# Development of a high pressure single-anode radial TPC for the search of 2β0ν decays


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**The R&D R2D2 collaboration**

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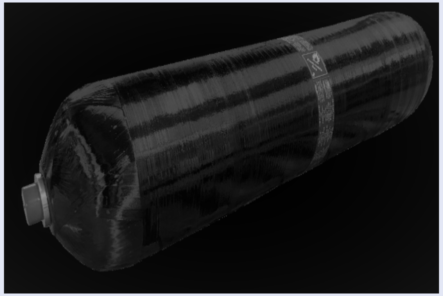
(a know-how from NEMO and NEWS-G)

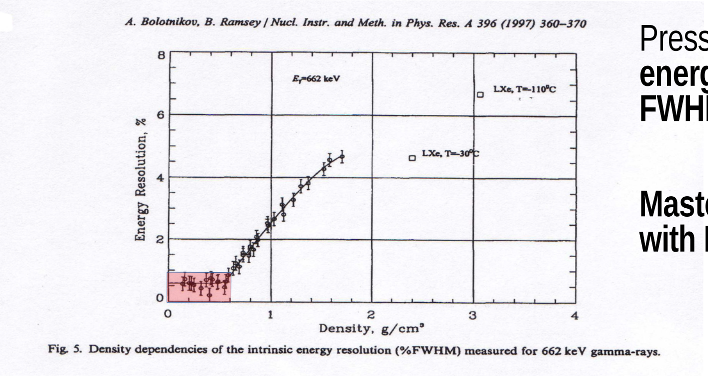



# Motivations

NEWS-G showed that the **Spherical Proportional Counter (SPC)** is very attractive: (cf. Conf. ICHEP2022, UCLA-DM2013, TMEX2023, Blois2022….)

- Gain up to $10^4$ .
- Low detection threshold (down to single electron).
- Good energy resolution (12% @ 2.6 KeV).
- Discrimination from surface and bulk interactions

## For $\beta\beta0\nu$ decays

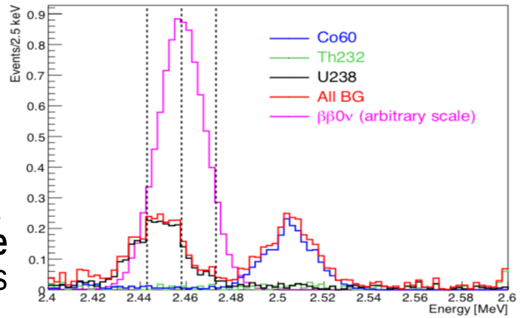



Pressurized Xenon would allow a **energy resolution of 0.6 % FWHM up to 50 bars**

**+**

**Mastering of the drift phase with LXe**

Our preliminary simulations indicated that an SPC filled **with pressurized 136Xe** could provide appealing performances




JINST 13 (2018) no.01, P01009

**Provided that the experimental constraints can actually be overcome**

- Energy resolution of 1% FWHM @ $Q_{\beta\beta}$ of 2.458 MeV .
- Operation with Xe at 40 bars.

**that the scalability of such a detector is possible**

- Up to a ton of Xe gas (~ 1-2 $m^3$ at 40 bars).

**With an extreme reduction of the radioactive background.**

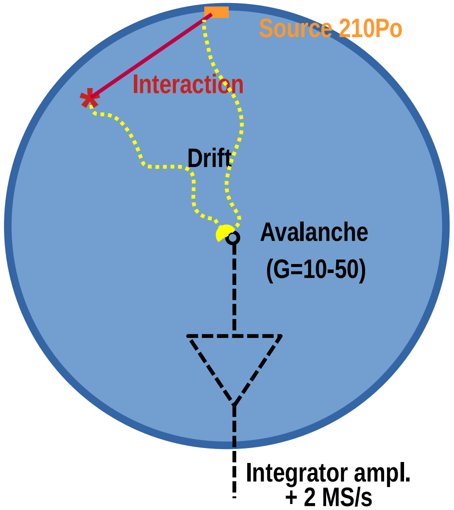
# Our approach

1) A central concern: the reduction of the near background
=> Use of the simplest and lightest possible structure in terms of mechanics and sensor.
=> Choice of a high pressure single anode radial TPC

2) Energy resolution of 1% FWHM

3) Track localization
4) 2-tracks recognition (for the background and function of pressure for 2β)

Additional assets for background rejection




**Studied configurations**

- SPC (Spherical Prop. Counter) - $1/r^2$ field
- CPC (Cylindrical Prop. Counter) - $1/r$ field
- Proportional / ionization modes
- Point-like / long tracks (function of pressure)

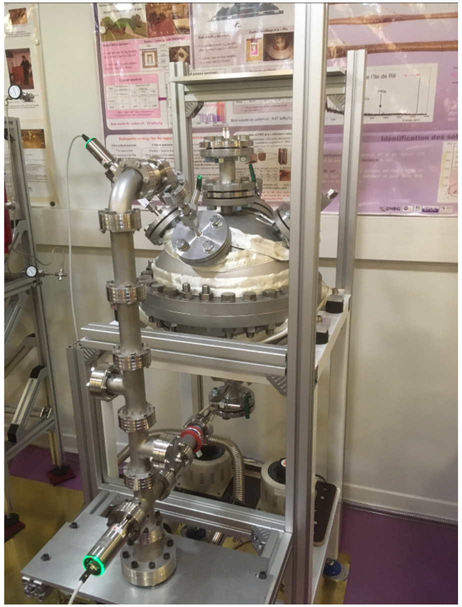
(Final objective is 0.5 m in radius and 40 bars of Xe)

# Detectors setup

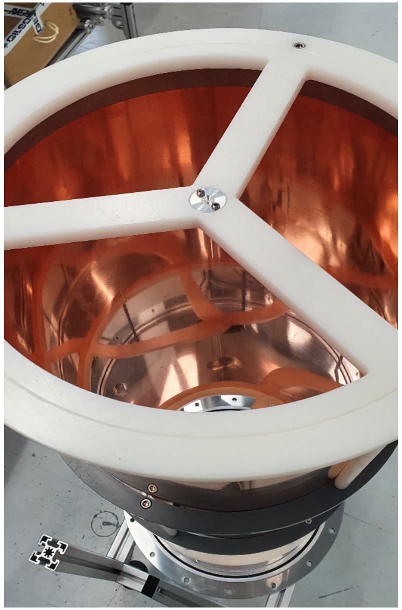
Test facility @ Bordeaux

(No radio-purity required & ArP2 gas mainly used at this stage of the R&D)

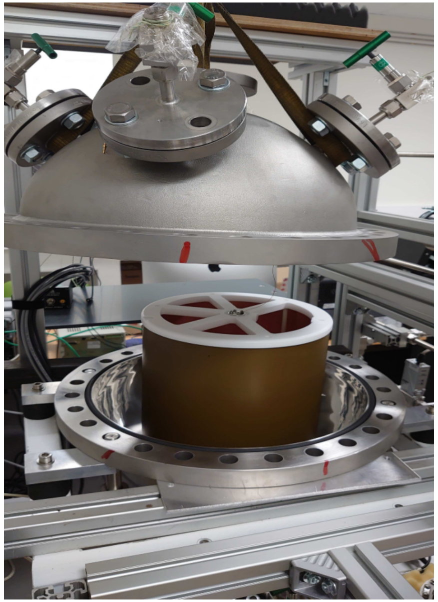
SPC-1 (2018)
D = 0.4 m
$r_{ball}$ = 1 mm
(1 bar)



SPC-2 (2021)
D = 0.4 m
$r_{ball}$ = 1 mm or 3 mm
(40 bar)



CPC-20 (2022)
L x D = 1 x 0.37 (m)
$r_{wire}$ = 20 $\mu$m
(1 bar)



CPC-50 (2023)
L x D = 0.27 x 0.27 (m)
$r_{wire}$ = 50 $\mu$m
(40 bar)

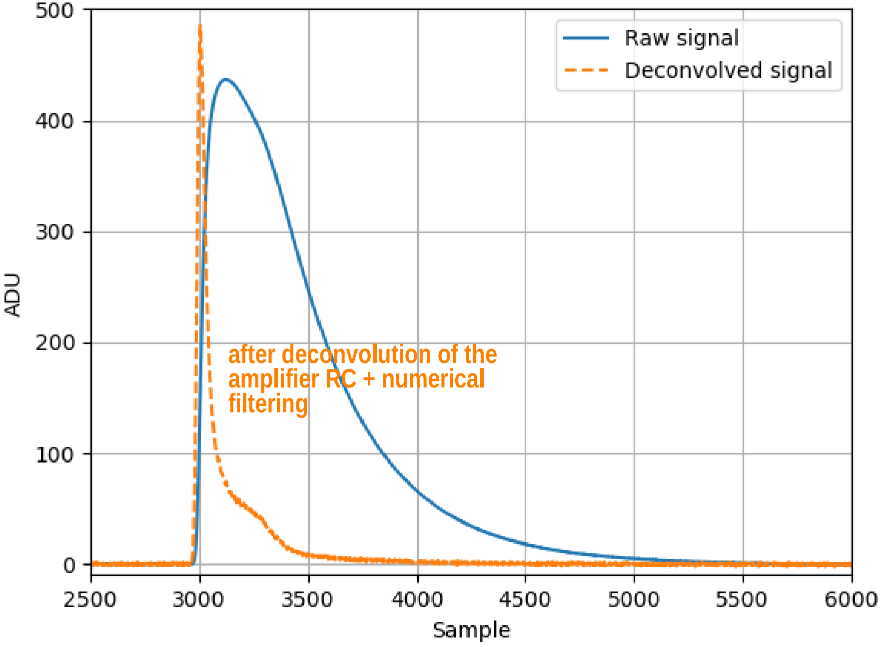
Amplifier positioned outside the tank (cables)

Used with cathodic HV bias

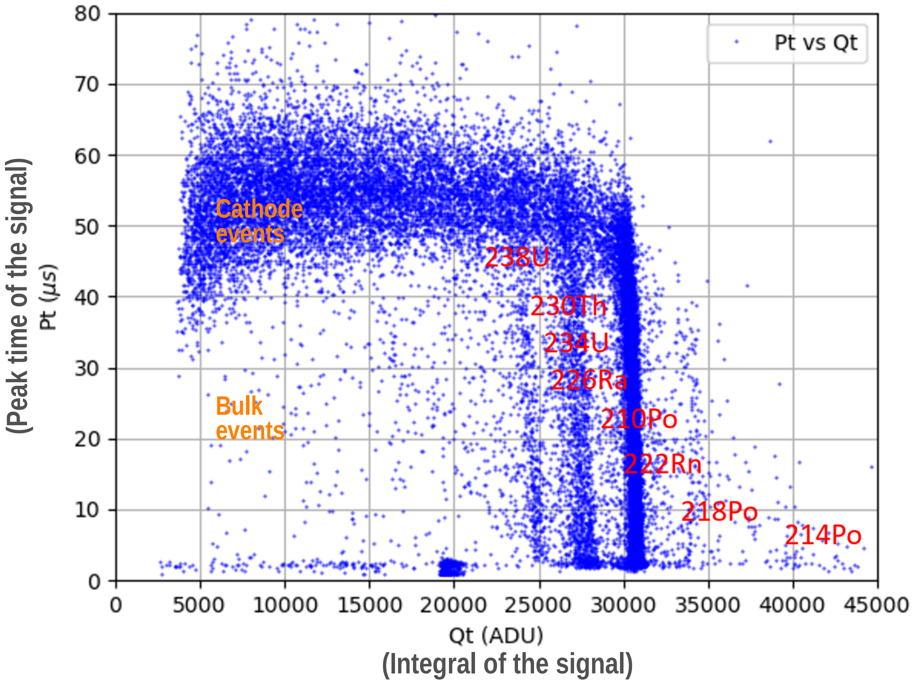
# Signal treatment

**To achieve very high precision measurements (single-channel detector) numerical signal processing becomes essential (even under excellent Signal / Noise conditions)**

*(SPC - ArP2@200mb, 210 Po source, Sampling 2 MHz) Track length ~17 cm*




*Using observables Pt and Qt of the deconvolved signals*

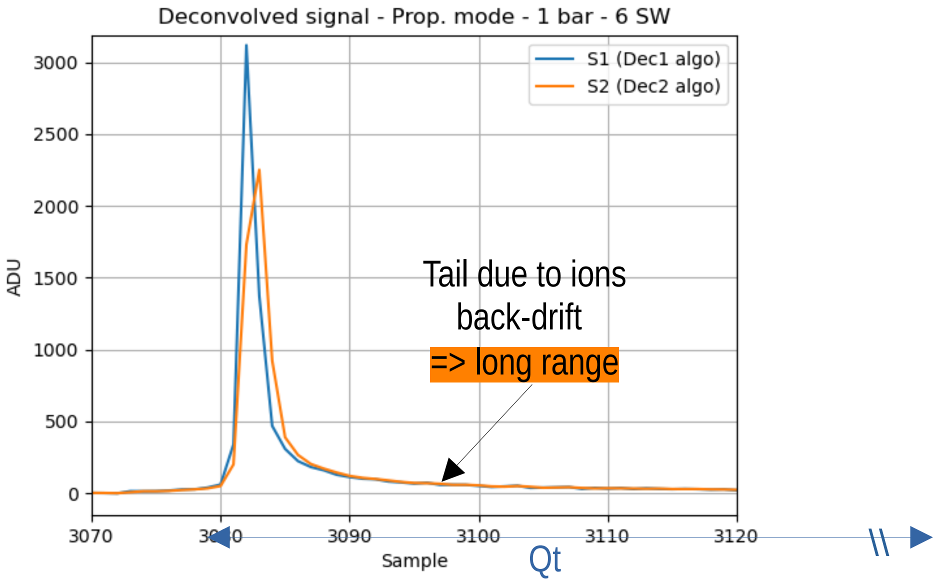


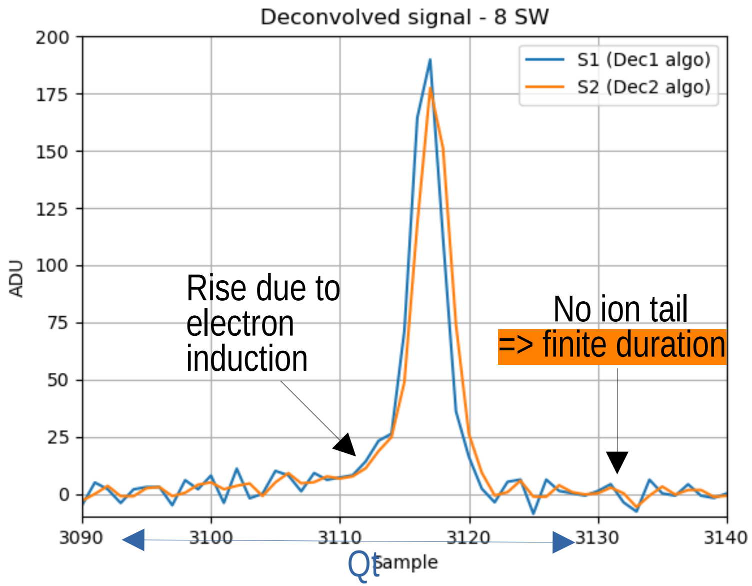

**=> Processing allows to extract new information**

# Ionization / proportional signals

Constraints in HV, Ion space charge, gain fluctuation, quenching….

*CPC-50 - Deconvolved signal - ArP2 - 1 bar – 210 Po - Track length ~3 cm*




Proportional mode

- High S/N
- Long duration of integration can alter E-Resolution (impose to control the LF noise)

Ionization mode

- Low S/N
- Duration almost independent of the gas nature
- Easier use with pure noble gases

# Energy resolution

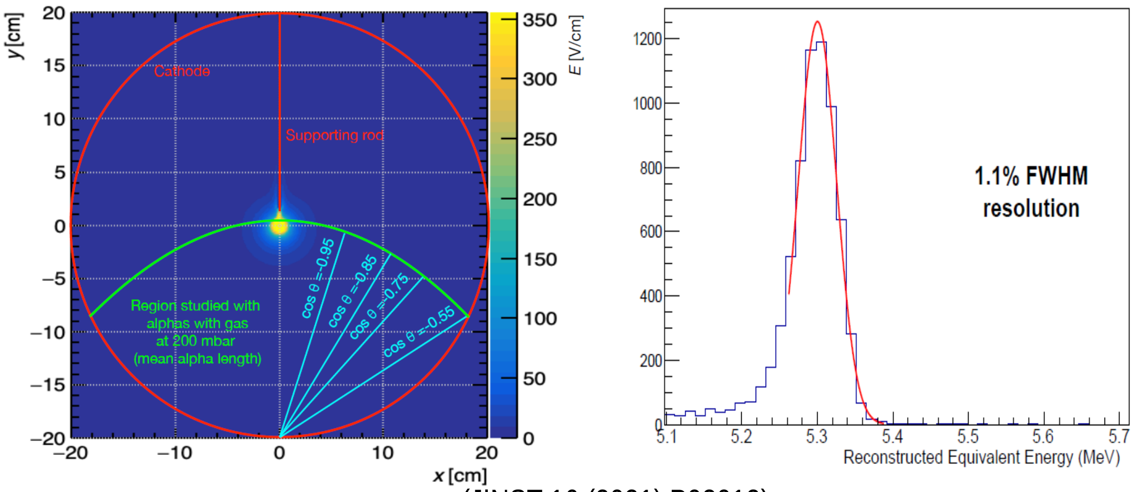
**The first stage of R&D focused on the attainable energy resolution.**

With ArP2 gas, we explored the SPC response from 0.2 bar to 1.1 bar ie. 17 and 3 cm track lengths
(with identical gains).

In proportional mode
=> Resolutions of 1.1 to 1.2 % FWHM were obtained.

=> Similar results were obtained with the CPC.

*SPC – 0.2 bar - ArP2 - Prop. Mode - 210Po source*



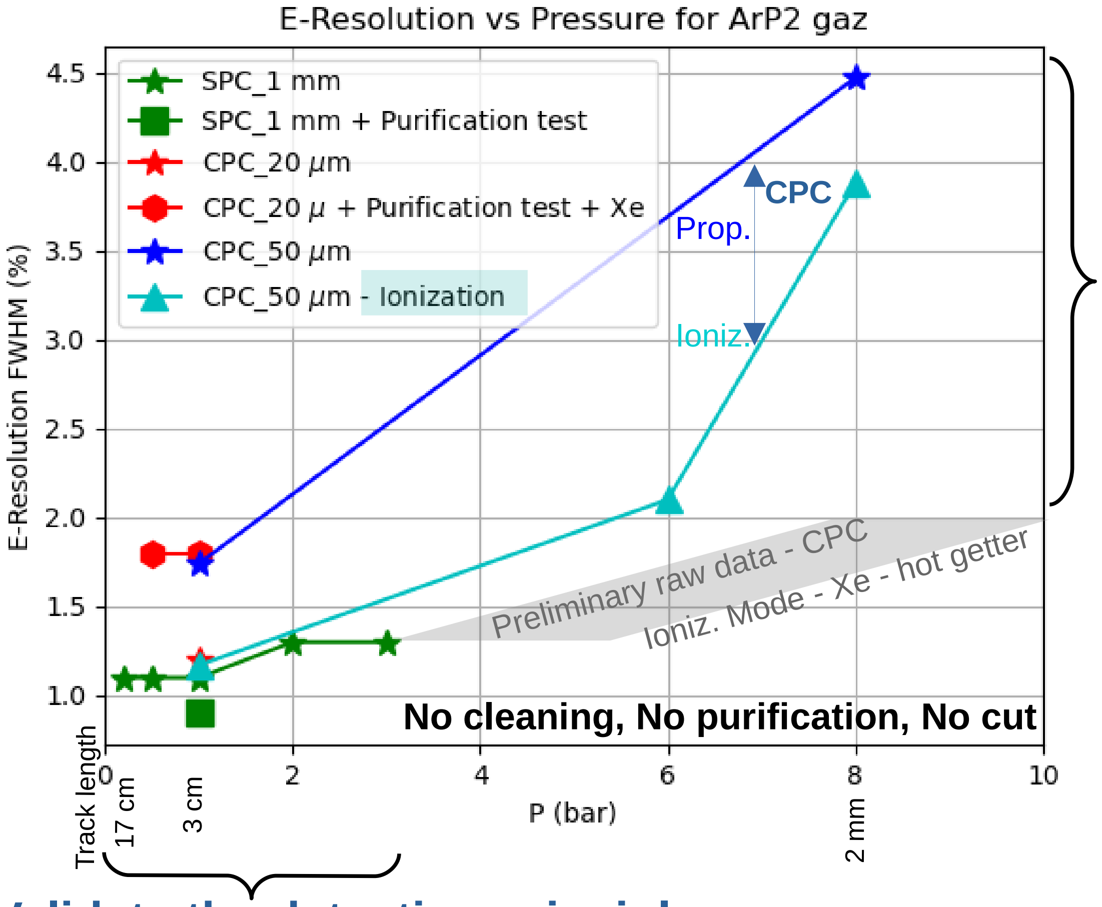

(JINST 16 (2021) P03012)

**=> Track direction doesn't affect energy resolution.**

**=> Track length doesn't affect the energy resolution.**

**(Contribution of the source and the electronic was estimated to account for 0.6%).**

# Energy resolution




**Validate the detection principle**

**The number of primaries being identical this degradation indicates that the gas did not have the right level of purity.**

=> At this stage of R&D (with pressure rise), the use of a clean detector and a gas filtration system become essential.

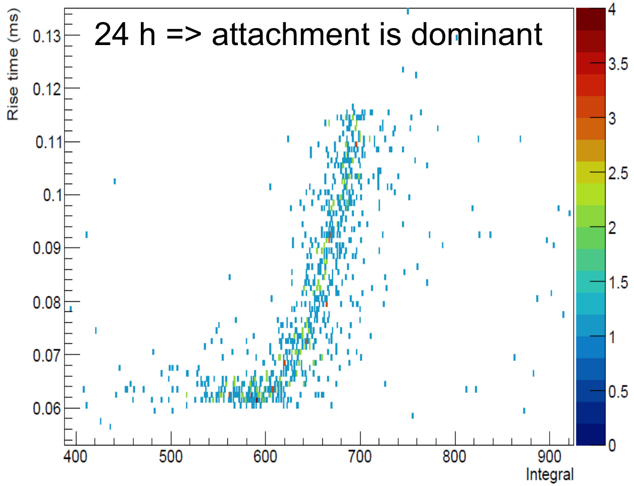
Another strong improvement in resolution (> 1 %) is also expected by FEE optimization (in board FEE).

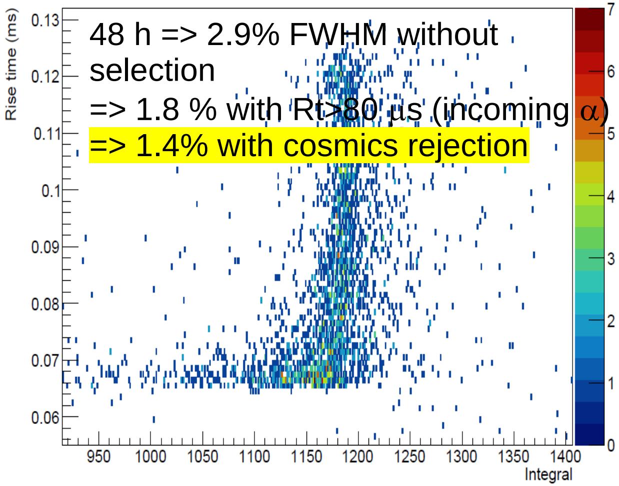
# Preliminary tests with Xe

(Xe recovery system only available since July 2022)

*CPC-20 – Raw signal (no signal processing) - Xe - 1 bar - 1200 V - Prop. Mod - $^{210}$Po source*

After filling (during some hours)
=>
No observed source signal (except cosmic tracks)




Our simple system based on a circulating pump and 2 cold getters to trap electronegative molecules in Xe was not sufficient.

**=> Upgrade of the system adding a hot getter (in test)** => for now, resolution results are not stable… (see previous slide)

Additional stage ? use of spark discharge purifier ?

# Track localization

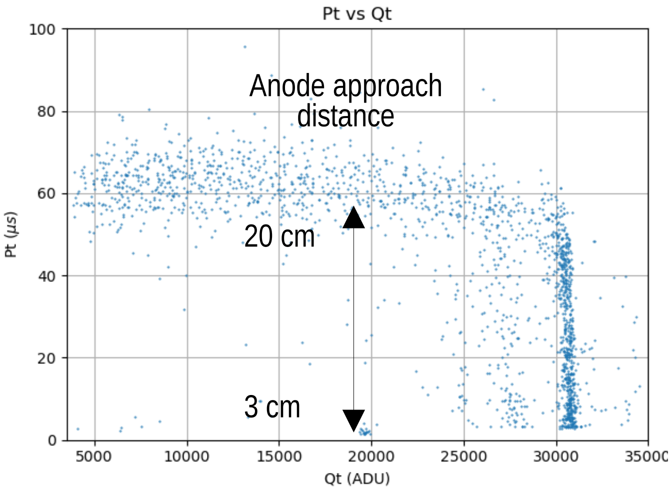
**Experimentally, the variability of the observable Pt suggested that it depends on :**

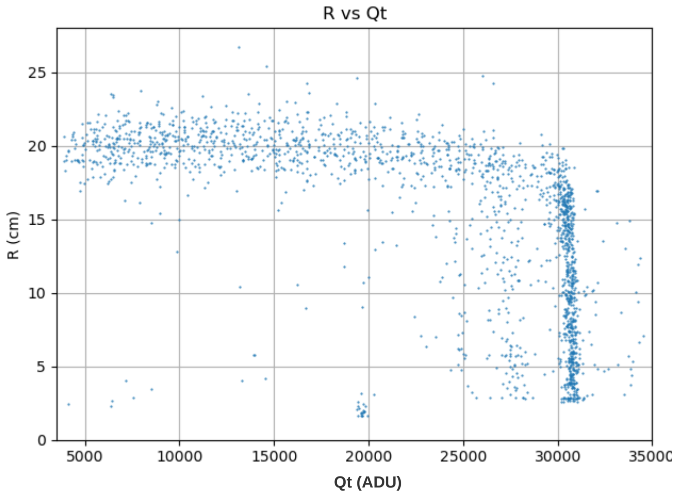
- The minimal distance of energy deposition relative to the anode
- The diffusion of the primaries during their drift

**and followed a dependency like: $Pt = Pt_{max} * (R/R_{max})^{\alpha}$**

**Inversion of this functional then made it possible to recover the distance of the track**

*SPC – ArP2 - 0.2 bar - 800 V - Prop. Mode - $^{210}$Po source - Deconv. signal*



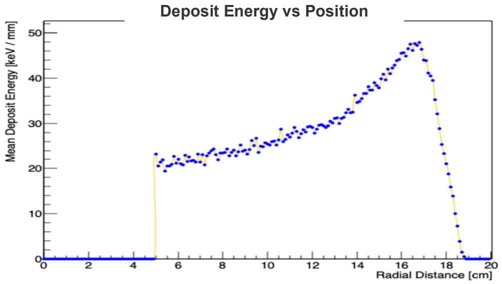



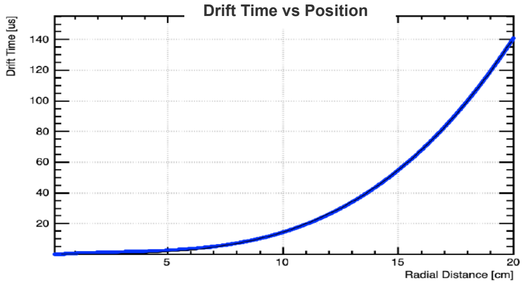

LTPC 2021, J. of Phys. Conf. Series **2502** (2023) 012006

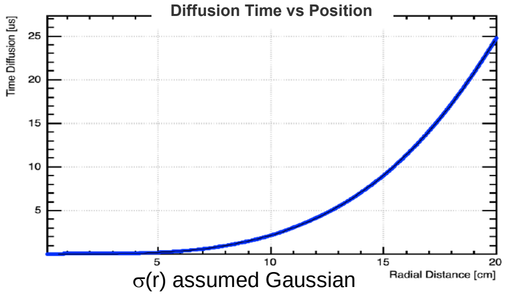
**=> To verify this empirical interpretation, we developed a very simple macroscopic modeling of the signals**

# Simulations

It uses outputs from (Geant4, Garfield, Magboltz) for the drift of the primary electrons.

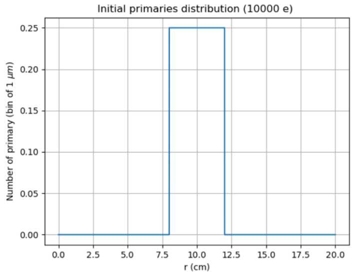


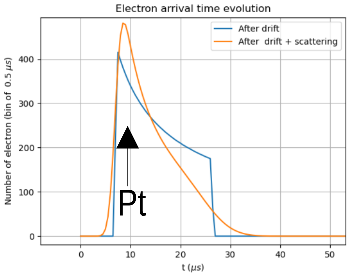




σ(r) assumed Gaussian

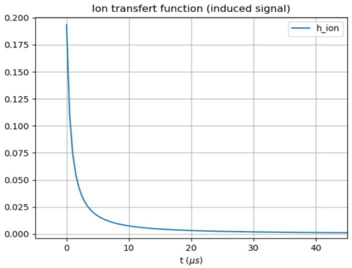
- These dependencies must be computed beforehand for each new operating conditions (nature of the gas, pressure, electric field).
- The mechanisms of drift and scattering of the electrons are modeled by simple analytical functions as:
  - $T_{drift}(t) = t_{max} * (r/r_{max})^{\alpha}$
  - $\sigma_{scat}(t) = t_{max} * (r/r_{max})^{\beta}$




After transport and diffusion effects of the primary electrons



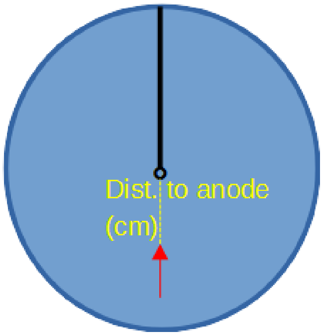

**final signal**

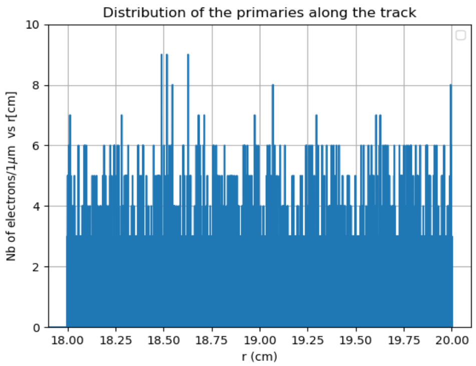


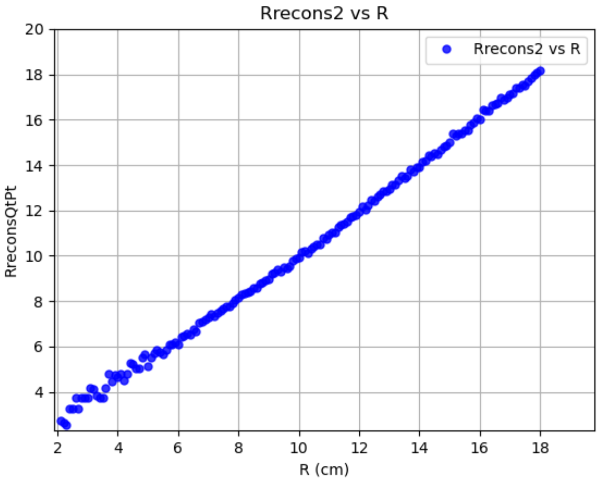

- The ion induction transfert function h_ion(t) is derived analytically from the electric field geometry;
- Then it is convolved to the electron time distribution.

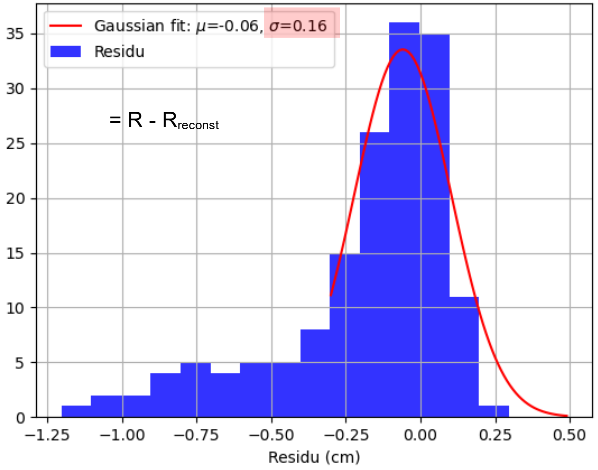
# Radial localization

Simulation of the SPC response with:
Track length of 2 cm - non-uniform ionization - 10000 $e^-$ - ArP2 gas - Prop. Mode (G=8)



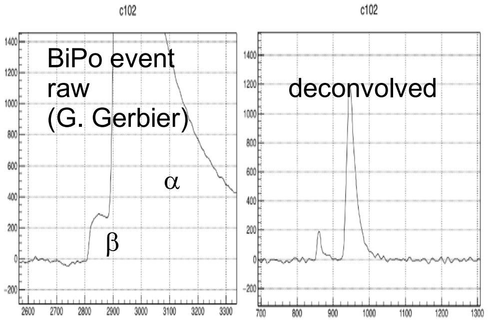



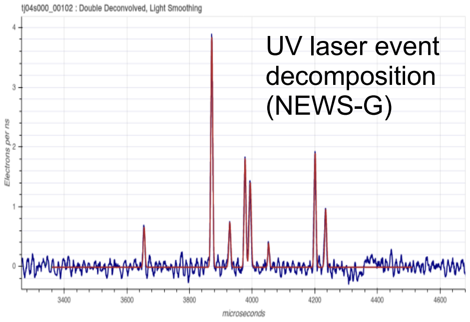

- $Pt_{max}$, Pt are deduced from plot (Qt, Pt)
- Rrecons2 = $r_{max} * (Pt / Pt_{max})^{1/a}$ is then compared to the initial distance R set for the simulated event through residues

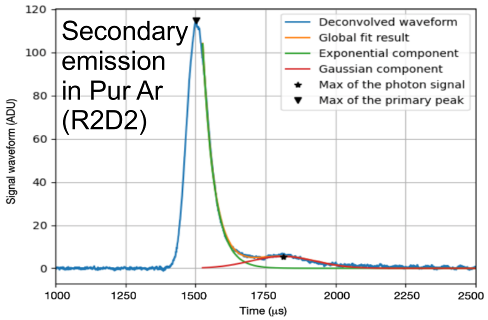
**=> Localization capability is proved**

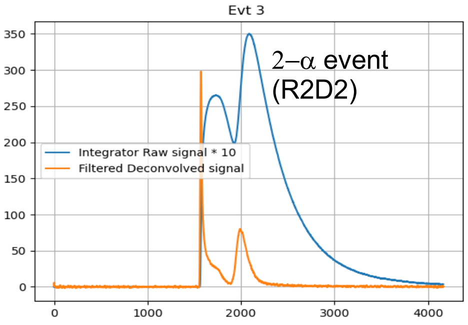
# Multi-tracks recognition

@ low pressure, this kind of detector allows to observe fine details about the interactions:



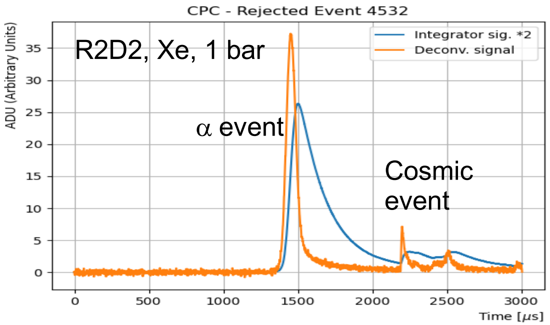




NIM A 1028 (2022) 166382

=> Efficient recognition of background events (Compton, cosmics, etc.) should be achieved:



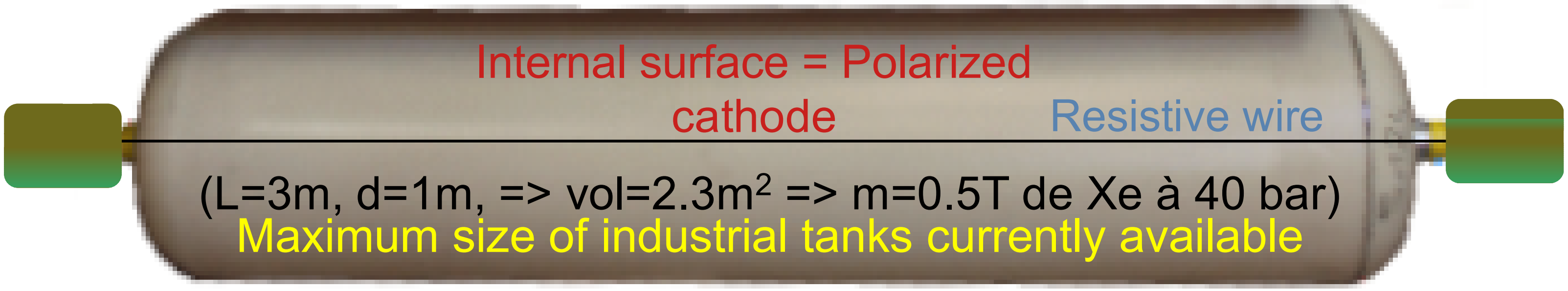

@ high pressure, except for cosmics, all interactions appear as point-like => recognition of the 2-tracks of $2\beta0\nu$ decay can become very challenging => work is in progress (set a limit in pressure ?)

# Next CPC design

Cylindrical geometry is mostly use in industry

**=> Design based on composite tank technology (600 bars) developed for $H_2$ storage**

- Easy detector scalability up tons
- Low material budget (& and cost)
- Low internal amount of metals to reduce Rn attachment (< 1 gram ?)
- Additional longitudinal localization by charge sharing on a resistive wire => background rejection *(NIM A 492 (2002) 26–34)*



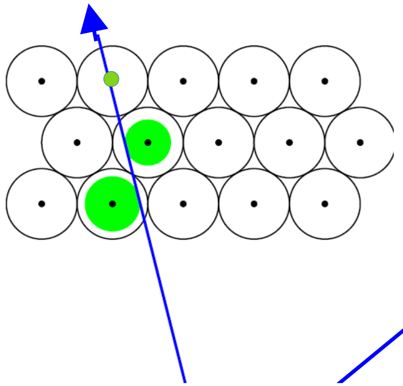

Futur goals: demonstrate the ability to instrument a tank (end-caps which hold the wire)
(and many unknowns...: selection of radio-pure materials => NEMO expertise)

Backup design: a conventional open metallic tank

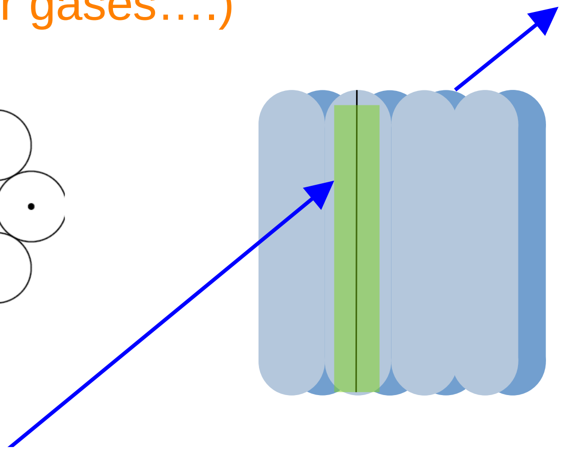
# Conclusion & Perspectives

- Several results essential to the proof of concept have been aggregated, especially in terms of energy resolution and localization.
- For 2β0ν, CPC in ionization mode could become our preferred option.
- A huge amount of work remains to be done to bring this concept to an operational scale (size, pressure, radio-purity, etc.).

**Could we use industrial tanks with $H_2$ at 600 bars as tracking chambers ?** (or with other gases….)



**Source of radiation :**
Reactors, Cosmics....
**Particles detected :**
α, β, γ, ν, μ, n....

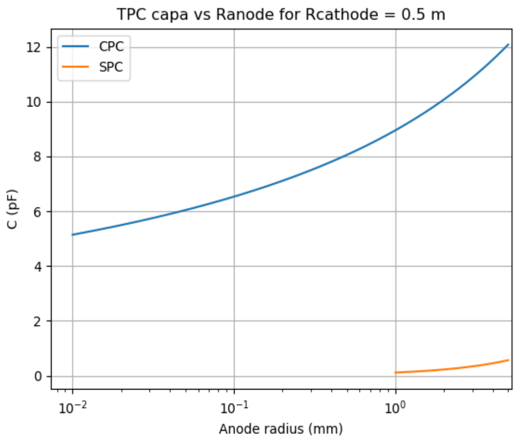


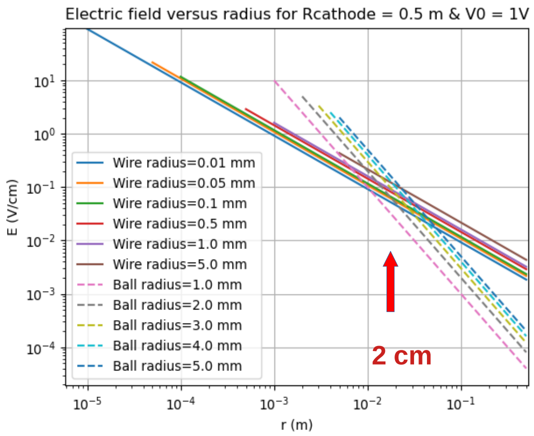
**Tanks wall**
(conceivable over hundreds of m)

**and why not using liquids (ionization mode) ?**

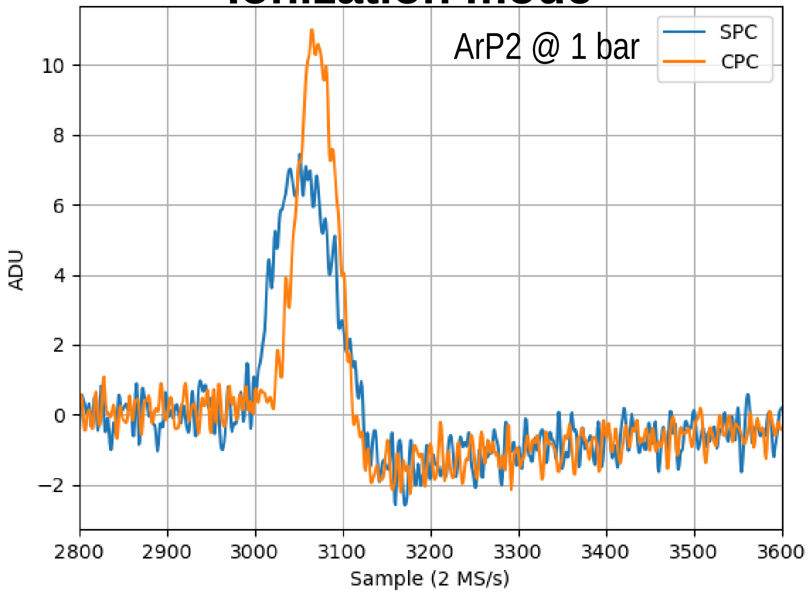
THANK YOU FOR YOUR ATTENTION

# Backup: SCP / CPC Features



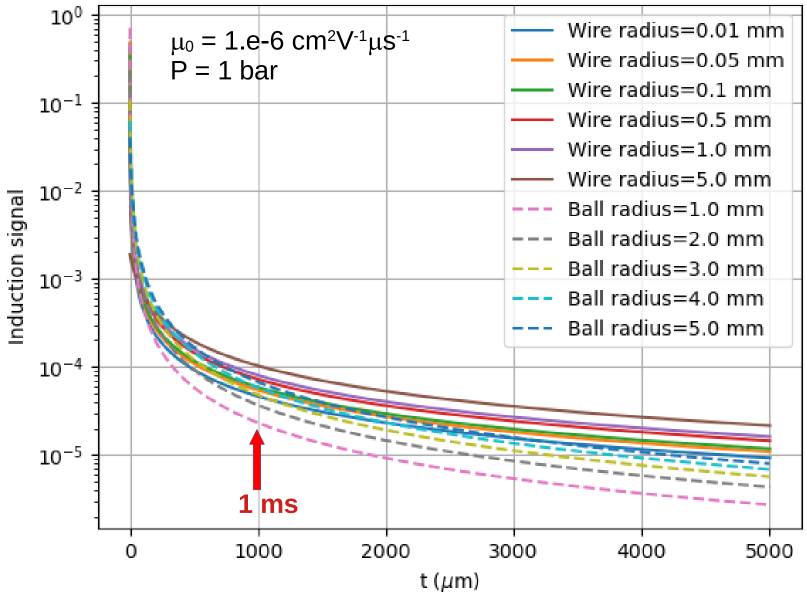

## Ionization mode




**SPC is slower due to the lower E-field**

## Proportional mode

Ion transfer function according to the anode radii




**Ions mobility governs the signal duration.**

**CPC has faster but longer signal**

### Pro (ionization)

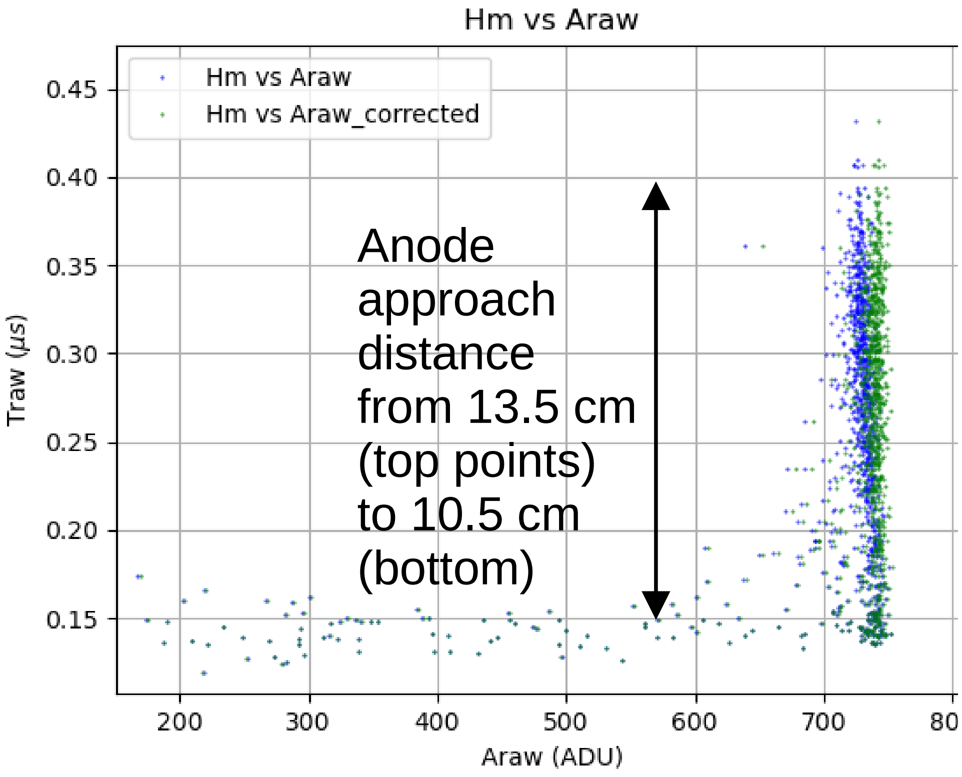
- Low HV
- No field screening
- No ion tail (=>duration)
- No gain fluctuation

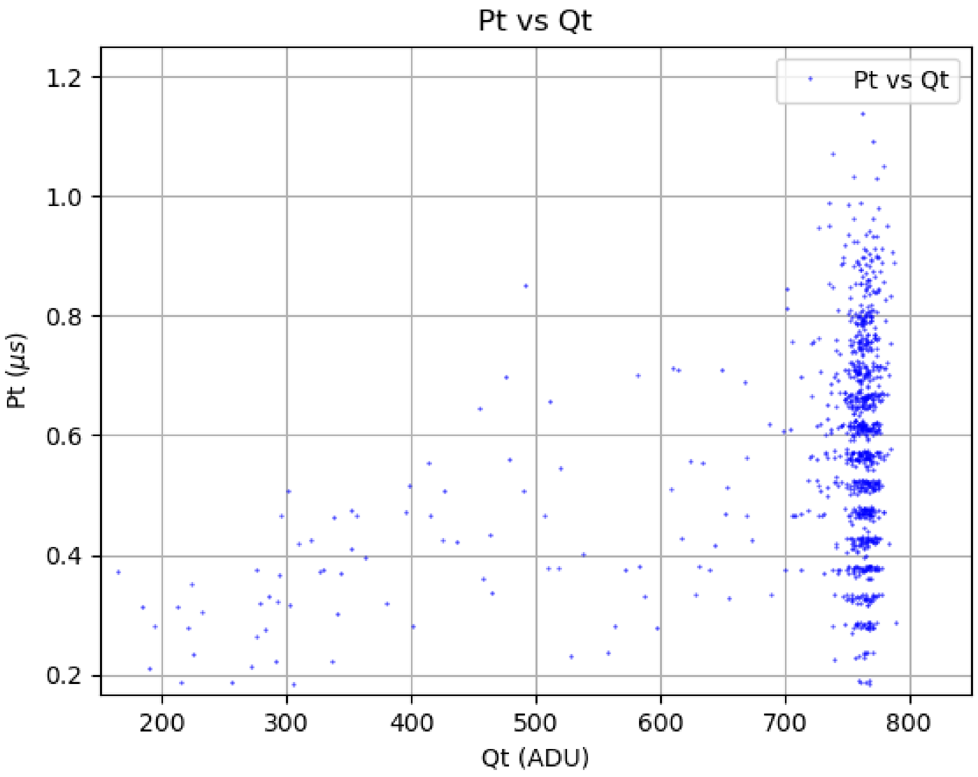
### Cons (ionization)

- signal / noise

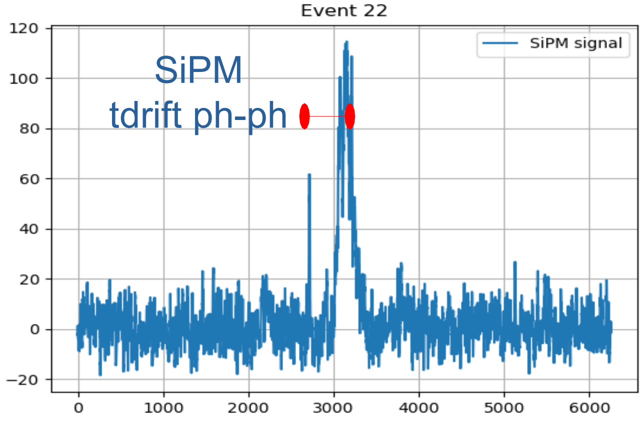
# Backup: Track distance sensitivity

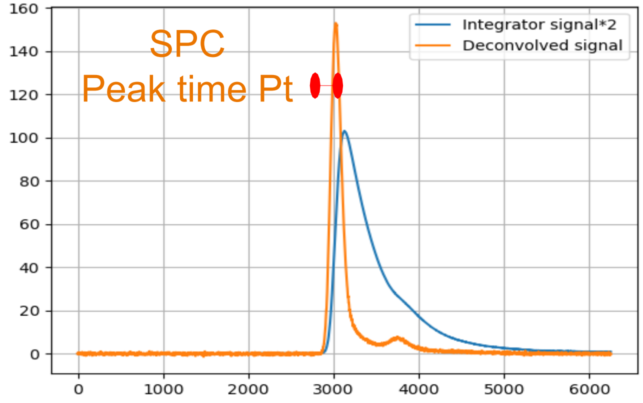
*CPC-50 - Deconvolved signal - ArP2 - 1 bar – 210 Po - Track length ~3 cm*



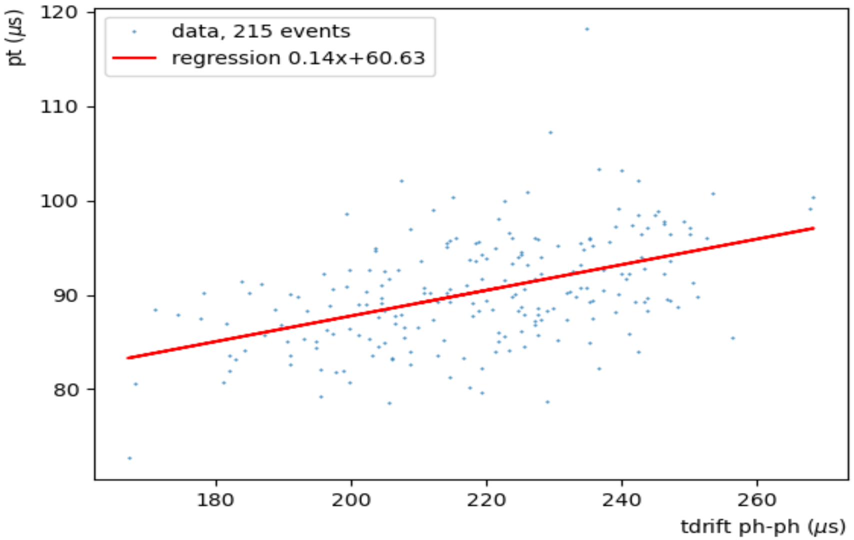



# Backup : Correlations between light & SPC signal



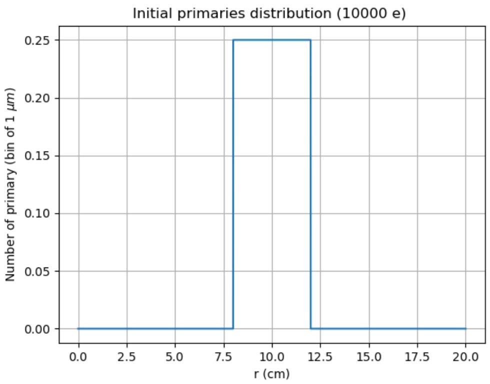

Pure Ar @ 1.1 bar – 210 Po source – Track length of 3 cm



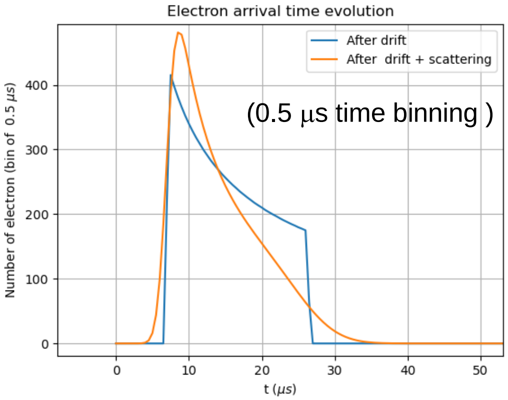

**=> Correlation drift time (SiPM) - peak time (SPC) observed.**

**=> A way to bypass the use of the light emission...**

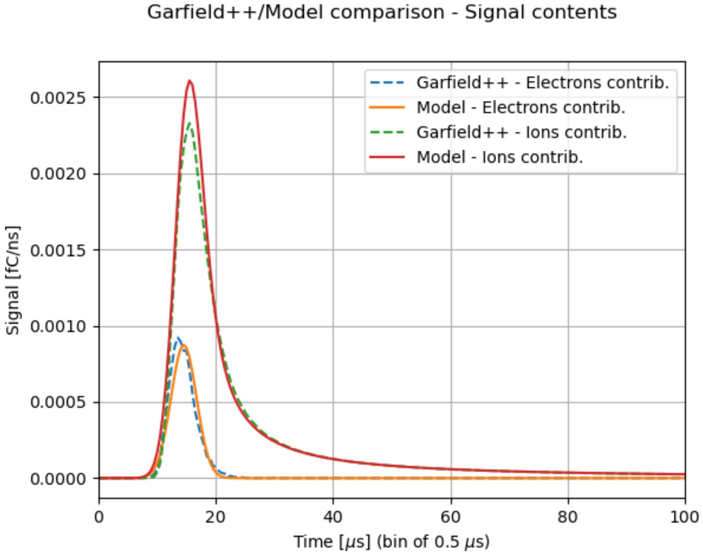
# Backup: signal formation




Transport and diffusion effects for primary electrons




Convolution of the final Electron arrival time distribution
With the ion induction function h_ion(t)




Response with to a Dirac primary charge @ 10 cm
*SPC ($r_{cathode}$=20 cm, $r_{anode}$=1mm) - Gas ArP2 - P=200mb - HV=700V,*
*$\mu_0$=1.e-6*
*Gain = 8*