, phase II

## Test experiments on the AIFIRA facility in 2018

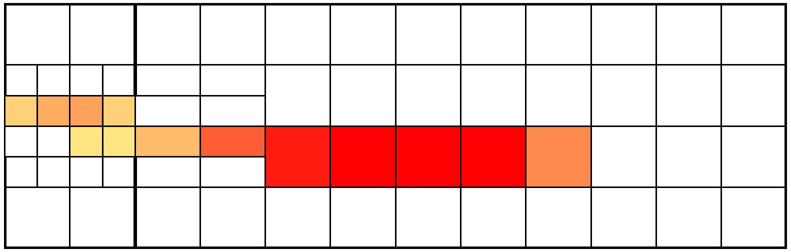
- irradiation with neutrons ($E_n$ down to 200 keV)
- same conditions than usual experiments (distance, reaction)

## Validations

- good static electric field behavior ✓
- good electric field behavior under irradiation ✓
- 3D tracks reconstruction ✓
- low detection energy limit: 200 keV (at least) ✓

**track for $E_n$ = 200 keV**

limitation due to the
H-rich sample thickness
(0,5μm max at 200keV)



**Test experiments on the AIFIRA facility in 2018**

- irradiation with neutrons ($E_n$ down to 200 keV)
- same conditions than usual experiments (distance, reaction)

# Validations

- good static electric field behavior ✓
- good electric field behavior under irradiation ✓
- 3D tracks reconstruction ✓
- low detection energy limit: 200 keV (at least) ✓
- $\varepsilon_{intr}$ = 100% not proven ✗

need a quantitative and accurate experiment

# Next experiment

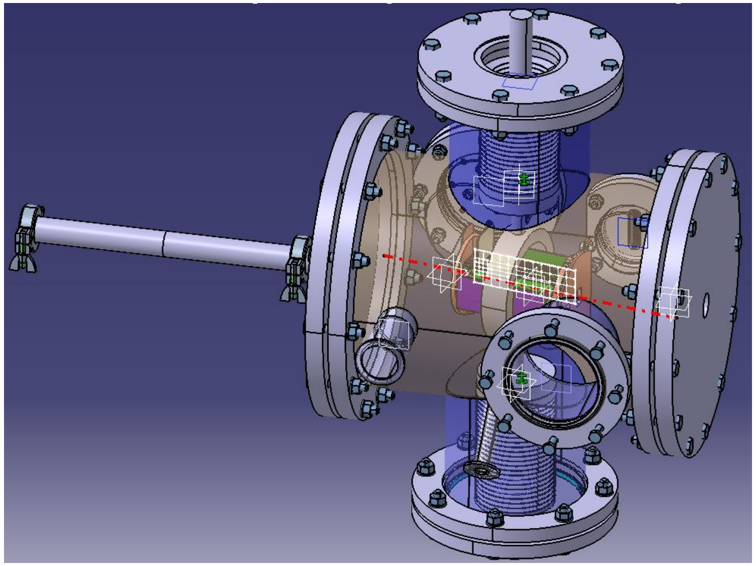
**Goals** - better understanding of the detector

- prove $\varepsilon_{intr}$ = 100%
- determine the detector rate limit

## Direct proton beam experiment

A new chamber has been designed:

- direct proton micro beam
  (few p/s to few 10 p/s)
- GPRD shift in (x;y)
  to irradiate different parts
- Si detector
  to monitor the counting rate



# Conclusion

## A difficult energy range for recoil proton

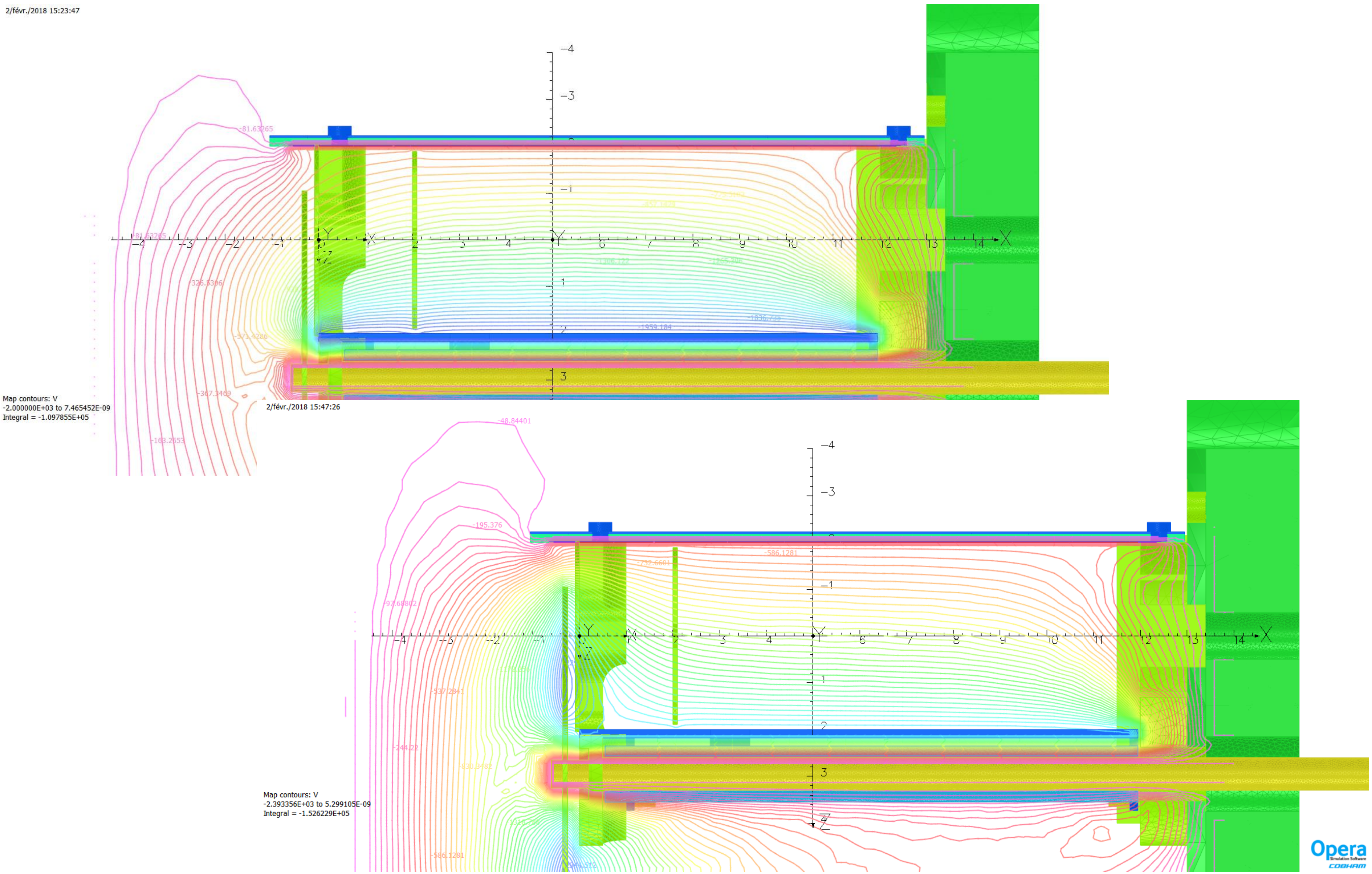
- very high background due to n->$\gamma$->$e^-$
- prevent an accurate counting of recoil protons

## The Gaseous Proton Recoil Detector

- built in 2016
- designed for a low sensitivity to $\gamma/e^-$ background
- test experiments @AIFIRA facility :
  . good behaviour under irradiation
  . validation of the low sensitivity to background
  . track reconstruction
  . low energy limit of 200 keV (limited by the thinness of the H-film)
- a direct proton experiment planned to investigate the efficiency

**Perspectives :** The GPRD will be completed and used to measure the $^{242}$Pu(n,f) cross section below 1 MeV (submitted to EURATOM WP2018)

# Thank you for your attention


2/févr./2018 15:23:47
Map contours: V
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Integral = -1.097855E+05
2/févr./2018 15:47:26
Map contours: V
-2.393356E+03 to 5.299105E-09
Integral = -1.526229E+05
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