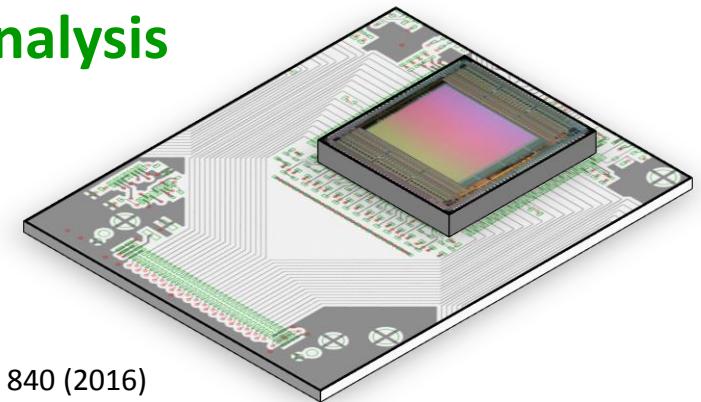


GET data samples processing for ACTAR TPC tracking

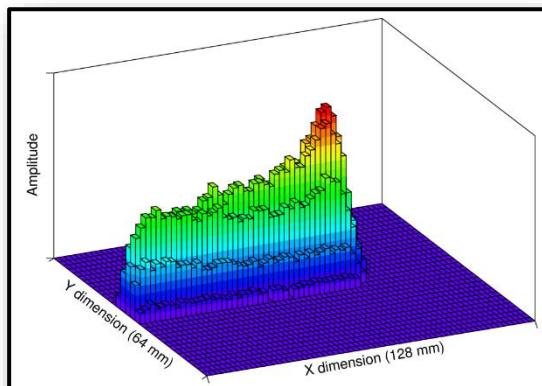
J. Giovinazzo et al.

GET electronics and test-bench data analysis

- channel signal processing principles
- raw samples corrections
- input signal reconstruction



published in NIM A 840 (2016)



ACTAR TPC demonstrator tracking tests

- tracks fitting model
- alpha source tests results

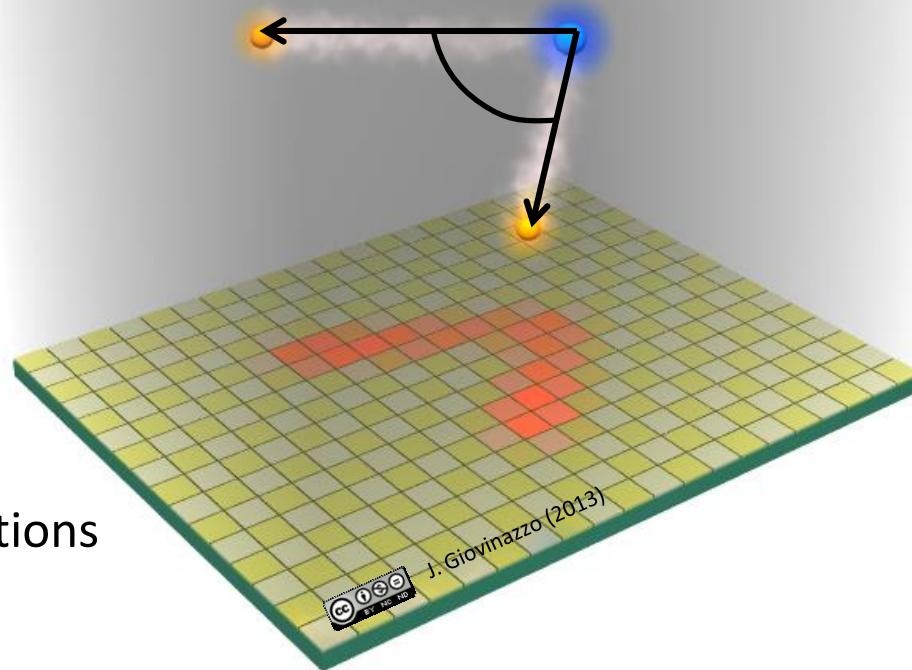
submitted to NIM A

context

from “end user” point of view (extract relevant information from data)

low energy nuclear physics experiments

- protons or ions
 - few MeV / nucleon
 - few μ s drift time
- (almost) full track(ing)
in gas volume



information

- energy deposit / loss
(Bragg peak / identification)
- track length, start/stop positions
- emission direction

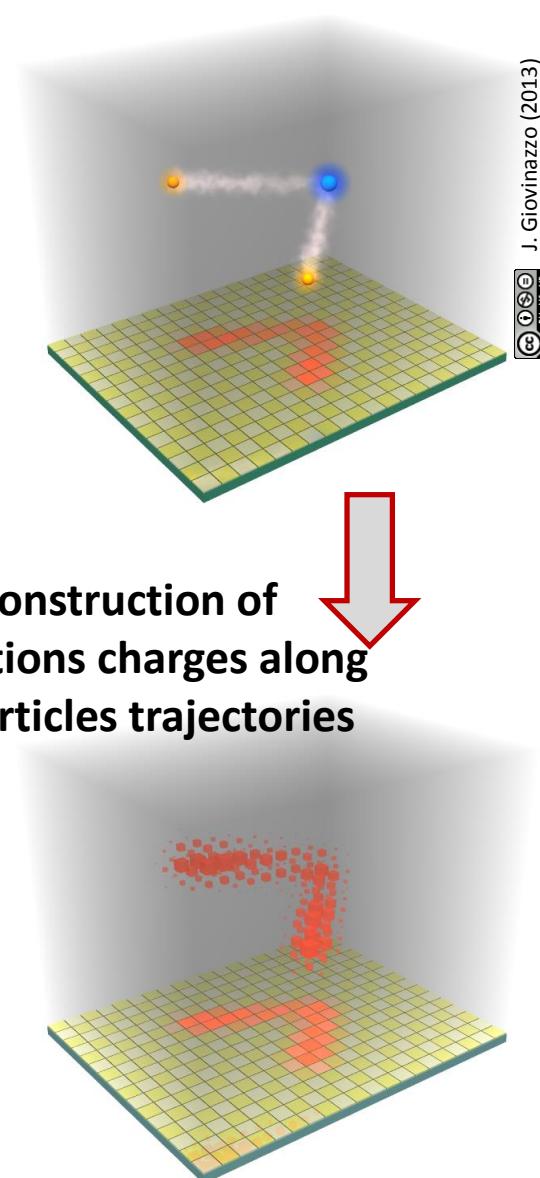
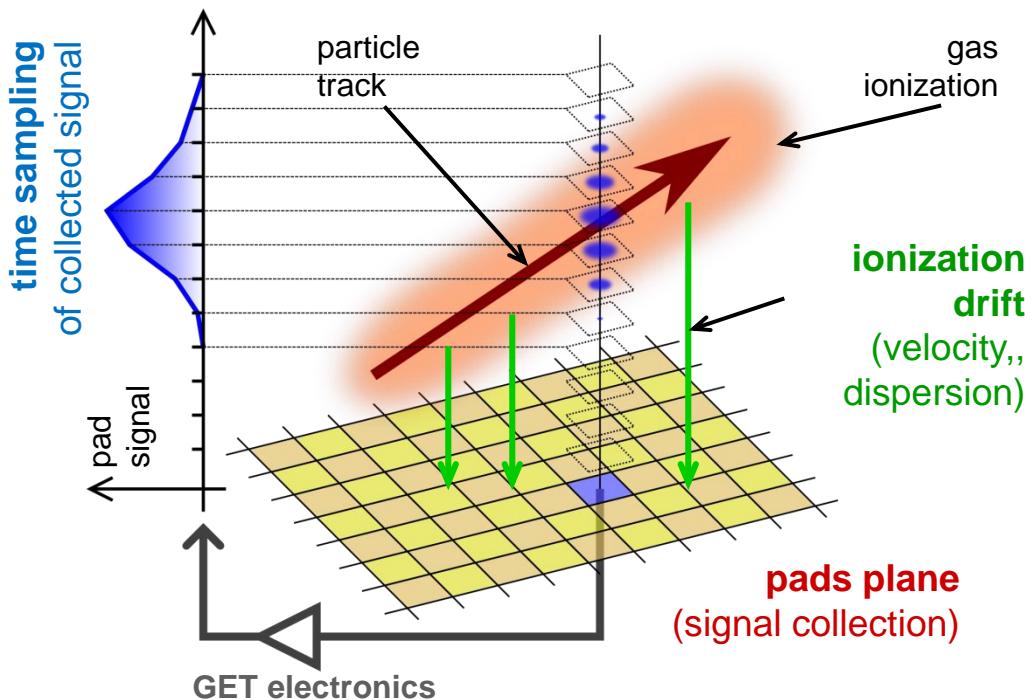
ACTAR TPC + GET electronics: 3D “photograph” of charge deposit

pads plane
(signal collection)
2D digitization

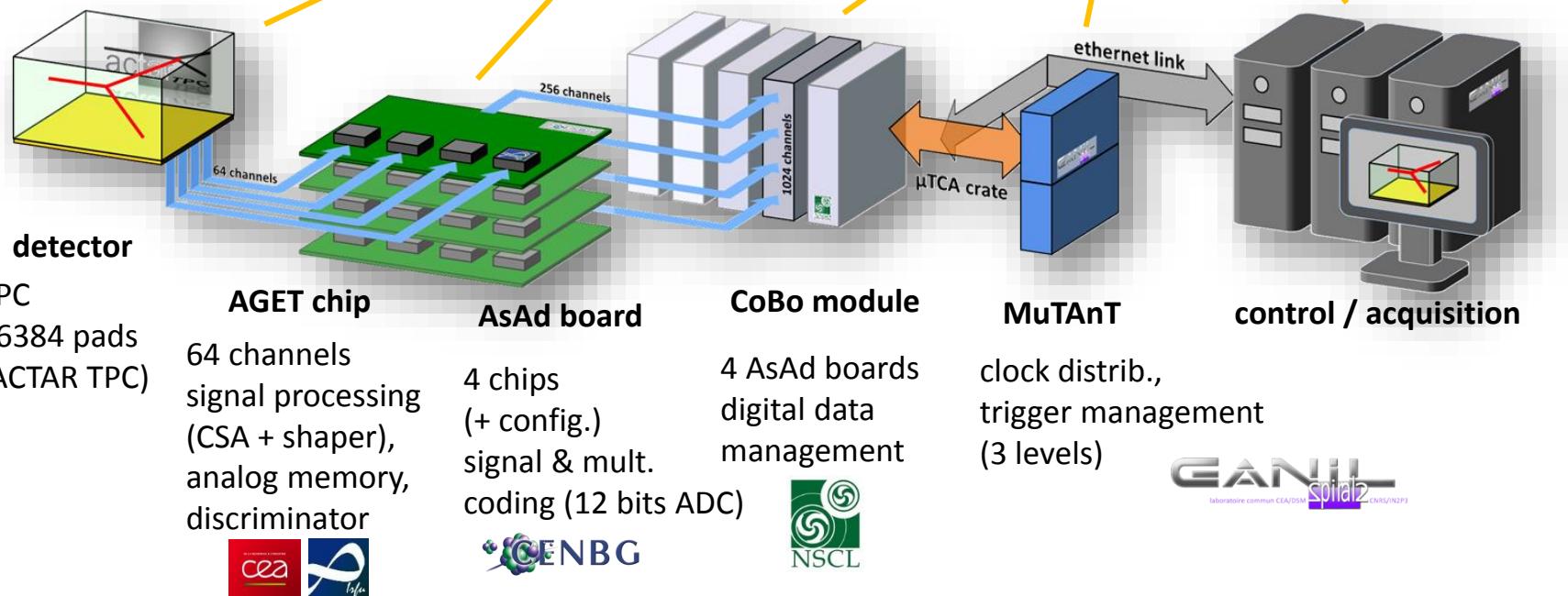
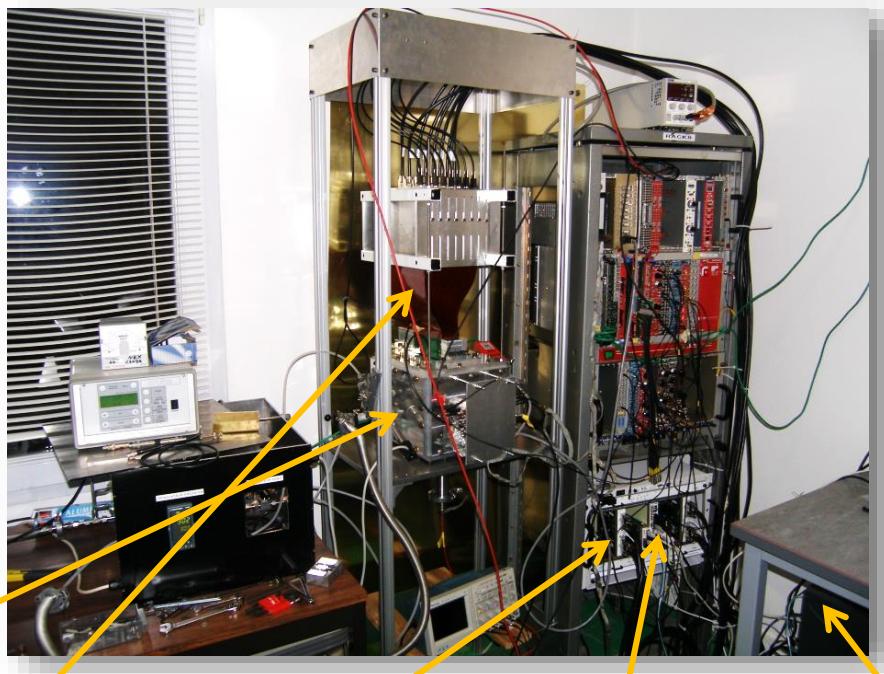
TPC principle
 $z \Leftrightarrow t$

**time sampling
of signal**
3D digitization

$\Delta E(x,y,z) \Leftrightarrow \Delta E[x_i, y_j](z) \Leftrightarrow \Delta E[x_i, y_j](t) \Leftrightarrow \Delta E[x_i, y_j, t_k]$



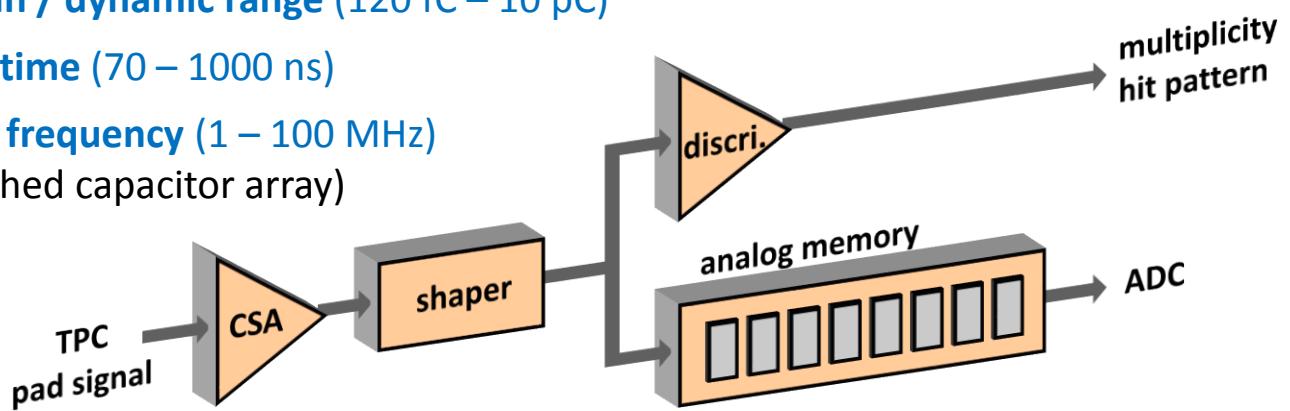
GET electronics



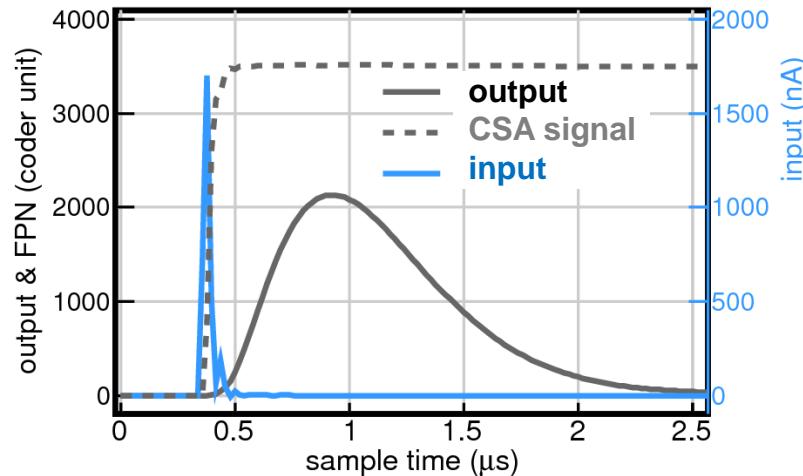
GET signal channels

highly versatile electronics / many configuration parameters
(only basic features considered here)

- charge preamplifier: **gain / dynamic range** (120 fC – 10 pC)
- shaper / filter: **peaking time** (70 – 1000 ns)
- analog sampling : **write frequency** (1 – 100 MHz)
(circular memory: switched capacitor array)

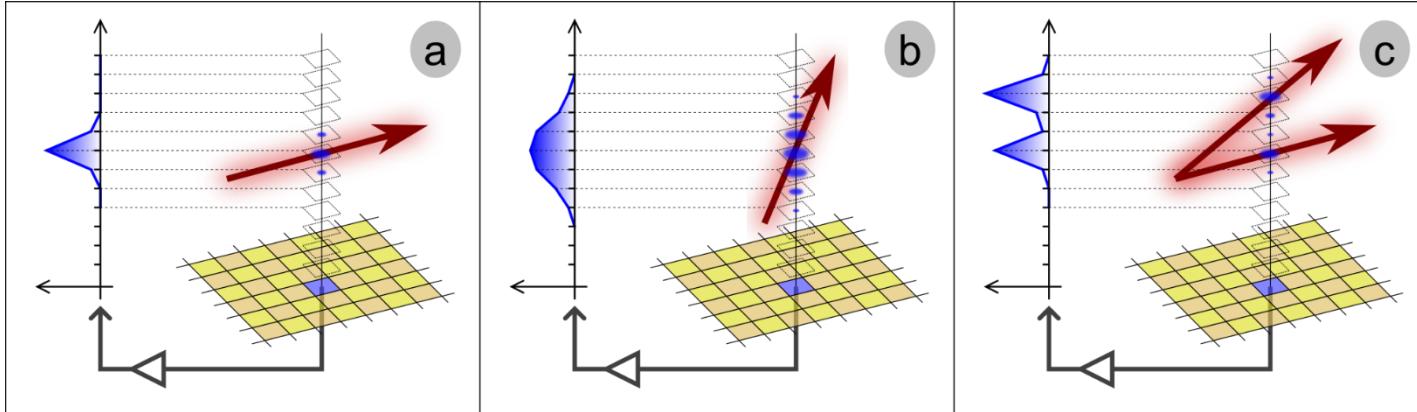


digitization (AsAd board)
& data processing / storage



input signal reconstruction: motivation

single pad input signal depends on track(s)



information washed out by CSA + shaper

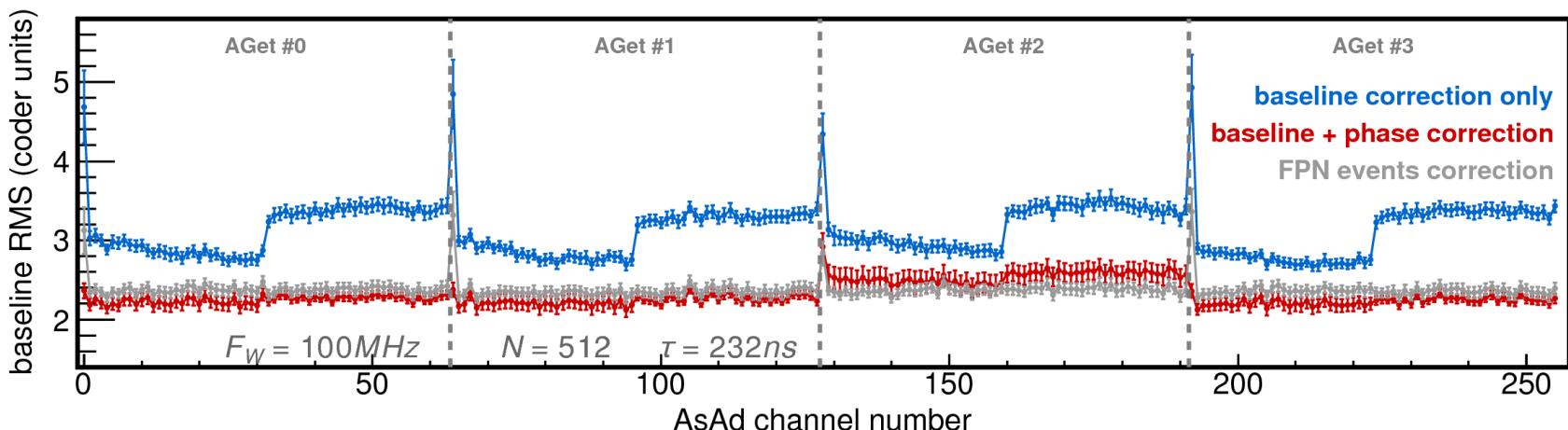
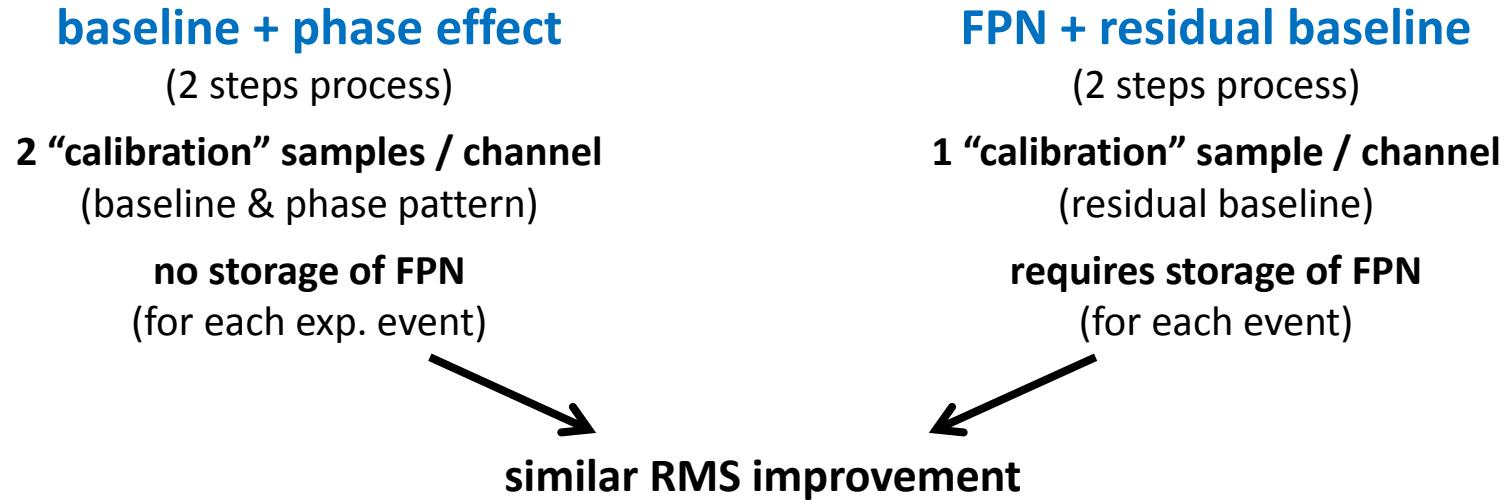
- case of multiple tracks (pile-up)
- reconstruction of input charge distribution ?
for an **effective “3D-photography” of charge deposit**

GET data processing

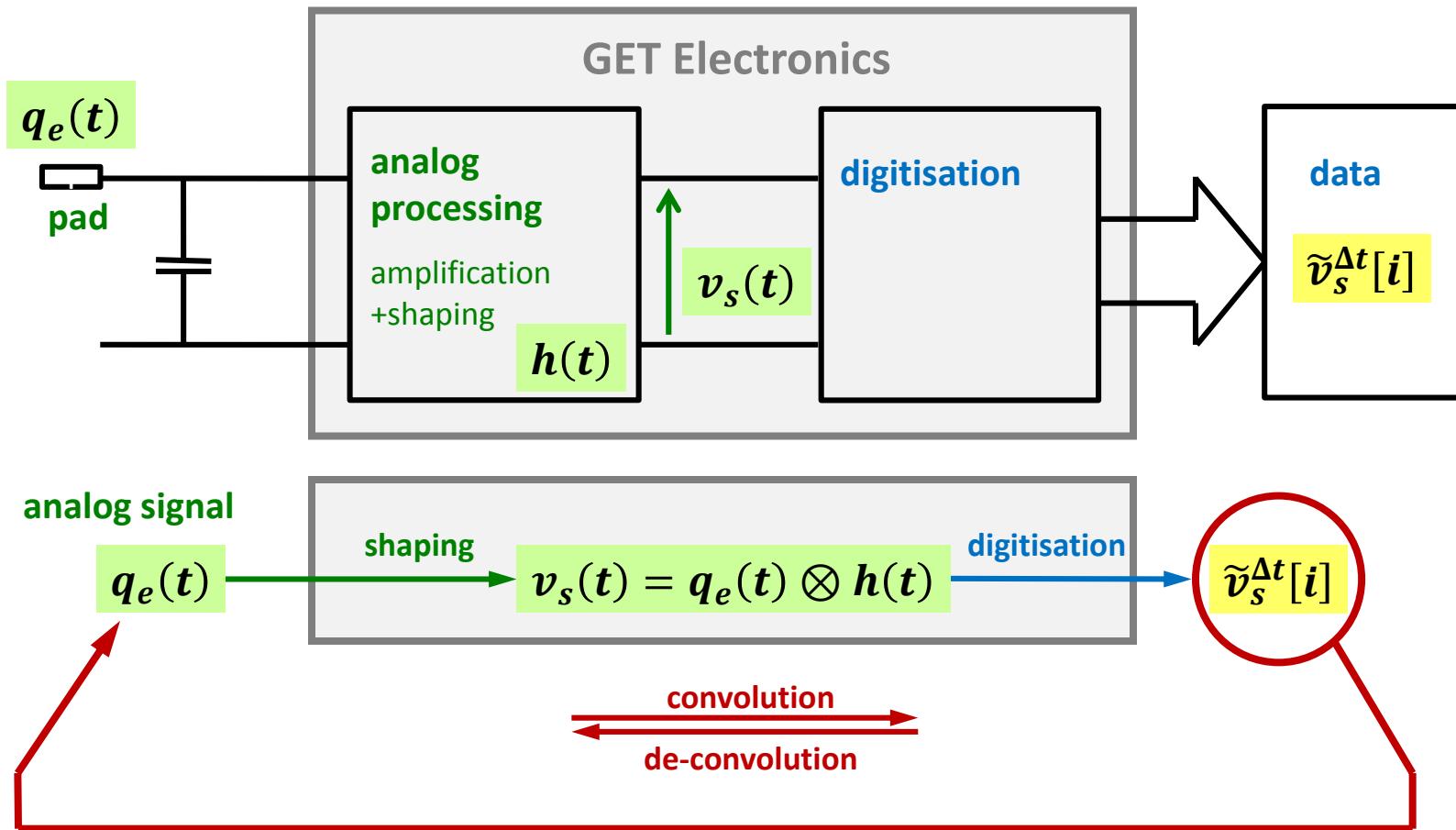
- raw data corrections
- input signal reconstruction

preliminary stage: raw samples correction

2 alternatives
for first stage corrections

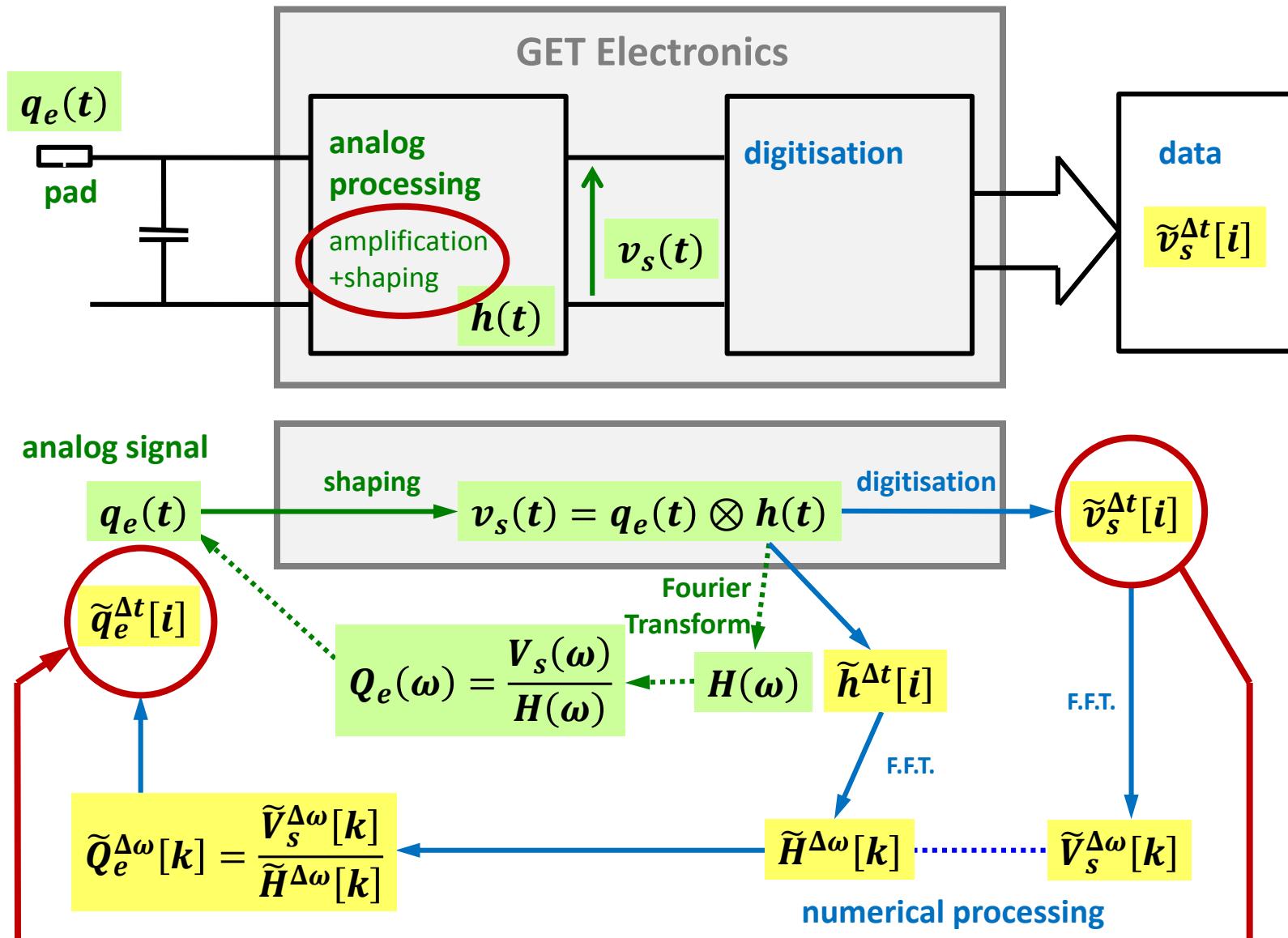


input signal reconstruction: principle



→ deconvolution from **shaping**
→ gain calibration alignment

input signal reconstruction: FFT



input reconstruction: (empirical) response function

“theoretical” response function (P. Baron)

$$h(t) = A \cdot e^{-3t/\tau} \cdot \left(\frac{t}{\tau}\right)^3 \cdot \sin\left(\frac{t}{\tau}\right)$$

not precise enough for real data... (may be used in simulations)

empirical response function

know pulse generator input (on test capacitor)

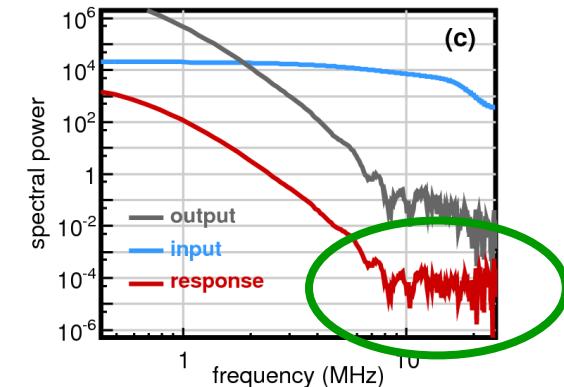
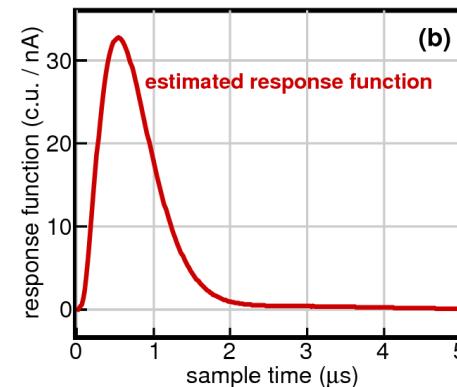
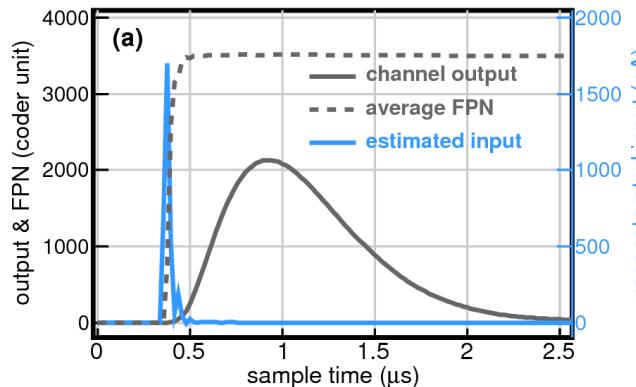
→ AsAd pulser (with FPN channels ≡ input signal)

→ external pulser

de-convolution in Fourier space:

$$\tilde{H}[k] = \frac{Out[k]}{\tilde{In}[k]}$$

1000 events average → residual fluctuations

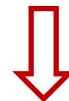


input reconstruction: need for filtering

reconstruction filter

- de-convolution in Fourier space
- residual **fluctuations** of response function
- additional **low-pass filter**:

$$\tilde{I}_j^{[k]} = \frac{s_j^{[k]}}{\tilde{H}_j^{[k]}} \cdot \Phi^{[k]}$$



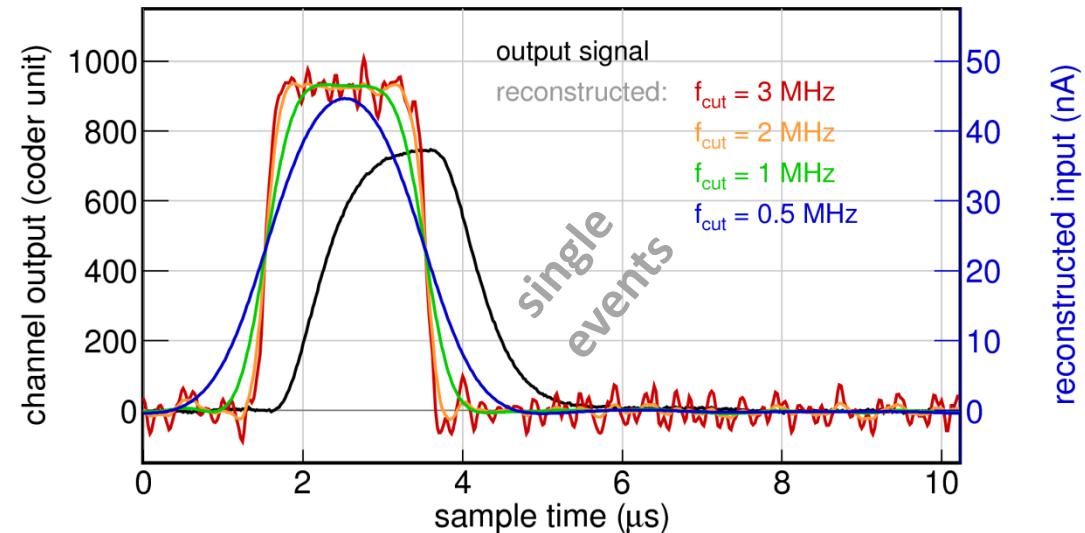
signal distortion

reconstruction quality

- criteria** → reconstruction precision:
signal deformation (filter distortion)
time / amplitude precision
→ time resolution (separation power)

parameters

- filtering: cut frequency, filter type... depends on signal / noise
- dynamic range (gain), peaking time, sampling frequency



input reconstruction: quality

noise versus distortion

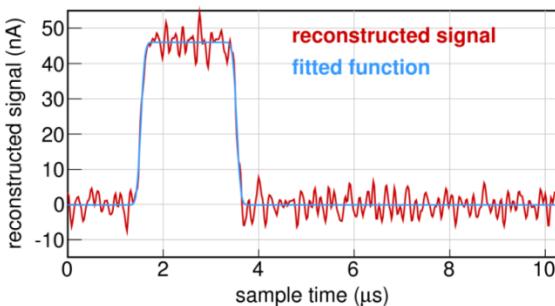
quantitative criteria

many factors...

(\Rightarrow filtering compromise)

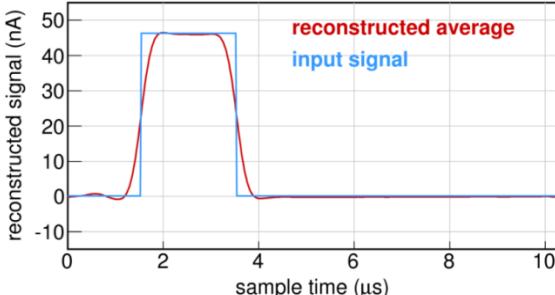
\rightarrow fluctuations around average

“noise” criterion



\rightarrow average deviation / input signal

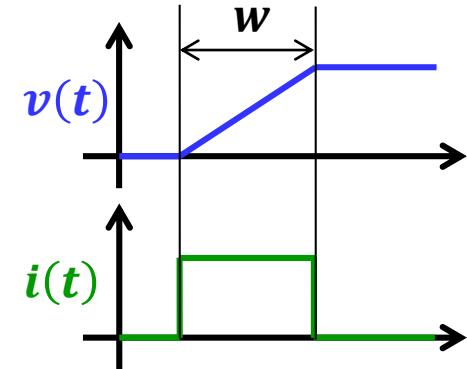
“reconstruction” criterion



function generator (voltage)

+ charge capacitor:

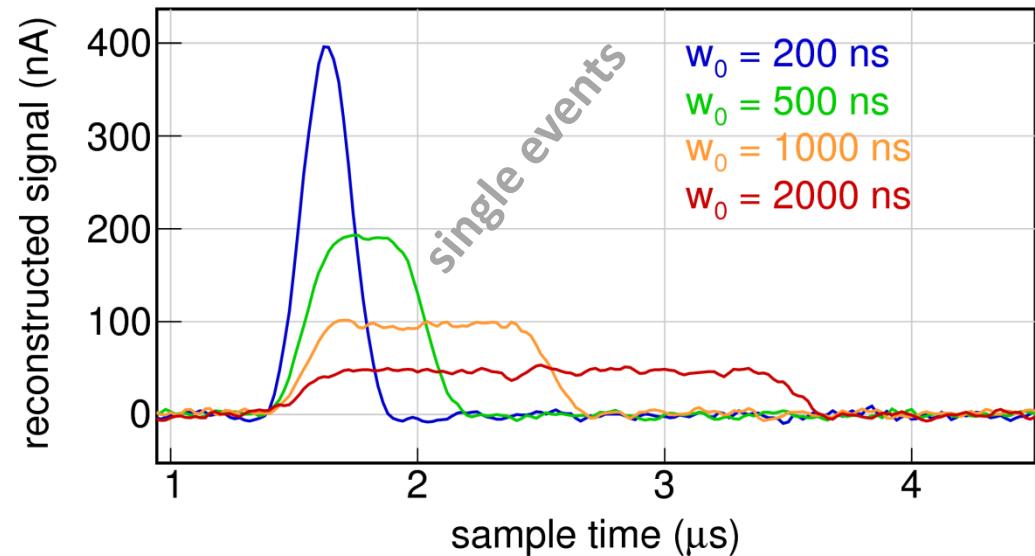
$$i(t) = C \cdot \frac{dv(t)}{dt}$$



square input signal

constant charge deposit (50 fC)

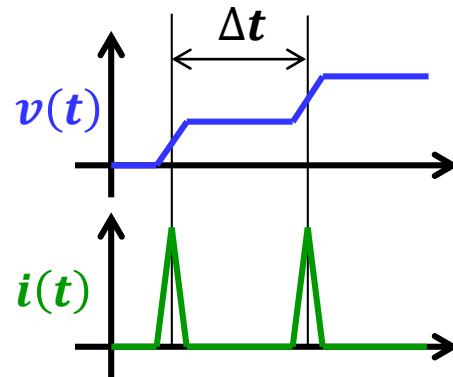
variable width



reconstruction std. dev. for Q_{tot} & $w \sim 1\%$

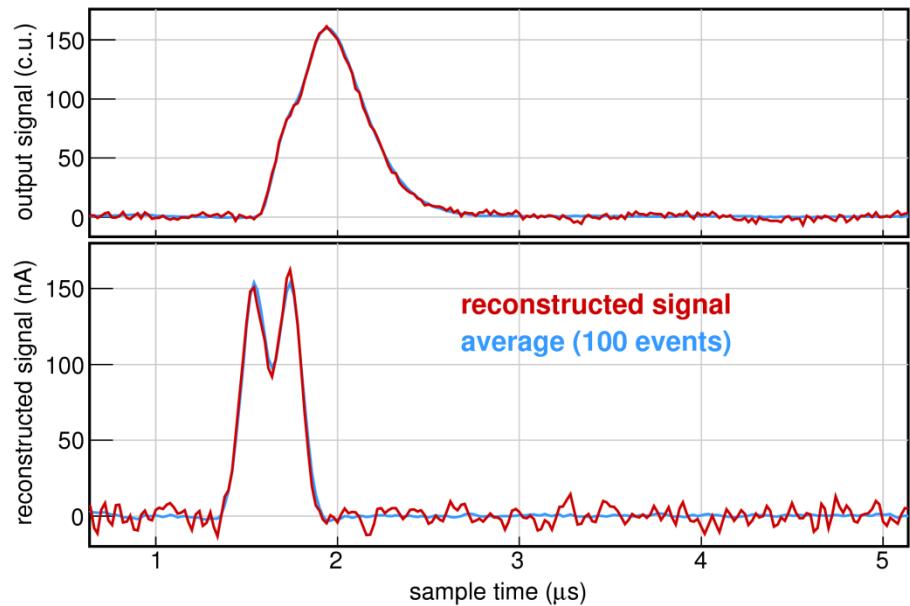
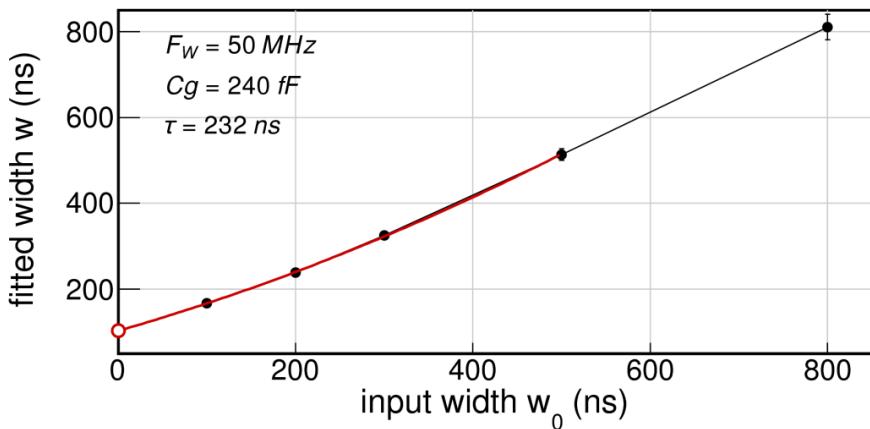
input reconstruction: time resolution

→ separation capabilities
for 2 charge deposits



→ FWHM of reconstructed signal

$$w_{fit} \simeq \sqrt{w_{input}^2 + w_{rec}^2}$$



depends on:

- requested quality criteria
- peaking time, write frequency
- ...

tests for $Q = 50 \text{ fC}$

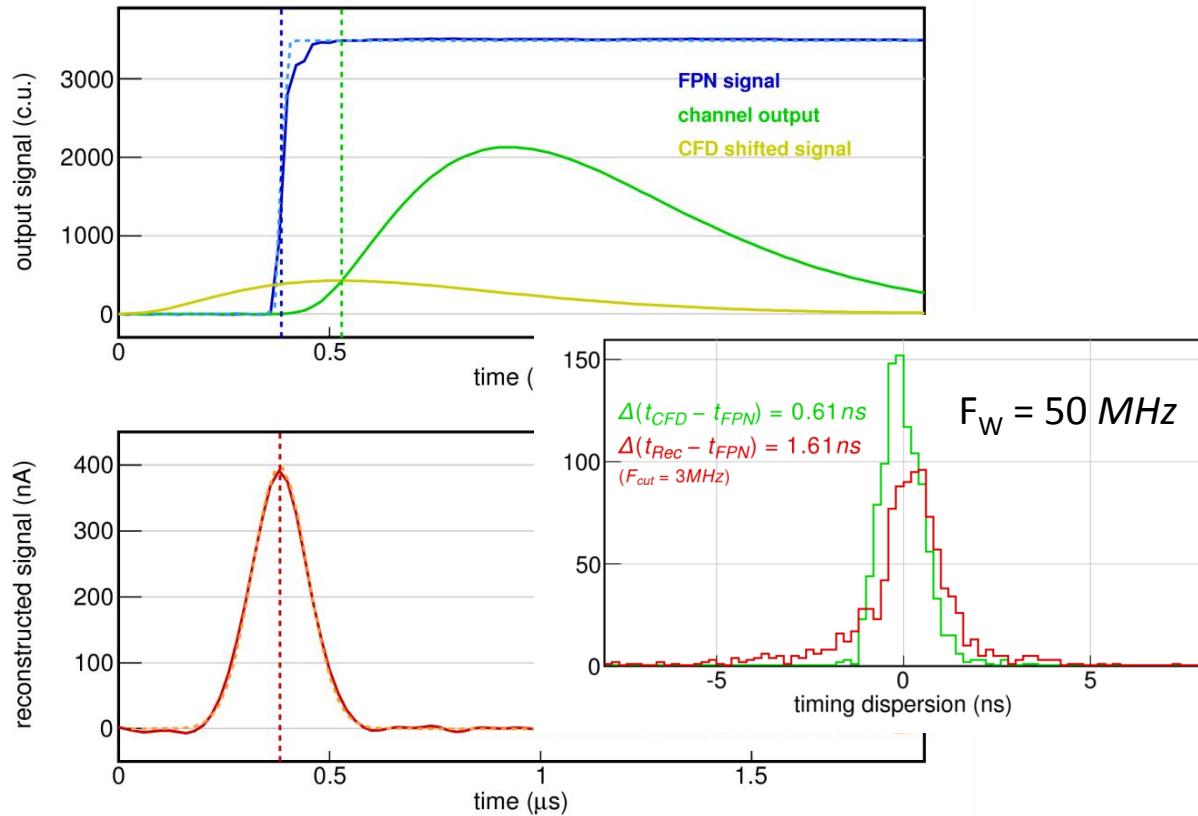
$w_{fit}(w_{input} \rightarrow 0) \sim 100 \text{ ns}$ for $F_W = 50 \text{ MHz}$
 $\sim 60 \text{ ns}$ for $F_W = 100 \text{ MHz}$

input reconstruction: time precision

AsAd pulser signal:

small dynamics ($C_g = 120 \text{ fF}$)
strong signal
(low noise conditions)

- **FPN** fit for reference timing
- **CFD** algorithm timing
- **Reconstructed signal fit**
(Gauss fit center)



“intrinsic” timing precision (strong signal – low noise)

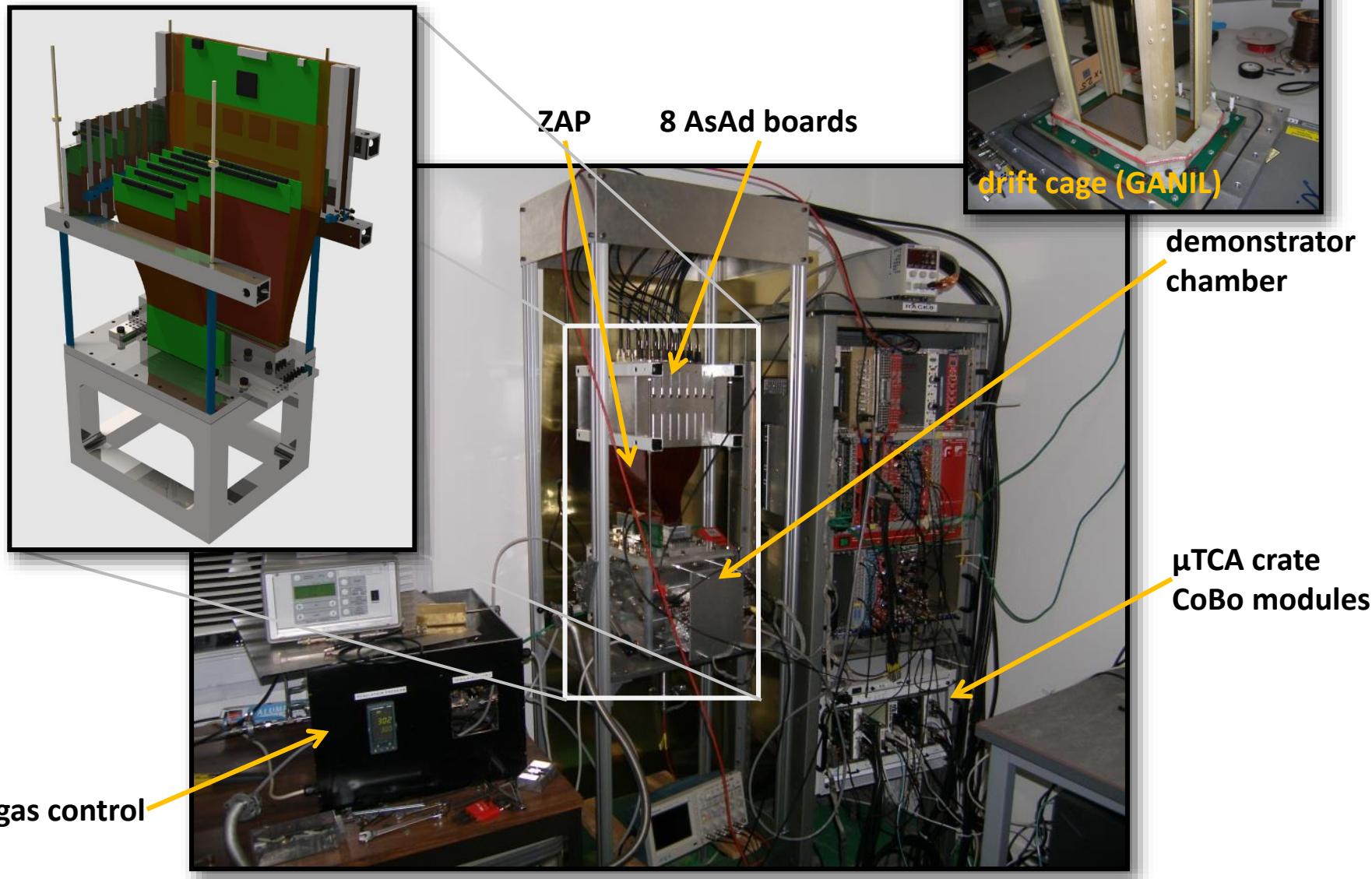
CFD timing → $\sim 0.6 \text{ ns}$ ($F_W = 50 \text{ MHz}$) / $\sim 0.4 \text{ ns}$ ($F_W = 100 \text{ MHz}$)
reconstruction → $\sim 1.6 \text{ ns}$ ($F_W = 50 \text{ MHz}$) / $\sim 0.9 \text{ ns}$ ($F_W = 100 \text{ MHz}$)

only limited comparison:

CFD timing → only a single time information
reconstruction → time distribution of charge

ACTAR TPC Demonstrator

full electronics (2016) → 2048 pads signal

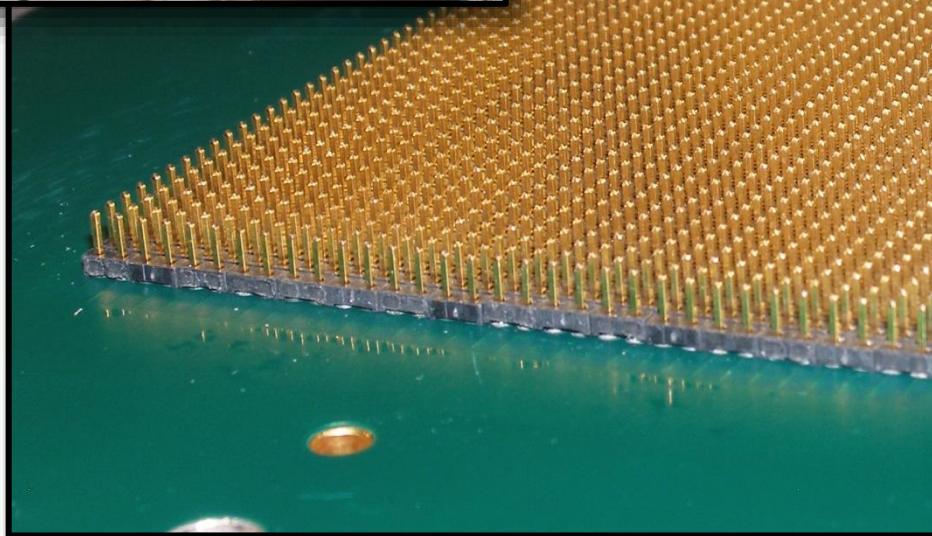
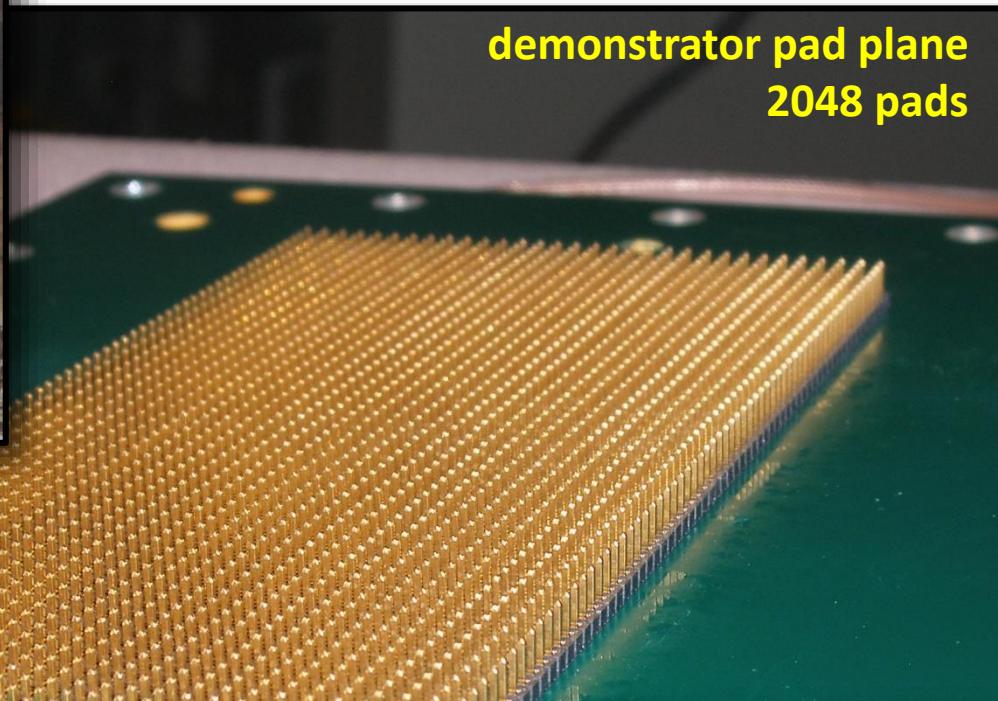


“FAKIR” pad plane

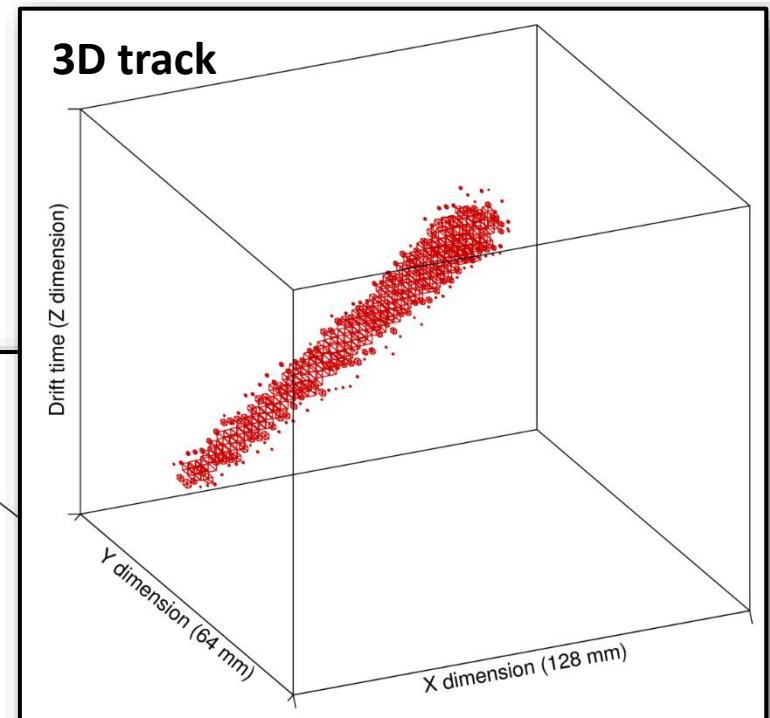
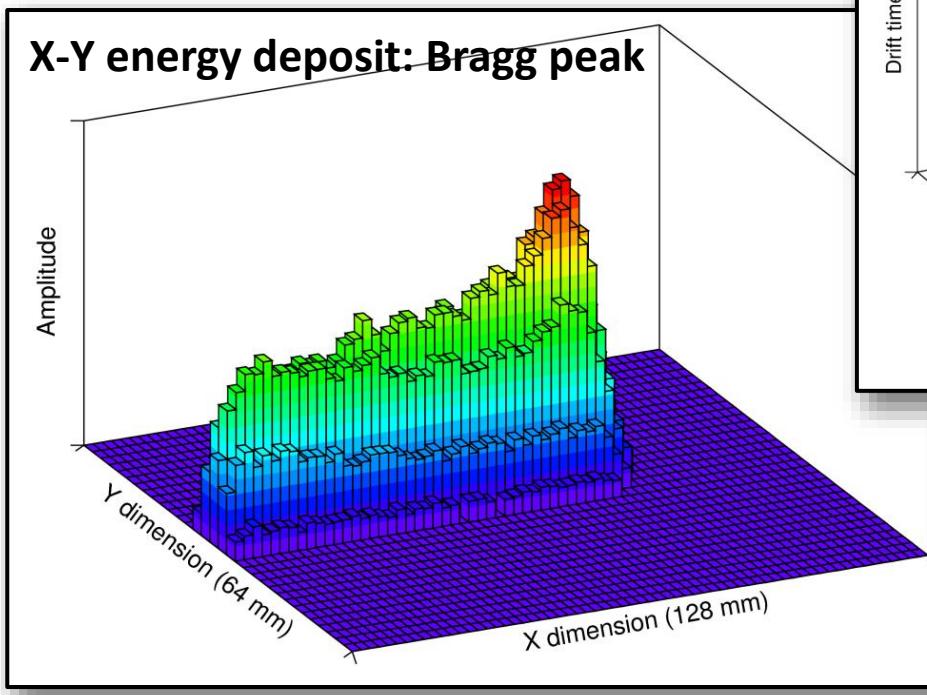
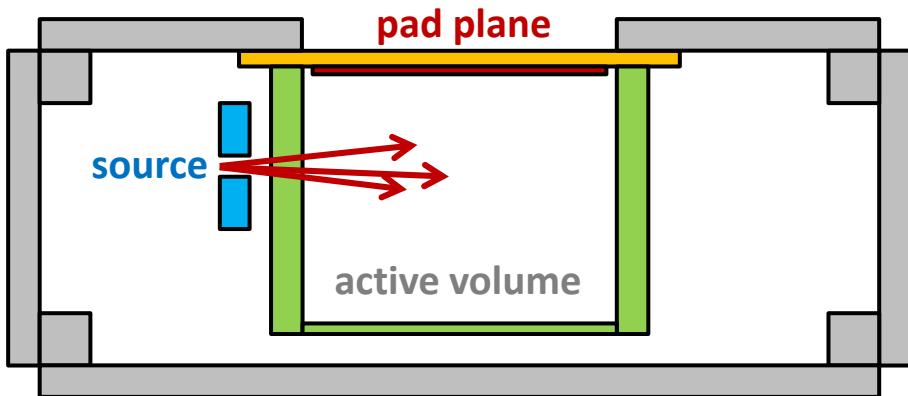


web image H. Ponting

demonstrator pad plane
2048 pads



3D track + signal amplitude



P10 gas (Ar-CH₄), 400 mbar

energy resolution

(base analysis: data correction / no de-convolution)
summed pad signal

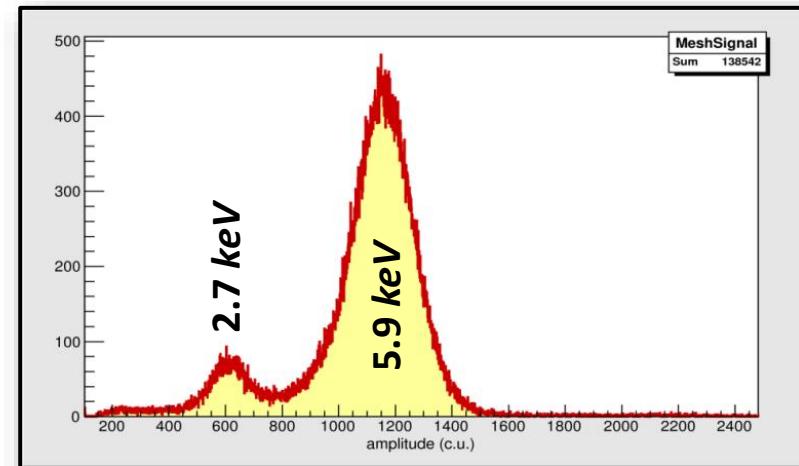
^{55}Fe source X-rays

drift volume thickness: **2.5 cm**

$$HV_{\text{mesh}} = -570 \text{ V}$$

$$HV_{\text{drift}} = -1000 \text{ V}$$

P10 gas (Ar-CH₄), 1 atm



resolution (FWHM) @ 6 keV: ~21 %

3-alpha source

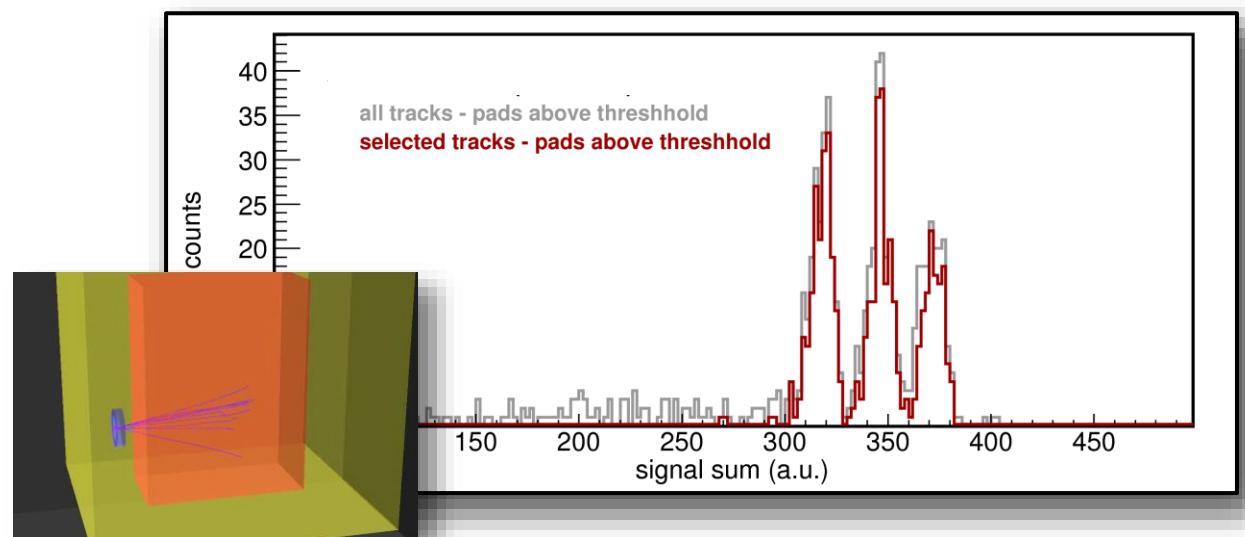
GANIL drift cage

$$HV_{\text{mesh}} = -350 \text{ V}$$

$$HV_{\text{drift}} = -2000 \text{ V}$$

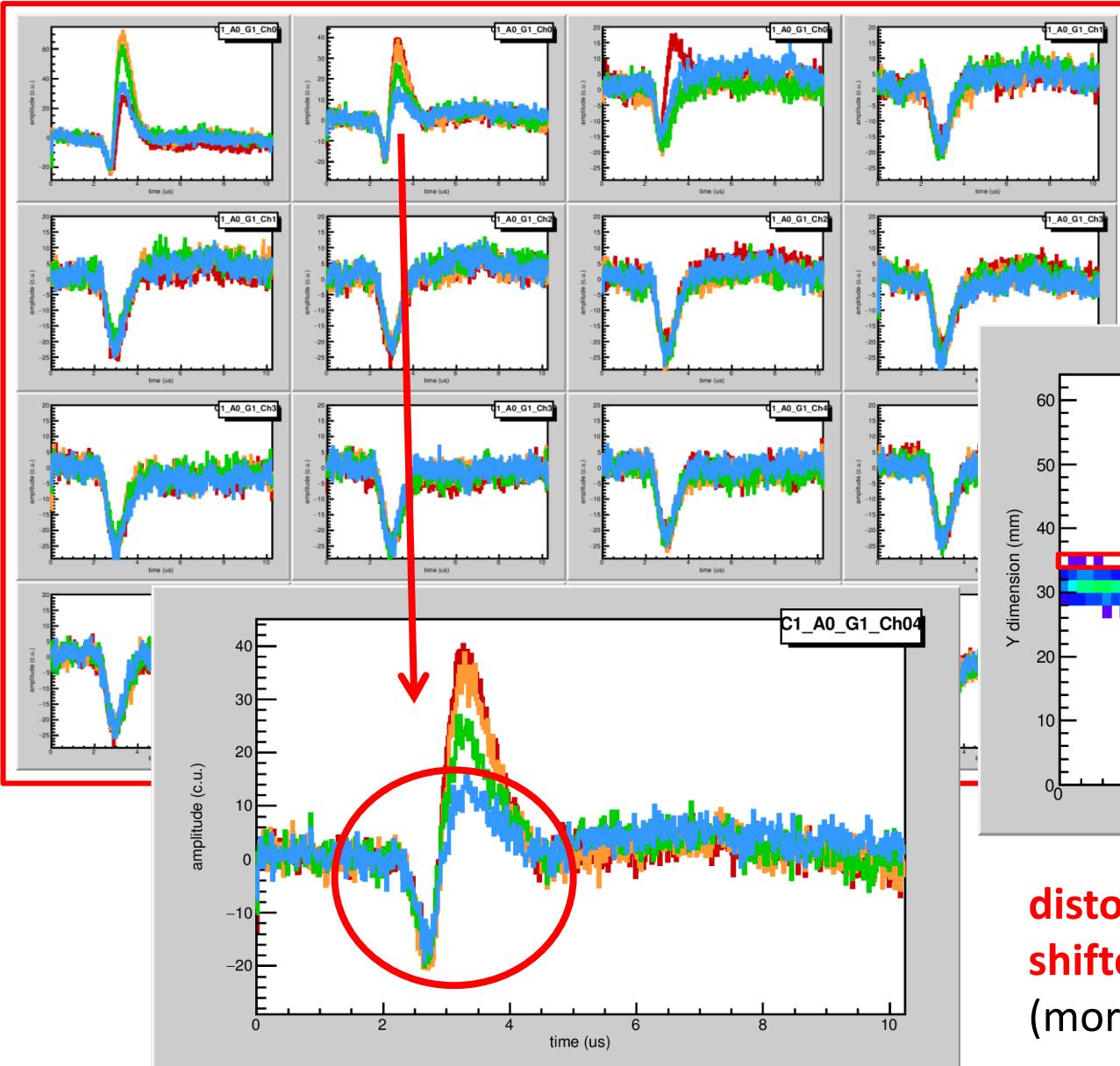
P10 gas (Ar-CH₄), 400 mbar

alpha energy correction
(Geant4 simulation)



resolution (FWHM) @ 5 MeV: ~130 keV

mesh-induced signal: undershoot



(alpha source)

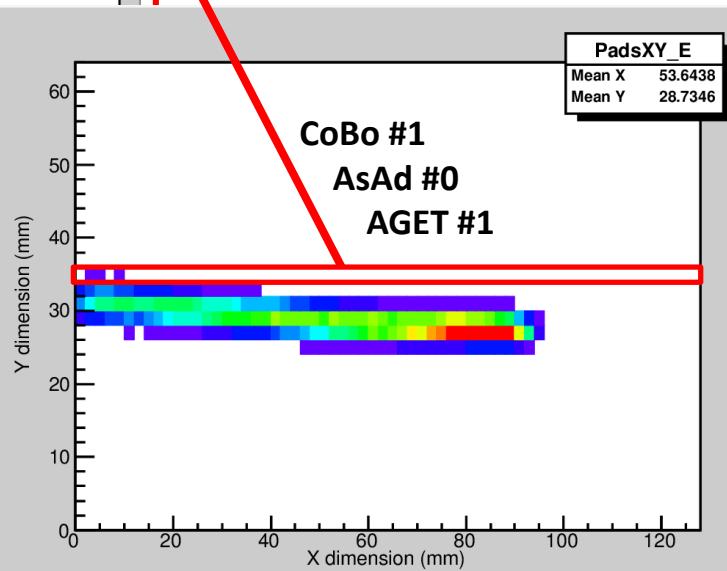
$$F_W = 50 \text{ MHz}$$

$$\tau = 502 \text{ ns}$$

$$C_g = 1 \text{ pC}$$

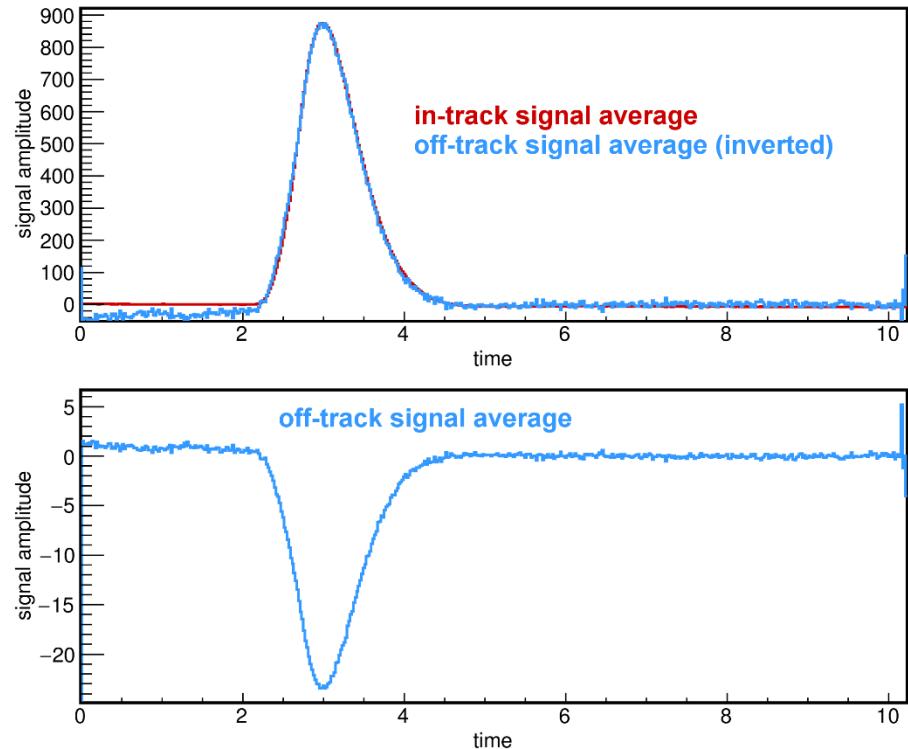
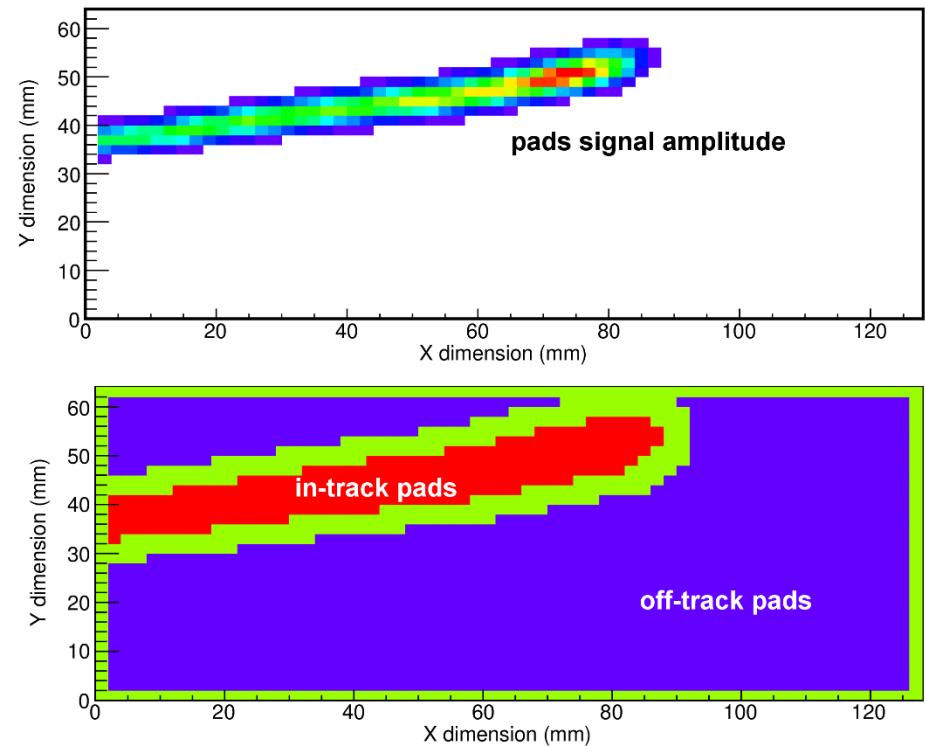
full readout

CoBo #1
AsAd #0
AGET #1

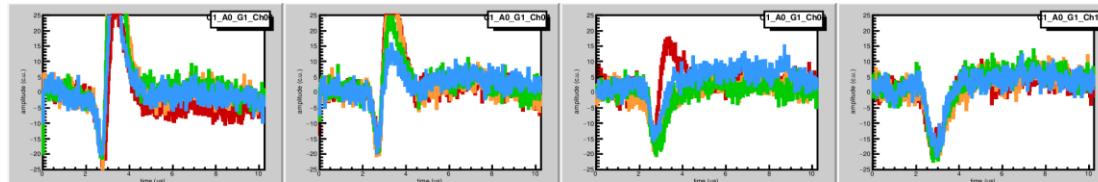


distorted energy
shifted timing
(more visible on track side)

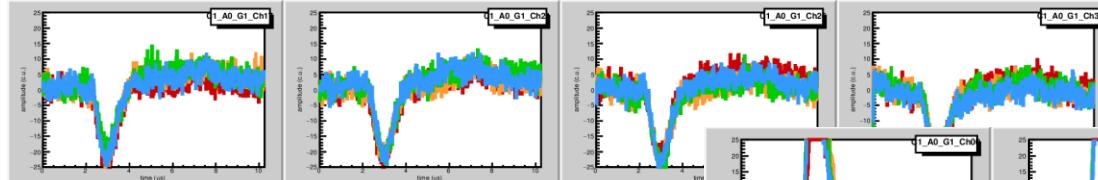
mesh-induced signal: off-track signal



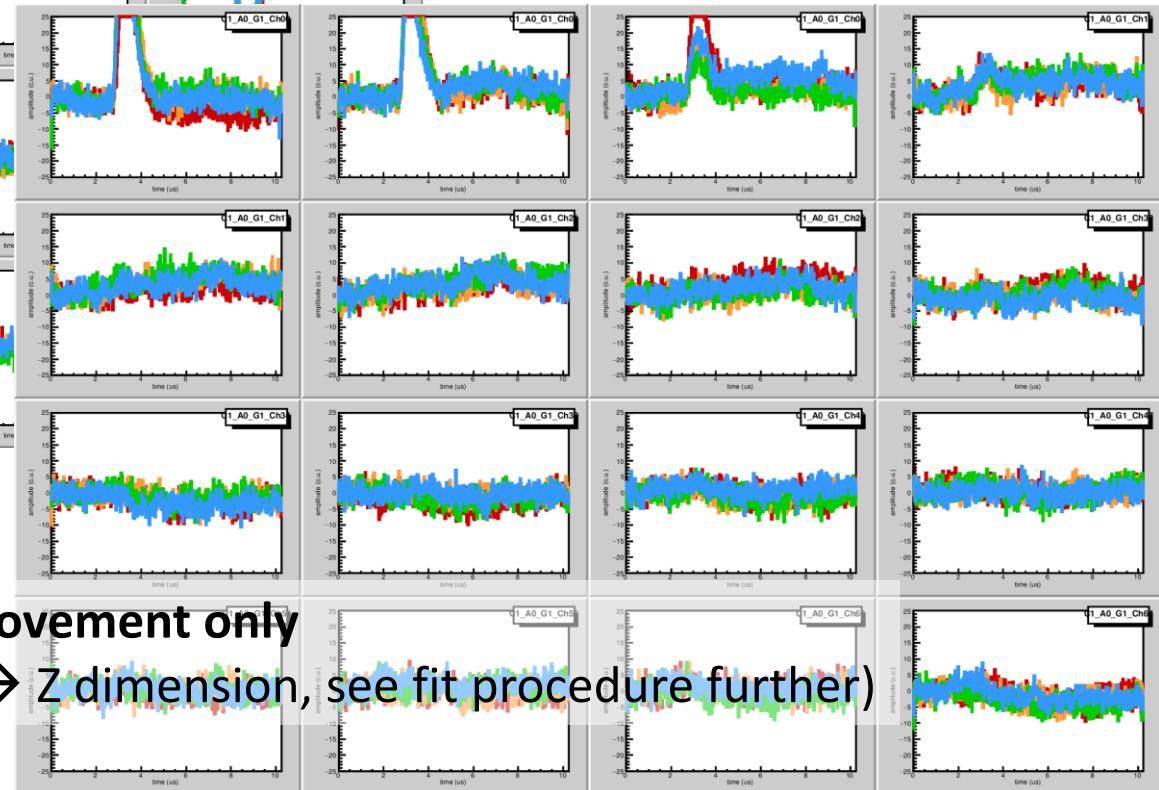
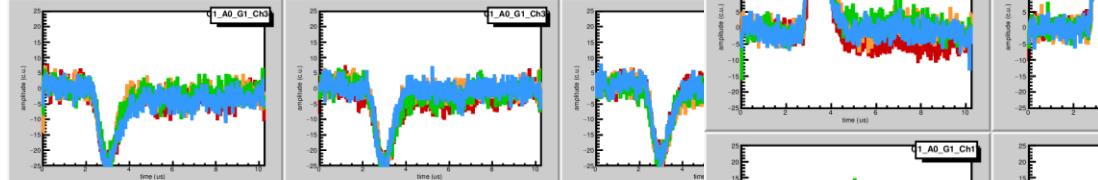
mesh-induced signal: undershoot correction



before
correction



after correction



energy: 1% resolution improvement only

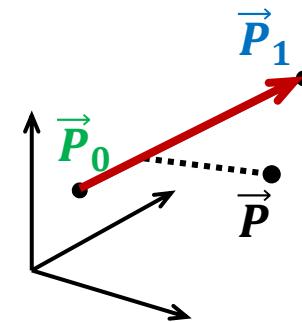
timing: 5% improvement (\rightarrow Z dimension, see fit procedure further)

to be checked with heavy ions (saturation)

particles (alpha) tracks fitting

track initial point: $\vec{P}_0 = (x_0, y_0, z_0)$

track final point: $\vec{P}_1 = (x_1, y_1, z_1)$



energy loss along the track

track length: $L = \|\overrightarrow{P_0 P_1}\|$

track path coordinate: $\varepsilon \in [0; 1]$ $\varepsilon = 0 \Leftrightarrow \vec{P} = \vec{P}_0$
 $\varepsilon = 1 \Leftrightarrow \vec{P} = \vec{P}_1$

energy loss function: $f_E(\varepsilon) = \frac{dE}{dx} (\varepsilon \cdot L)$ \rightarrow Bragg peak

total energy: $E = \int_{\varepsilon=0}^1 f_E(\varepsilon) \cdot d\varepsilon$

alpha tracks fitting: Bragg peak model

simulated energy deposit along the track

normalized function from simulation: $f_{Bragg}(\lambda_L)$

estimated at energy E_0 and gas pressure P_0

→ track length $L_0(E_0, P_0)$

energy loss along the track:

$$f_E(\varepsilon) = A \cdot f_{Bragg}(\lambda_L + (1 - \lambda_L) \cdot \varepsilon)$$

λ_L fraction of the track length for a particle with energy $E \neq E_0$

A normalization for total energy loss

- at \vec{P}_0 ($\varepsilon = 0$):

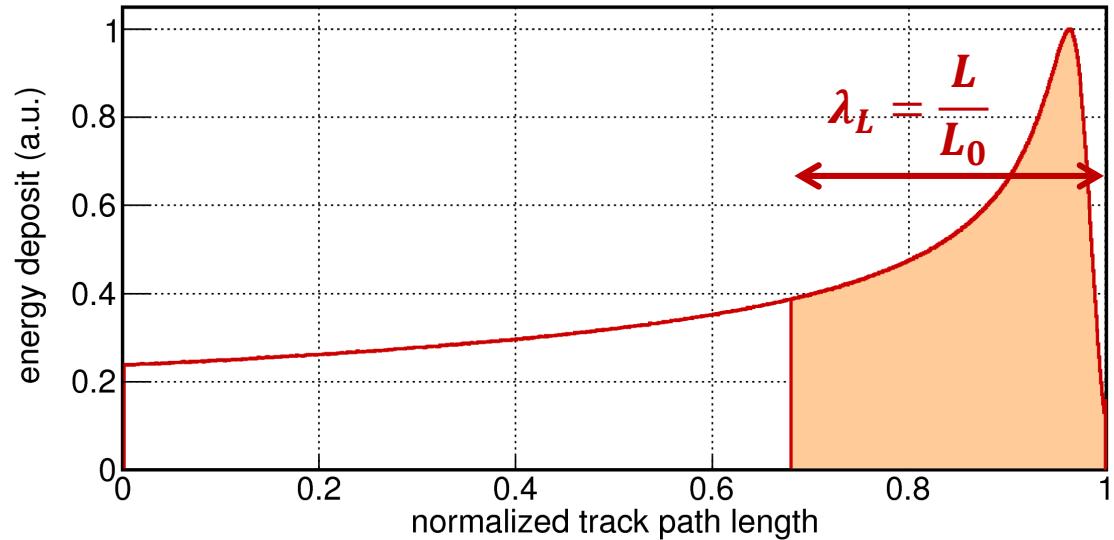
$$f_E(0) = A \cdot f_{Bragg}(\lambda_L)$$

- at \vec{P}_1 ($\varepsilon = 1$):

$$f_E(1) = A \cdot f_{Bragg}(1)$$

energy from track length:

$$E_{sim}(\lambda) = E_0 \frac{\int_{1-\lambda}^1 f_{Bragg}(\lambda) \cdot d\lambda}{\int_0^1 f_{Bragg}(\lambda) \cdot d\lambda}$$



alpha tracks fitting: energy projection

2D (X-Y) signal projection + T dimension

$$S_{XY}(x, y) = \int_{\varepsilon=0}^1 f_E(\varepsilon | \mathbf{A}, \boldsymbol{\lambda}) \cdot \frac{1}{2\pi \cdot \sigma_X(\varepsilon) \cdot \sigma_Y(\varepsilon)} \cdot e^{-\left[\frac{r(x|\mathbf{x}_0, \mathbf{x}_1, \varepsilon)^2}{2\sigma_X(\varepsilon)^2} + \frac{r(y|\mathbf{y}_0, \mathbf{y}_1, \varepsilon)^2}{2\sigma_Y(\varepsilon)^2}\right]} \cdot d\varepsilon$$

parameters

track start & stop positions: $(\mathbf{x}_0, \mathbf{y}_0, \mathbf{t}_0)$ and $(\mathbf{x}_1, \mathbf{y}_1, \mathbf{t}_1)$

energy loss along the track: $f_E(\varepsilon | \mathbf{A}, \boldsymbol{\lambda})$ ← peak shape from simulation

distance to track point \vec{P}_ε :
(linear track segment)
 $r(x|\mathbf{x}_0, \mathbf{x}_1, \varepsilon) = x - [x_0 + \varepsilon \cdot (x_1 - x_0)]$
 $r(y|\mathbf{y}_0, \mathbf{y}_1, \varepsilon) = y - [y_0 + \varepsilon \cdot (y_1 - y_0)]$

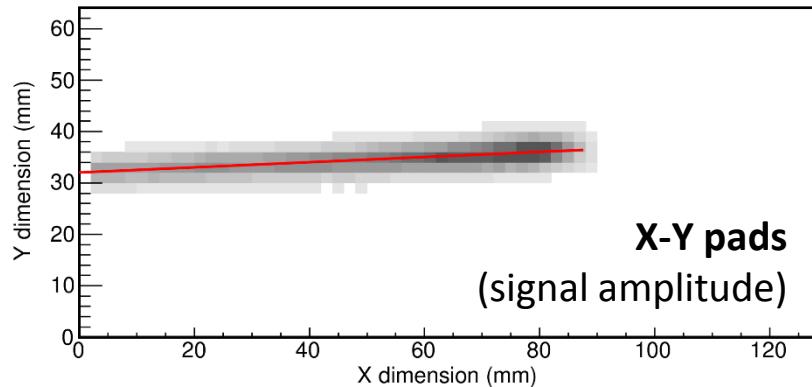
dispersion:
(variation along track) $\sigma_{X,Y}(\varepsilon) = \sigma_0^{(X,Y)} + \epsilon \cdot \sigma_1^{(X,Y)} \cdot \sqrt{z}$
with $z = [\mathbf{t}_0 + \varepsilon \cdot (\mathbf{t}_1 - \mathbf{t}_0)] \cdot v_{drift}$

time (z) fitting

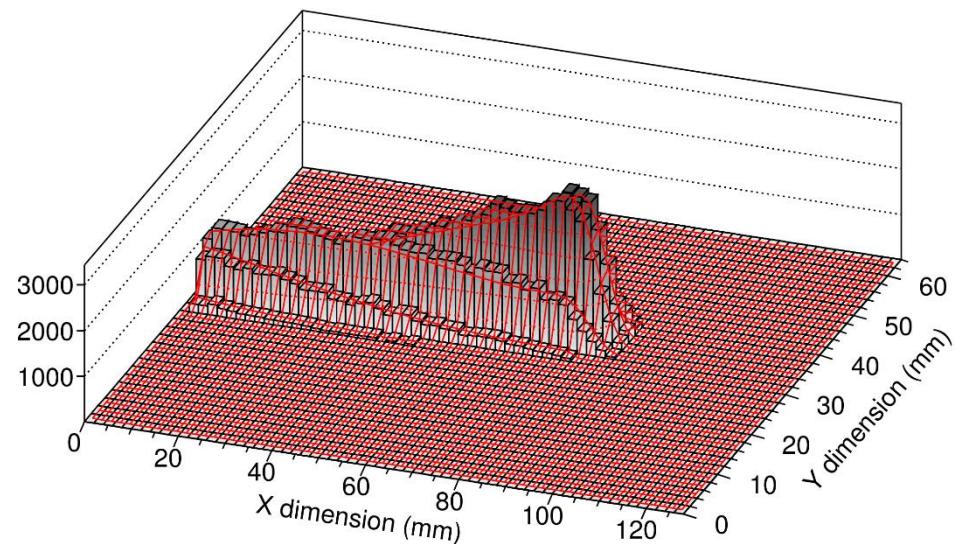
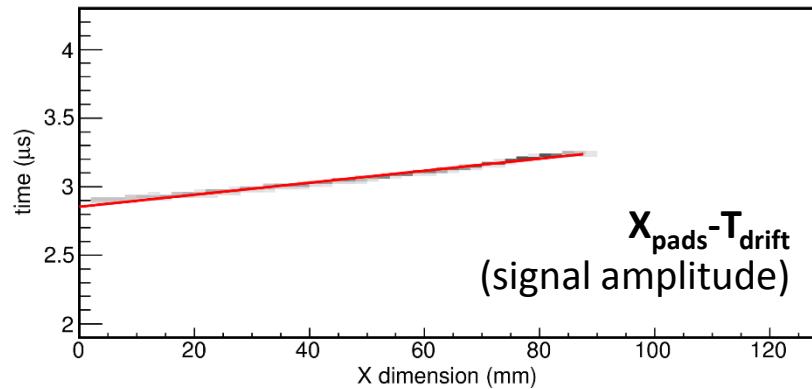
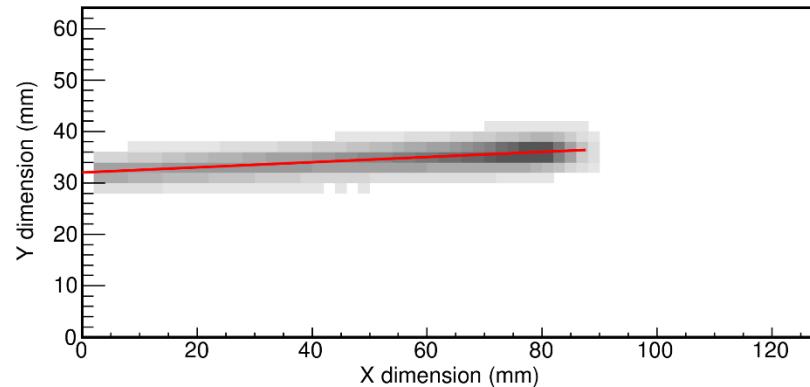
performed independantly

alpha tracks fitting: illustration

experimental data



fit result



(alpha source)

$$F_w = 50 \text{ MHz}$$

$$\tau = 502 \text{ ns}$$

$$C_g = 1 \text{ pC}$$

full readout

track length from the fit

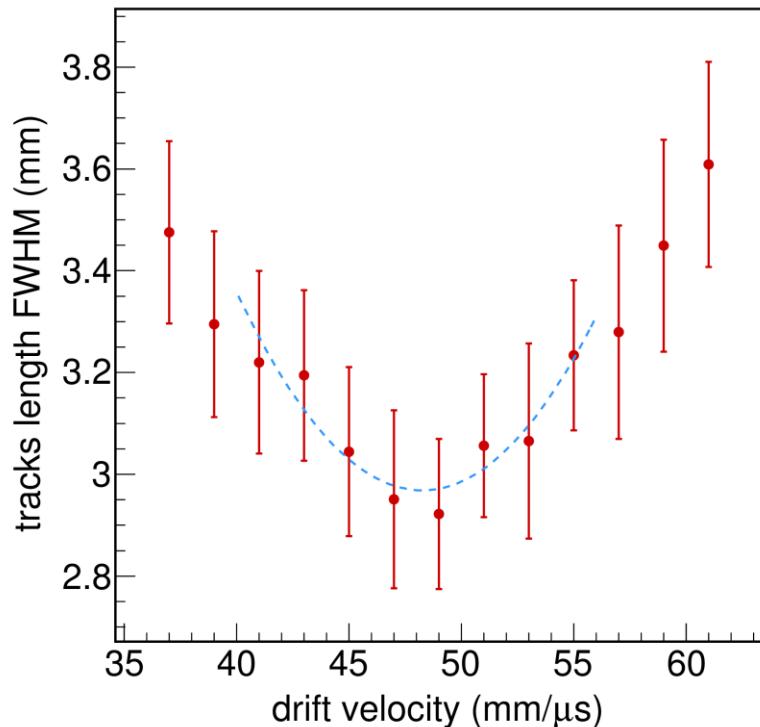
from tracks fit:

$$L_{XY} = \sqrt{\Delta X^2 + \Delta Y^2}$$

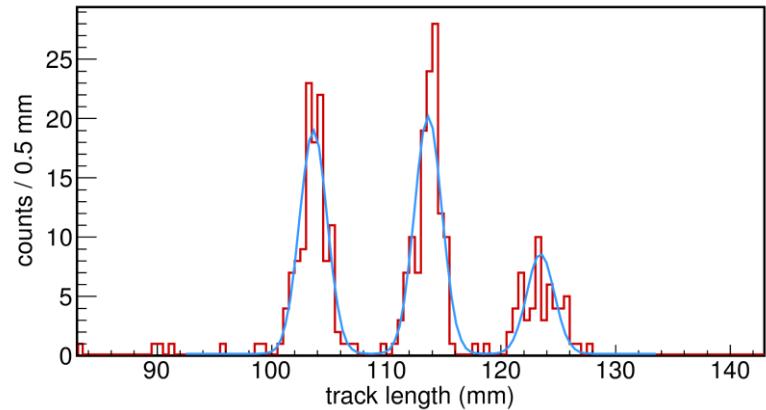
$$\Delta Z = v_{drift} \cdot \Delta T$$

total length (from fitted track):

$$L = \sqrt{\Delta X^2 + \Delta Y^2 + (v_{drift} \cdot \Delta T)^2}$$



collimated source runs (0°)
P10 gas @ 400mbar
drift HV: -100 V / cm



minimum L dispersion:

$$V_{drift} = 48.2 \pm 1.5 \text{ mm/}\mu\text{s}$$

(Magboltz: $47.7 \pm 0.9 \text{ mm/}\mu\text{s}$)

track reconstruction precision

collimated source runs (0°)
P10 gas @ 400mbar
drift HV: -100 V / cm

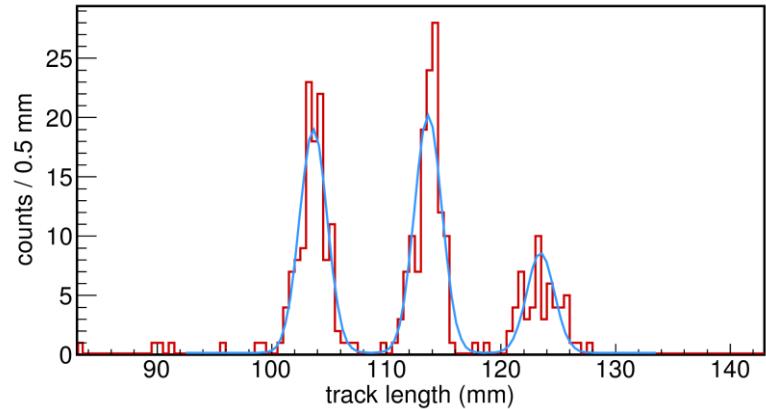
fitted length dispersion: $\sigma_L^{rec} = 3.2$ mm

$$\sigma_L^{rec} = \sqrt{(\sigma_L^\alpha)^2 + (\sigma_L^{det})^2}$$

σ_L^{det} detector resolution

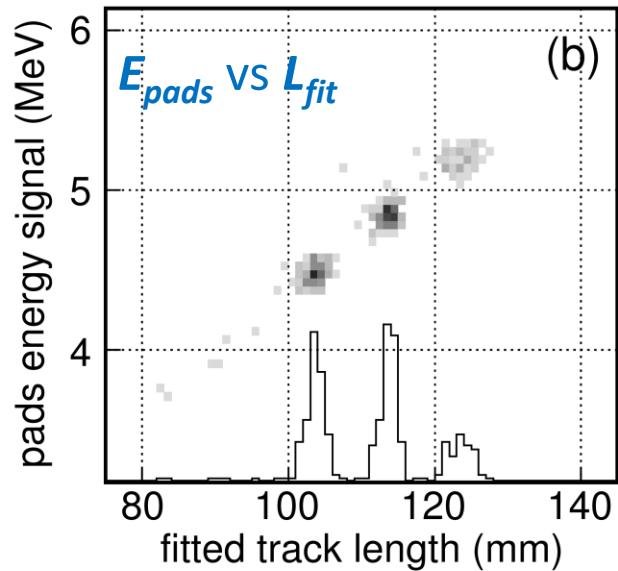
σ_L^α particles dispersion in gas

particles dispersion from simulation: $\sigma_L^\alpha = 3.4$ mm



independent precision of
energy estimate (pads signal)
& **track length** (fit)

⇒ no improvement expected from correlation



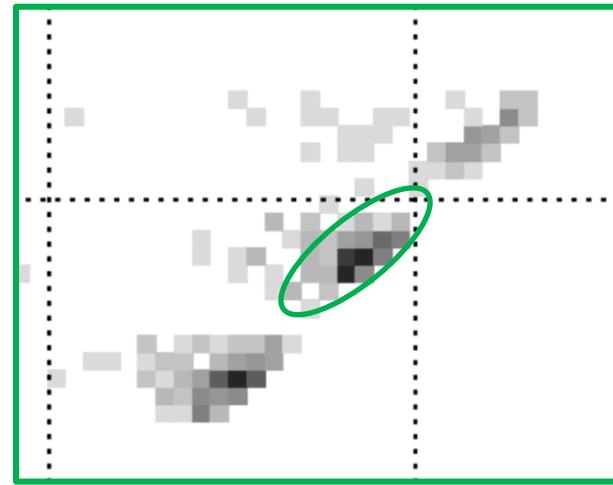
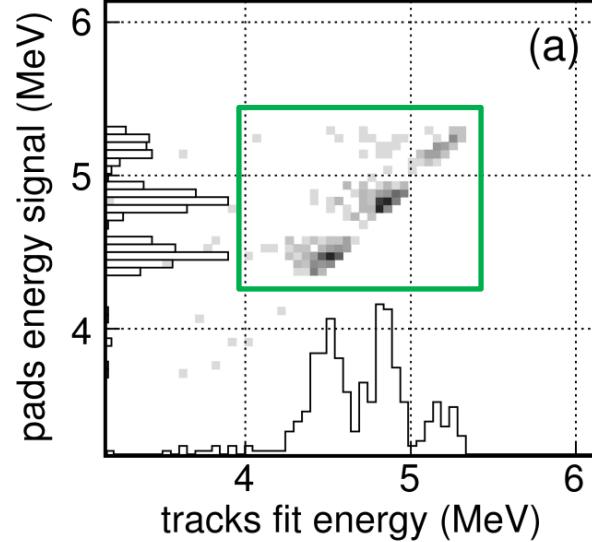
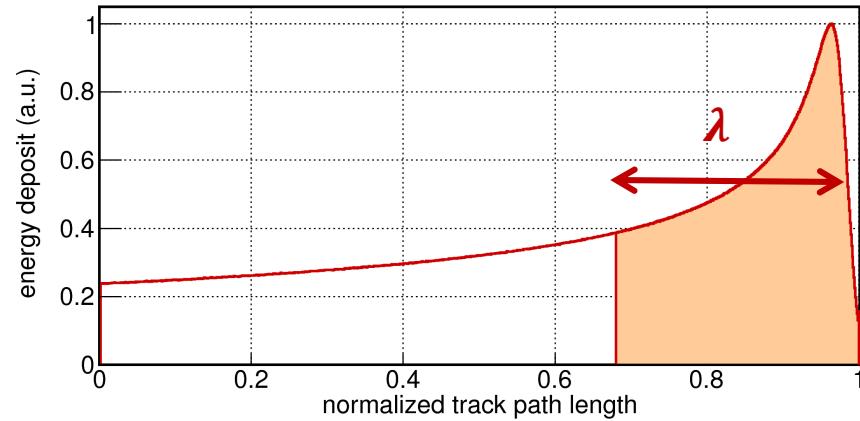
track reconstruction precision

energy from track length:

$$E_{sim}(\lambda) \propto \frac{\int_{1-\lambda}^1 f_{Bragg}(\lambda) \cdot d\lambda}{\int_0^1 f_{Bragg}(\lambda) \cdot d\lambda}$$

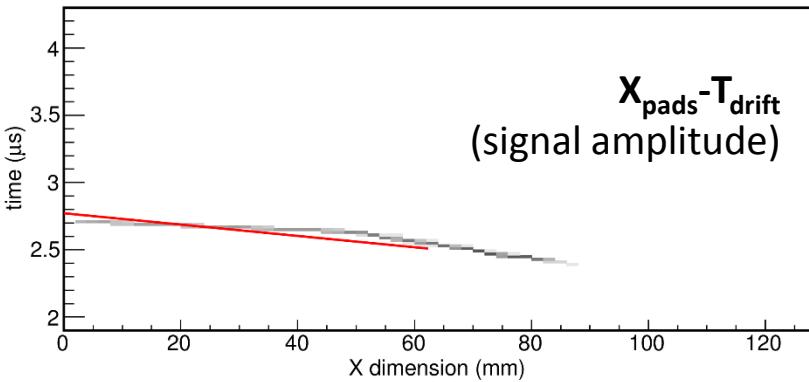
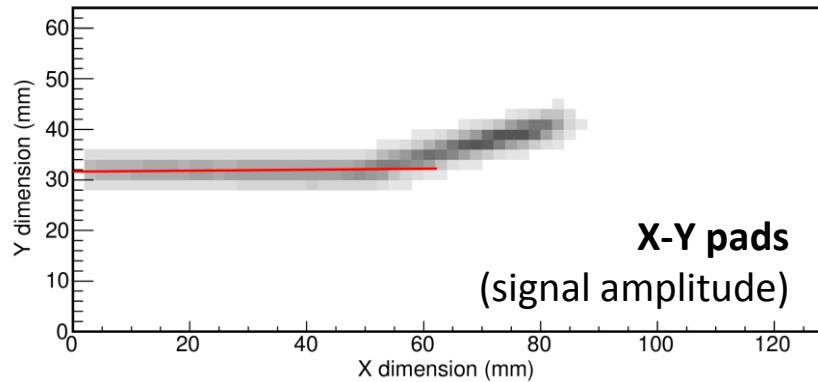
E_{pads} – E_{fit} correlation:

→ can be improved
but some bad E_{fit} ...



alpha tracks fitting: illustration – bad case...

experimental data



(alpha source)

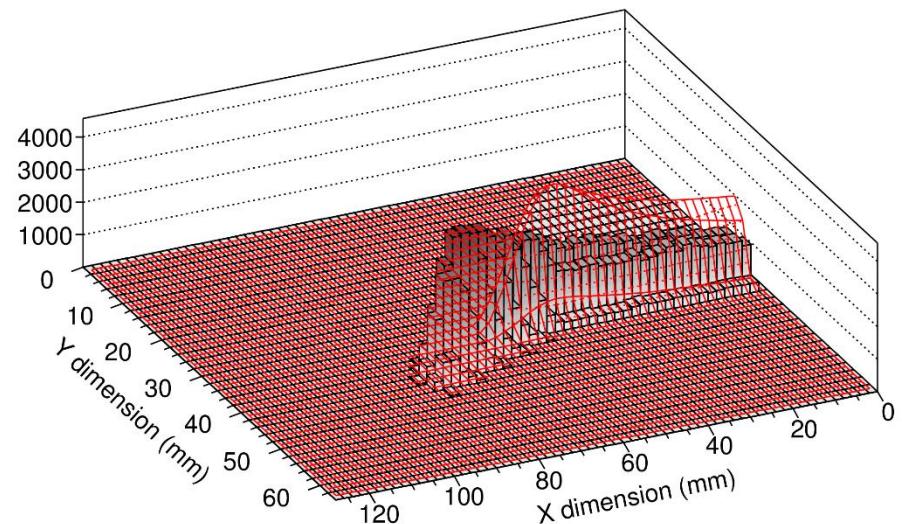
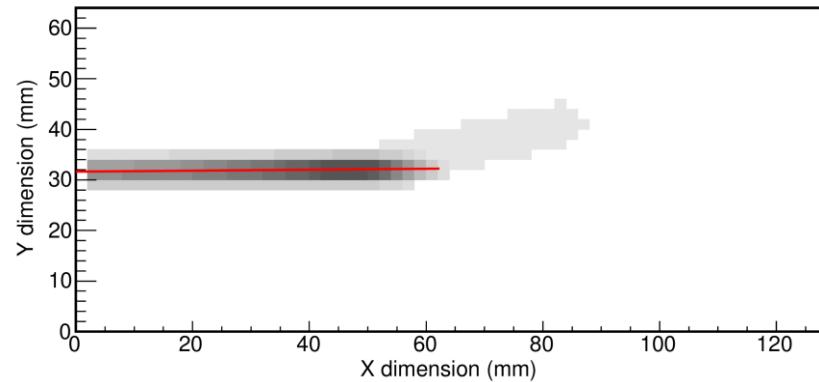
$$F_w = 50 \text{ MHz}$$

$$\tau = 502 \text{ ns}$$

$$C_g = 1 \text{ pC}$$

full readout

fit result



alpha tracks fitting: trajectory improvement ?

track initial point: $\vec{P}_0 = (x_0, y_0, z_0)$

track final point: $\vec{P}_1 = (x_1, y_1, z_1)$

considering a track that **is not a straight line**

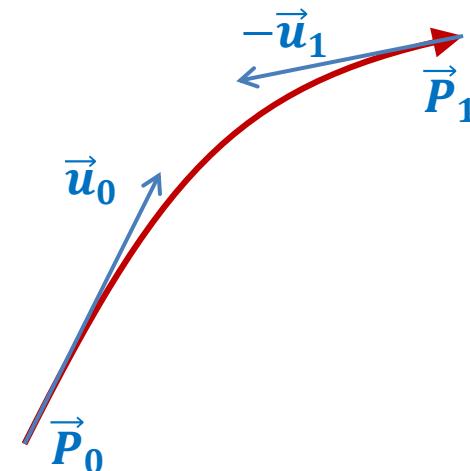
general case

2 additional points that define the

tangent vectors: \vec{u}_0 & \vec{u}_1

curve coordinate: c

$$\begin{aligned}\vec{P}(c) &= \vec{P}_0 + \vec{u}_0 \cdot c \\ &+ [3 \cdot (\vec{P}_1 - \vec{P}_0) - 2 \cdot \vec{u}_0 - \vec{u}_1] \cdot c^2 \\ &+ [-2 \cdot (\vec{P}_1 - \vec{P}_0) + \vec{u}_0 + \vec{u}_1] \cdot c^3\end{aligned}$$



problem

the track path $\vec{P}(c)$ is described by a curve coordinate c (with $c \in [0; 1]$)

the track length is *a priori* **not linear** with c !!

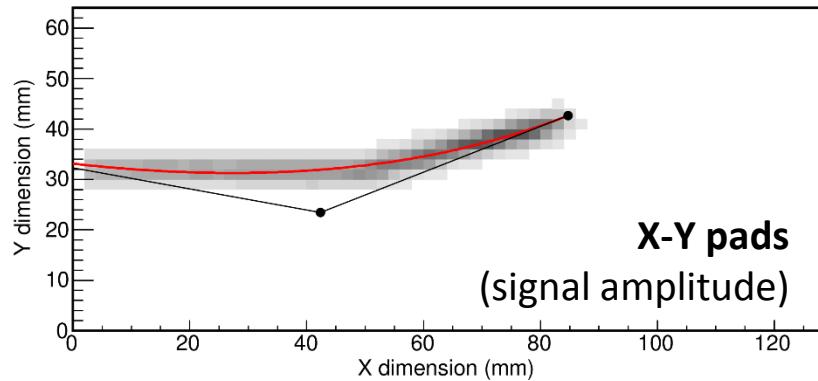
→ complicates the integration of energy loss $f_E(\epsilon)$ **for constant ϵ steps**

$$\lambda(c) = \frac{L(c)}{L_{tot}} \quad \text{with} \quad L(c) = \int_0^c \frac{dL}{dc}(c') \cdot dc'$$

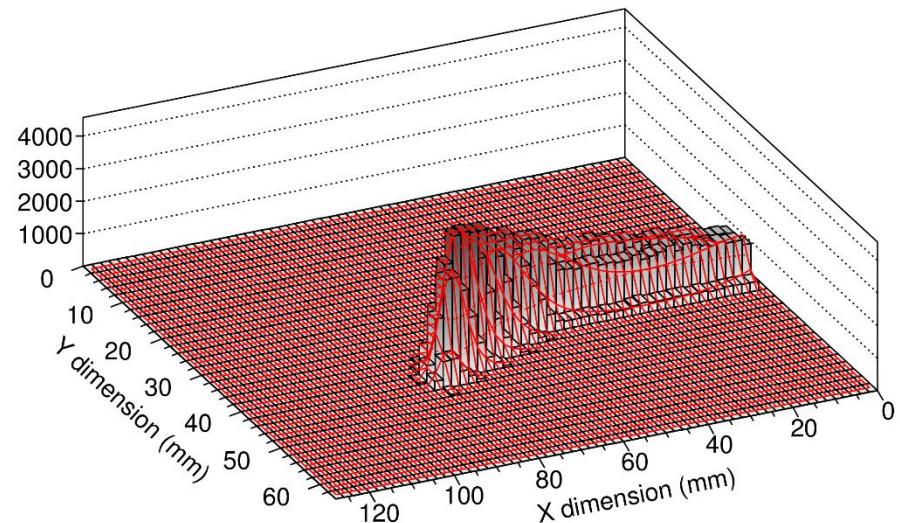
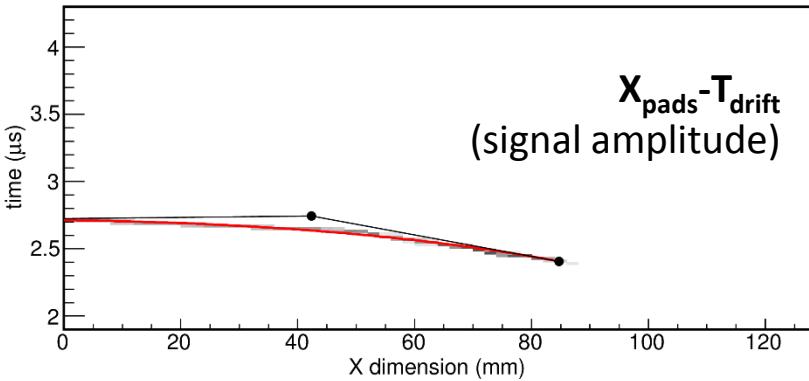
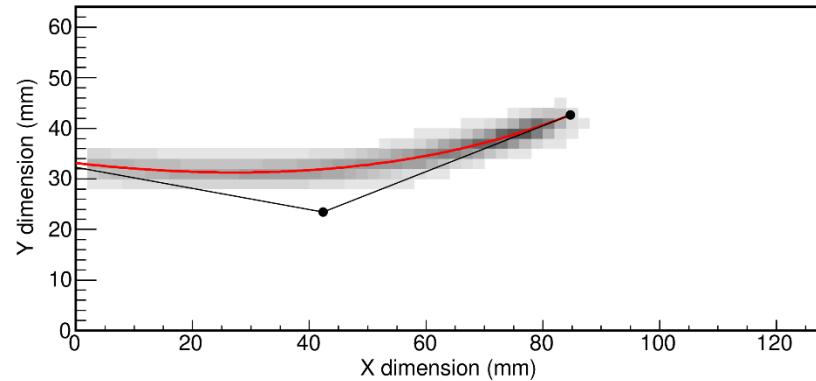
$$\text{and} \quad L_{tot} = L(1)$$

alpha tracks fitting: illustration – 3-point Bézier curve

experimental data



fit result



(alpha source)

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full readout

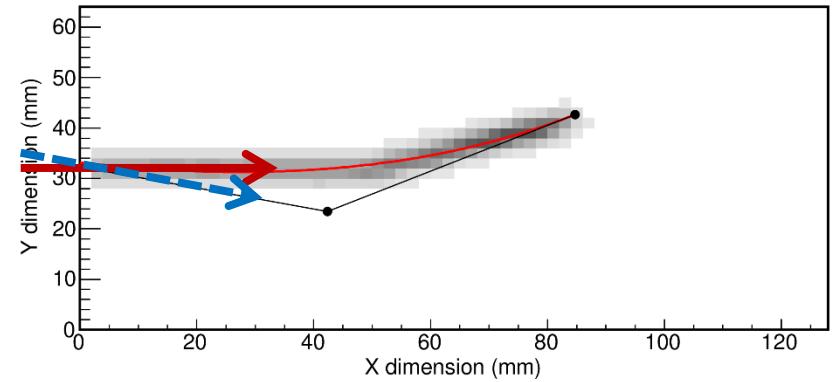
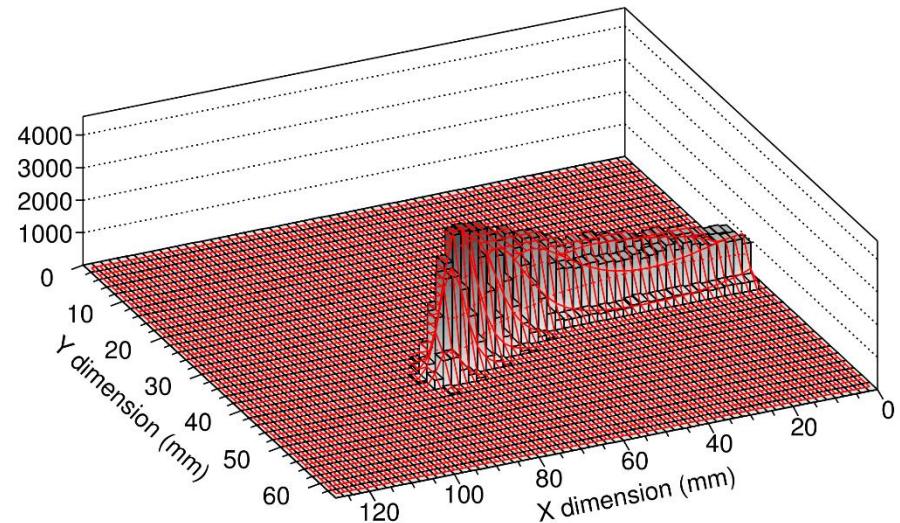
alpha tracks fitting: trajectory improvement ?

but... no systematic improvement...

→ better in the case of obviously scattered particles

→ not always ok for linear tracks

→ emission direction reconstruction
(important for angular correlations)



alpha tracks fitting: trajectory improvement ?

but... no systematic improvement...

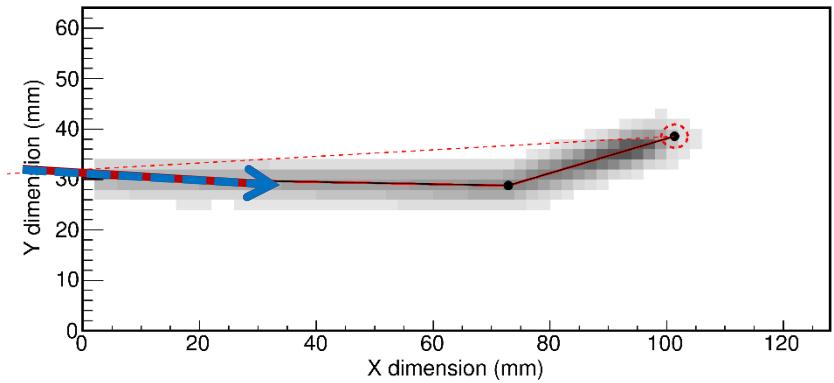
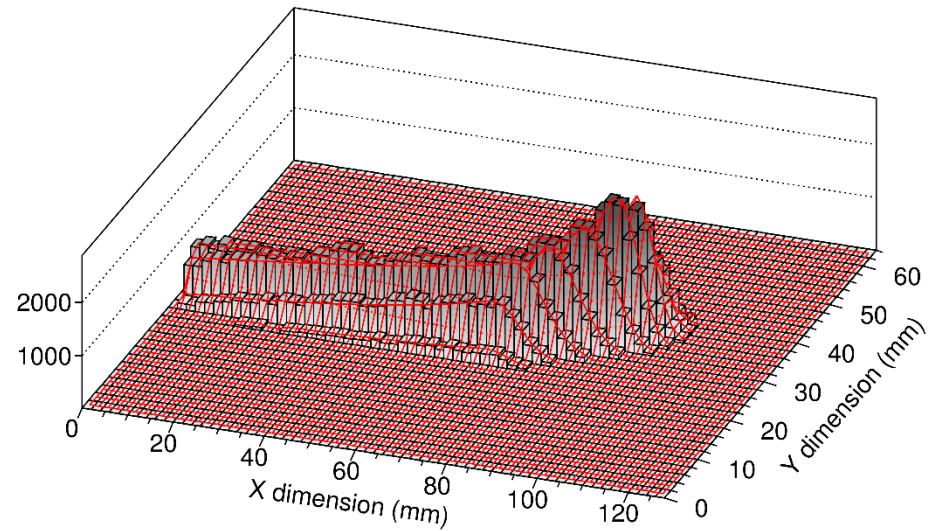
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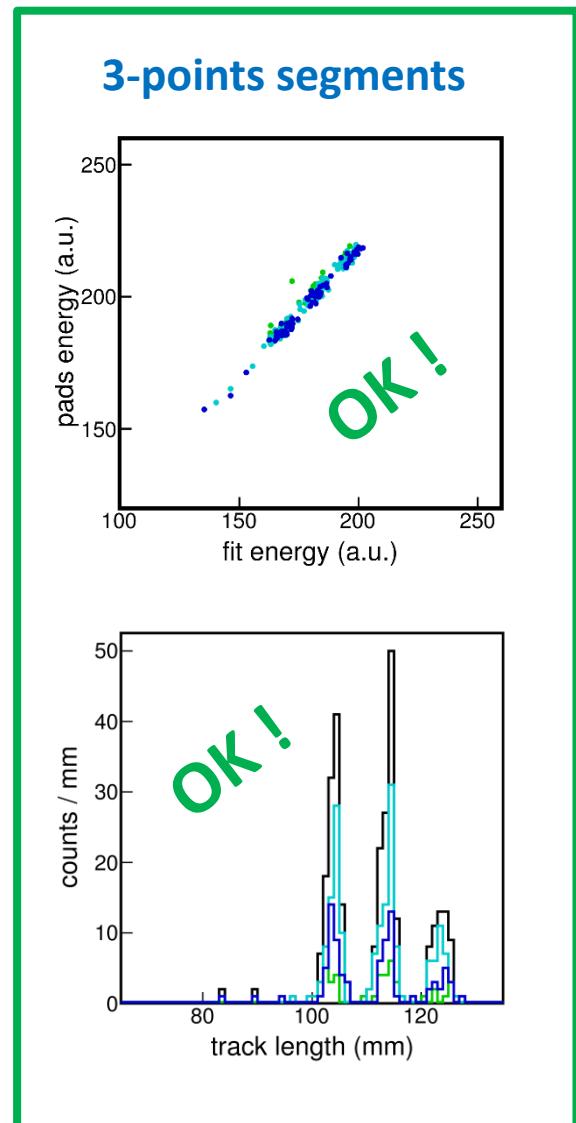
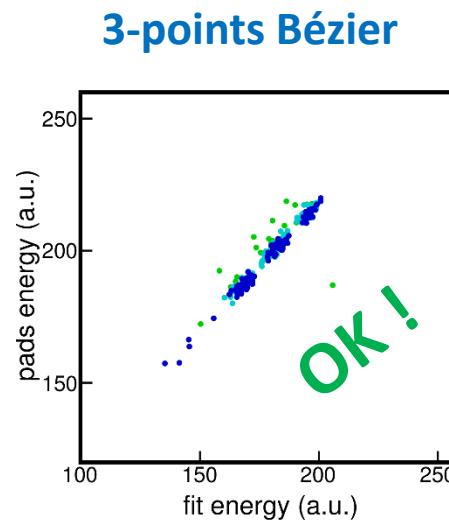
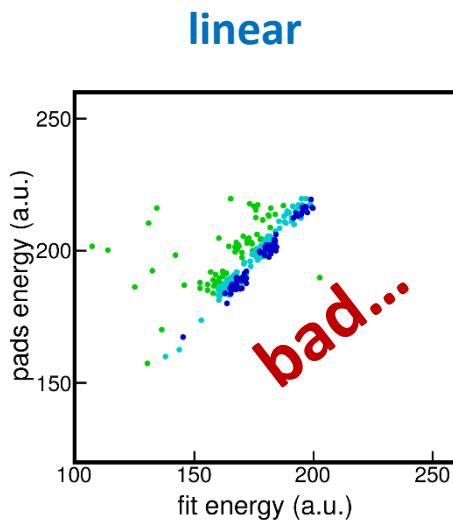
→ emission direction reconstruction
(important for angular correlations)
segmented track: better...

need for a **fitting strategy** to consider several possibilities...

how ?...



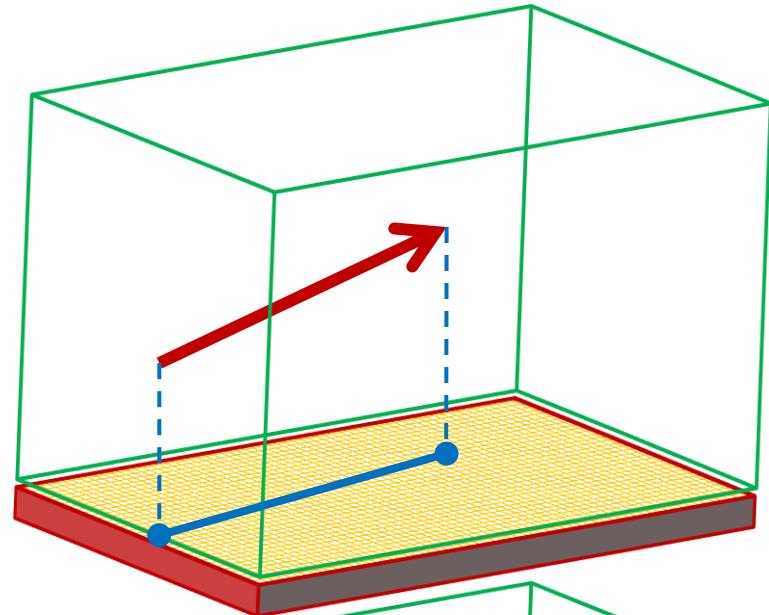
curve tracks fit: models comparison



need for improved tracking algorithm

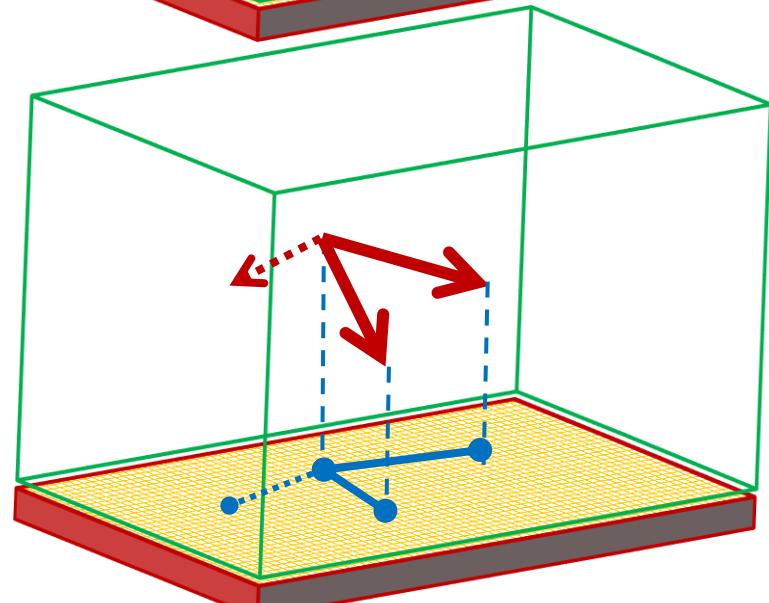
alpha test: the easy case...

- known track origin area
 - known track direction
 - single particle track
- ⇒ **easy fit initialization**



multi-particle radioactive decay

- any origin point and direction
 - various cases:
1 or 2 emitted protons (even 3...)
- ⇒ **need for a track / vertex finder ?**
- ⇒ **discrimination 1 / 2 / ... tracks ?**



any suggestion is welcome !!!

end...