IDEA Drift Camber:
the occupancy "saga" and other considerations

F. Grancagnolo
INFN – Lecce

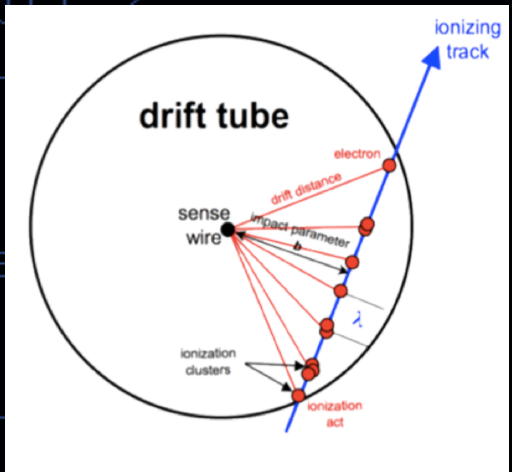
CERN, June 26, 2018

OUTLINE

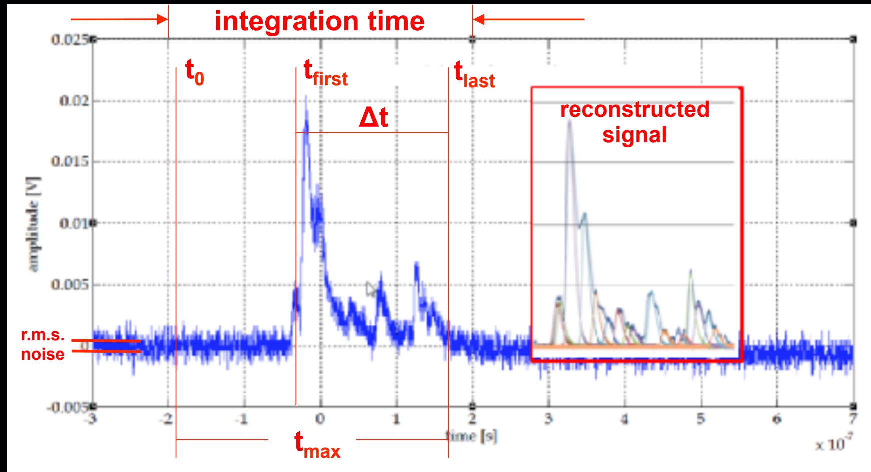
- A few facts exploiting **cluster counting/timing** besides **spatial resolution improvement** and **particle identification** (not discussed here).
- A short clarifying summary of the "**occupancy saga**".
- An example (MEG2) of **tracking in high occupancy** environment.
- A brief discussion on the drift chamber **DAQ** and **Data Transfer**.

A few facts

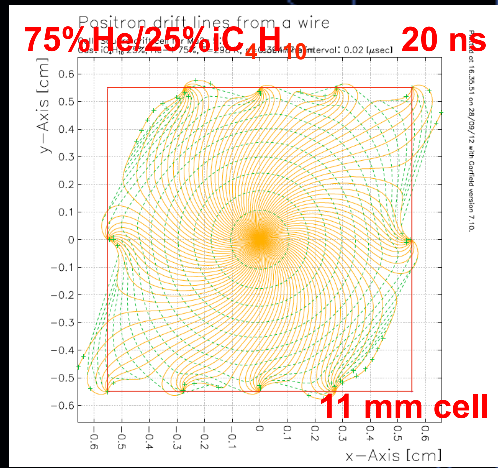
Ideal case: drift tube



Digitized signal (1 GHz, 2 GSa/s)

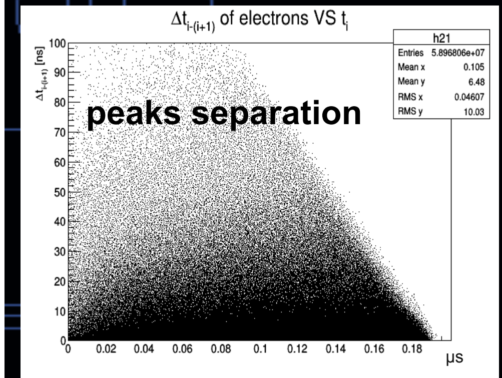


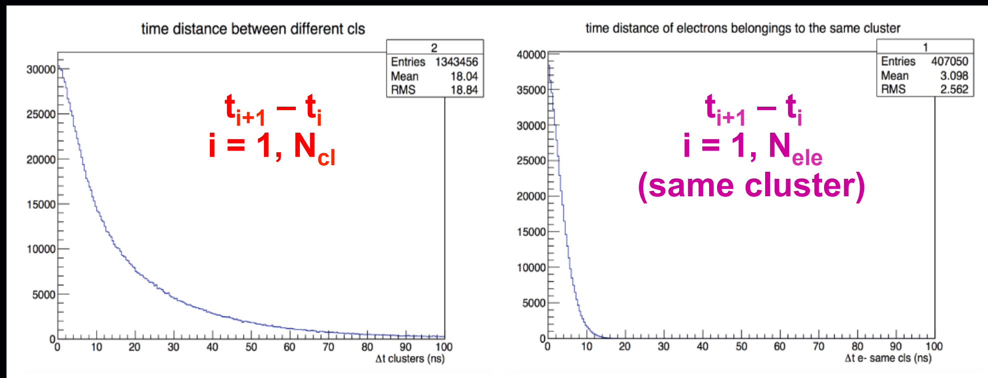
Real case: drift cell

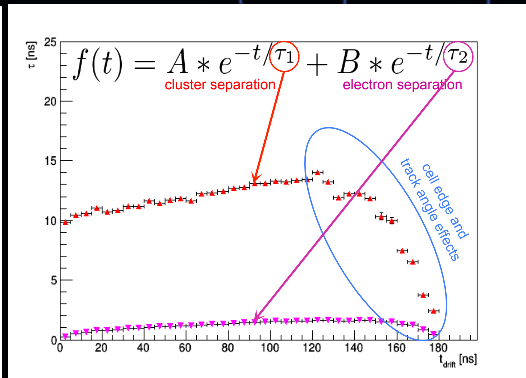


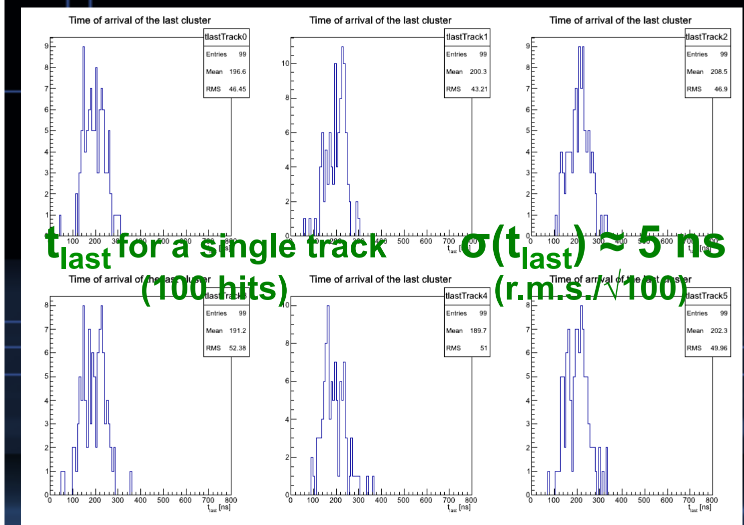
- **$t_{i+1} - t_i \approx$ a few ns** at small t_i, **$t_{i+1} - t_i \approx$ a few × 10 ns** at large t_i
- **t_{max} constant** in ideal case (slightly depends on track angle in drift cell case)
- **$\Delta t \leq t_{max}$**, length of digitized signal, depends on impact parameter **b (t_{first})**
- **N_{cl}** depends only on **Δt** (or **b**, or **t_{first}**) in cylindrical drift tube case
- **N_{cl}** doesn't depend on **b** in square drift cell case, but only on the track angle
- **t_{last} constant** in the ideal case => defines the **trigger time $t_0 = t_{last} - t_{max}$**

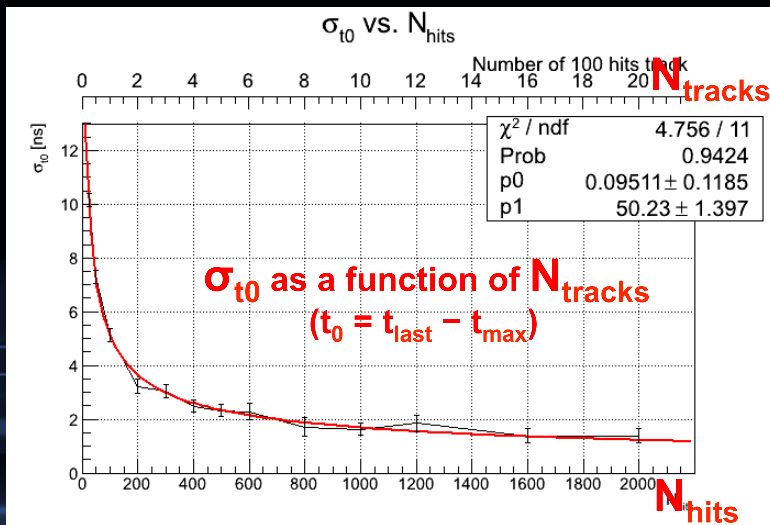
A few facts (7 mm cell, faster gas)



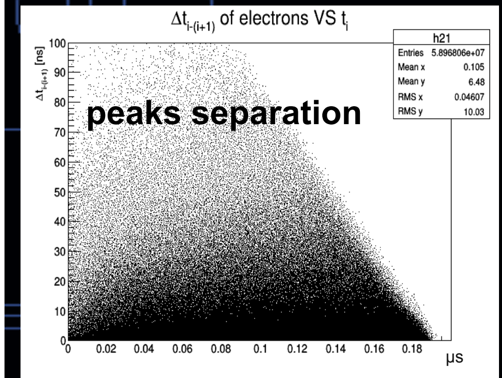


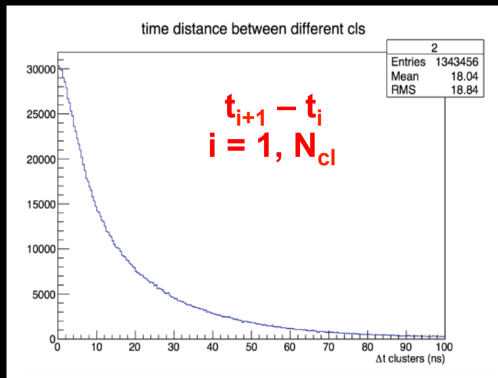


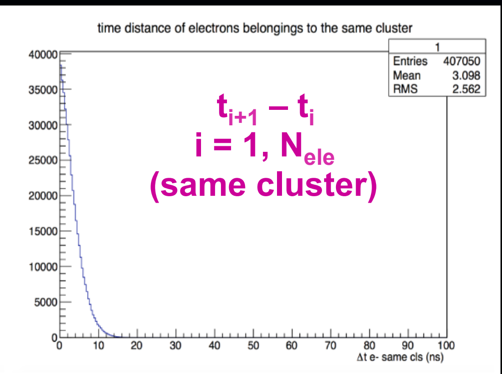


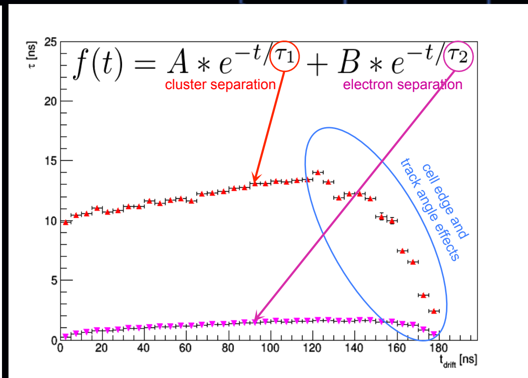


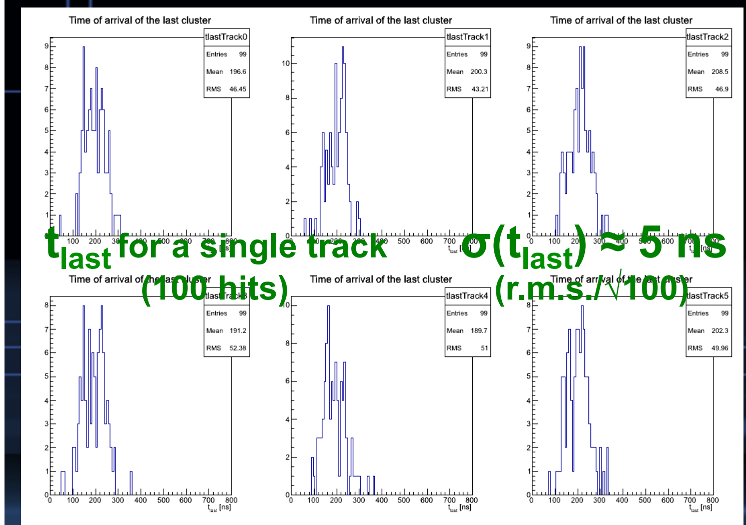
A few facts (7 mm cell, faster gas)

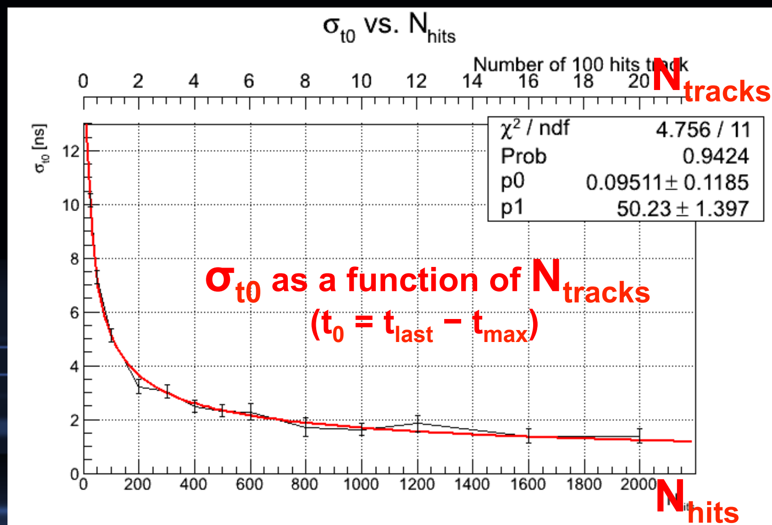












Bunch Xing identification!

Track filtering!

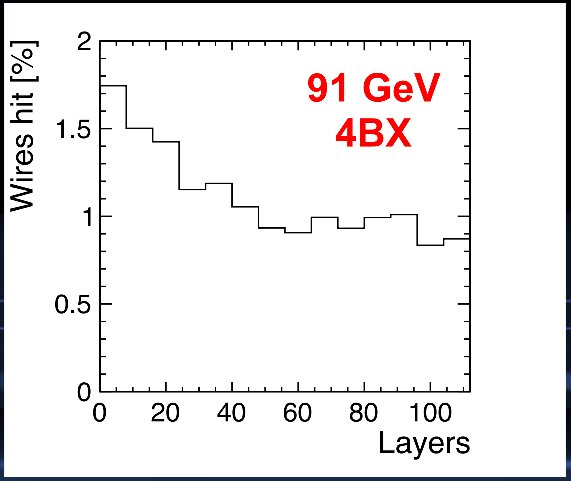
Trigger capabilities?

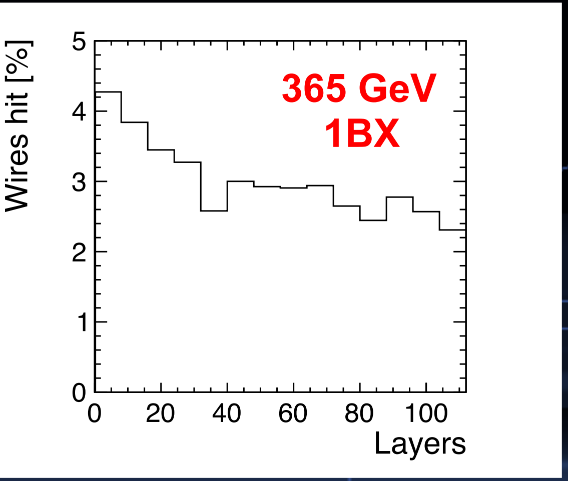
Consideration about occupancy

- Average drift signal duration: **$<\Delta t> = t_{max}/2$** (slightly larger given the time compression at small impact parameters) and **$<t_{first}> = t_0 + t_{max}/2$**.
- A peak in the signal is identified as an electron if above threshold and with proper rise and fall times.
- A physical hit must contain at least a few electron peaks spaced by no more than the cluster separation time, **δt_{cl}**.
- An isolated electron peak is suppressed if its time differs from t_{first} of the track hit by > δt_{cl}. Otherwise, it slightly affects the impact parameter and negligibly the particle identification.
- Two synchronous tracks overlapping in the same cell are indistinguishable, the promptest one defines the impact parameter.
- Two tracks delayed in time (i.e., belonging to different BX) can be separated if t_{last} of the earlier one and t_{first} of the later one differ by > δt_{cl}.

Consideration about occupancy

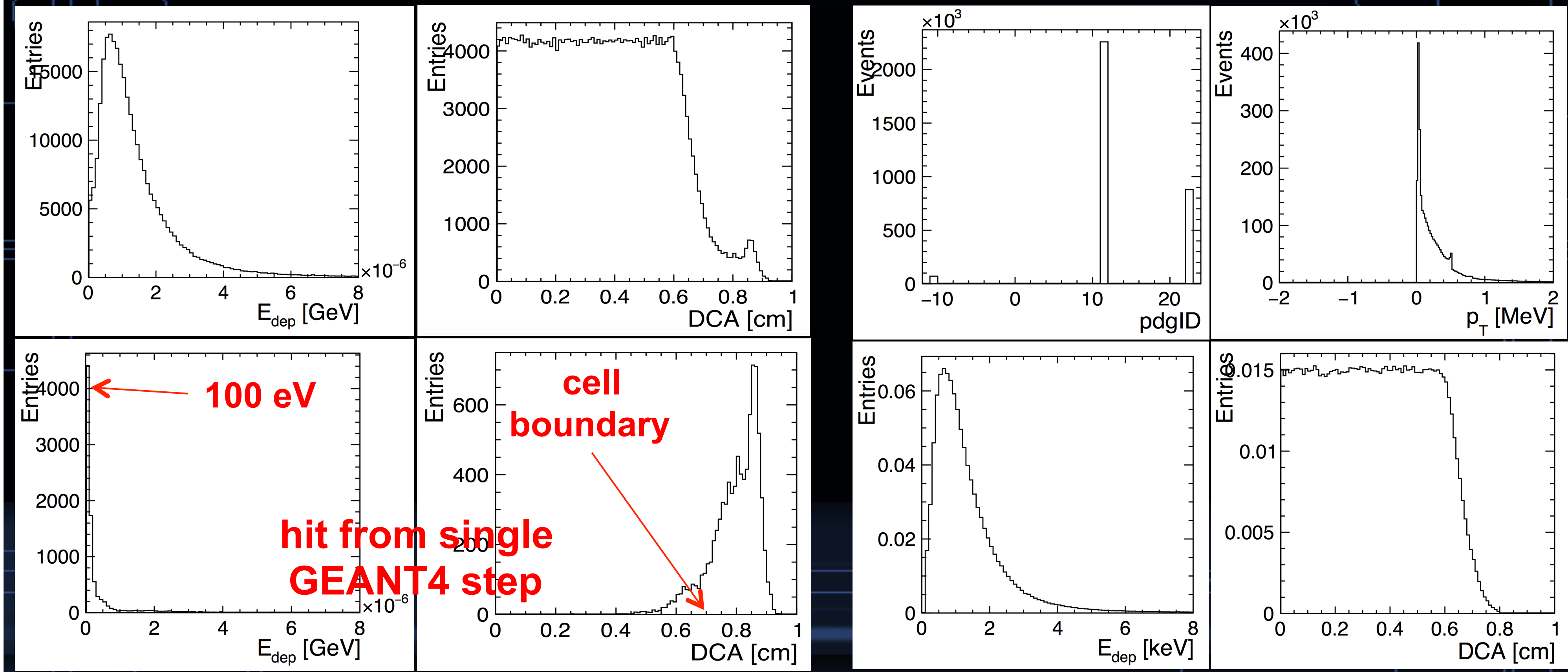
- In the case of 20 ns inter-bunch crossing time (at 91 GeV) and 400 ns maximum drift time, assuming that the hits are all from ionisation track segments and not from isolated Compton electrons from photons, it would be straightforward to integrate the occupancy over 20 BX.
- However,
  - hits associated to BX_i and BX_j are separated in time and will not contribute to the occupancy if **$(i-j)\times 20$ ns $\geq \delta t_{cl}$**.
  - assuming conservatively **$\delta t_{cl} \approx 100$ ns**, the occupancy must be integrated over **4 BX** at most.





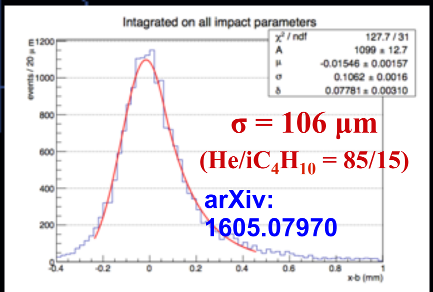
from Nilou

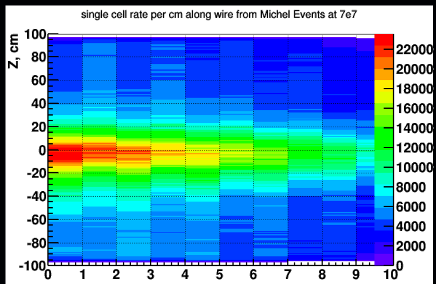
Consideration about occupancy

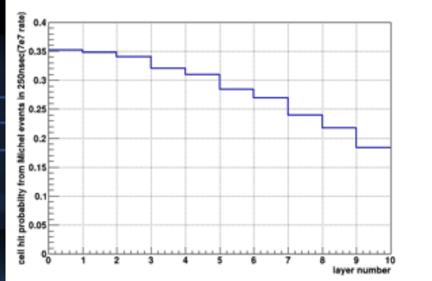


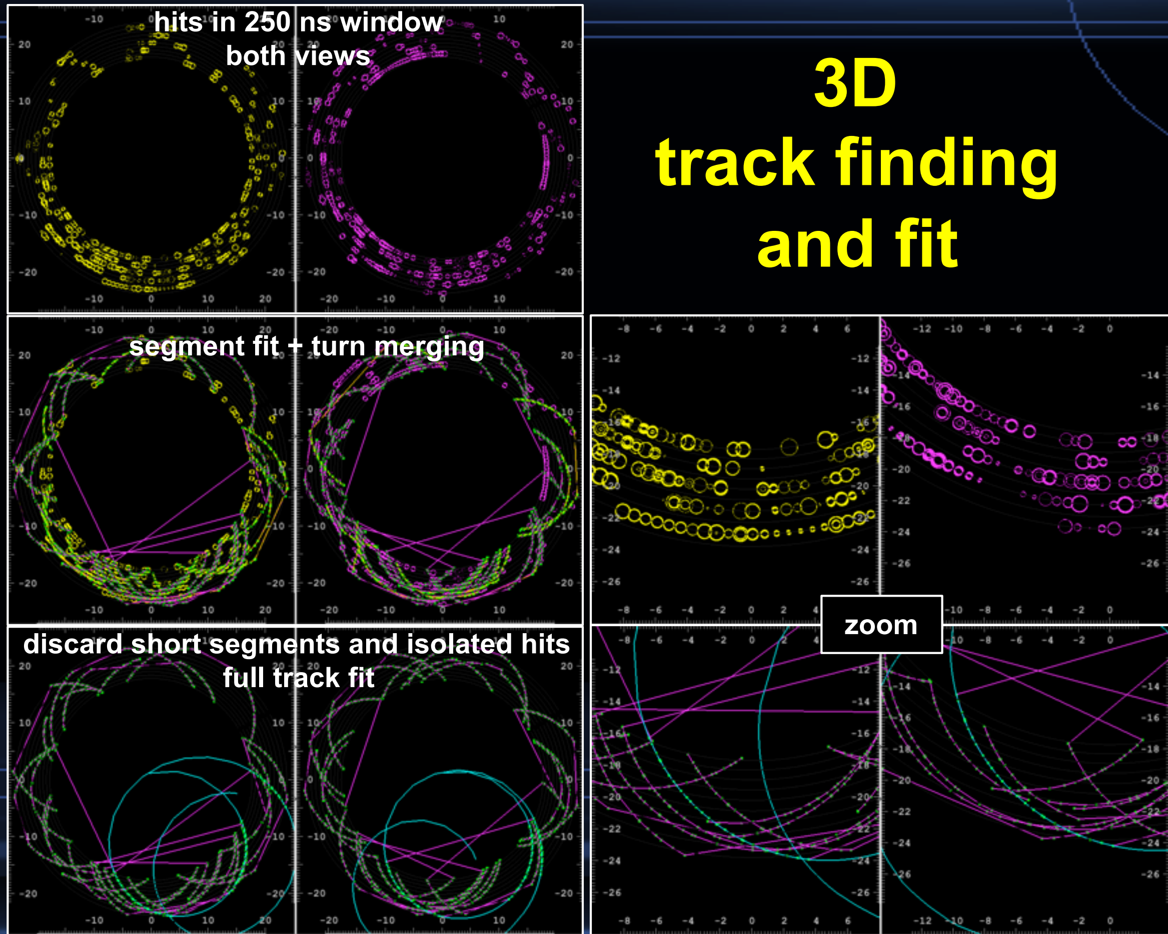
MEG2 DCH high occupancy

spatial resolution on 7 mm cell







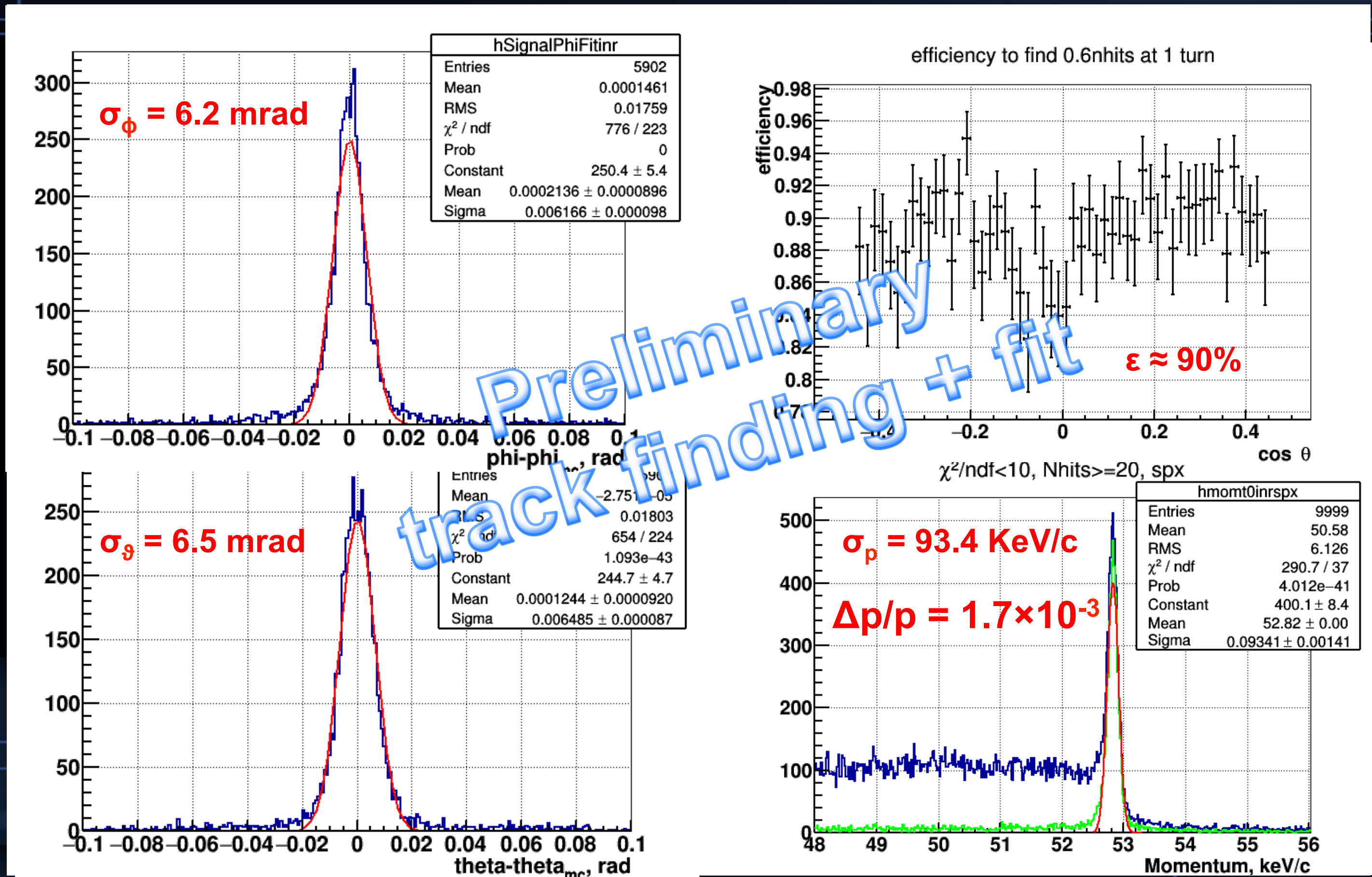


3D
track finding
and fit

signal track

michel tracks

MEG2 DCH Performance



Data Transfer: Example

Running conditions

- **91 GeV** c.m. energy
- **200 KHz** trigger rate
  - **100 KHz** Z decays
  - **30 KHz** γγ → hadrons
  - **50 KHz** Bhabha
  - **20 KHz** beam backgrounds

D.C. operating conditions

- drift cells: **56,000** , layers: **112**
- max drift time (≈1 cm): **400 ns**
- cluster density: **20/cm**
- gas gain: **6×10^5**
- single e^- p.h.: **6 mV**
- r.m.s. electronics noise: **1 mV**
- e^- threshold: **2 mV**; rise time **1 ns**
- signal digitization:
  12 bits at 2×10^9 bytes/s

Example: traditional data transfer

- **Z decays:**
  10^5 events/s × 20 tracks/event × 130 cells/track × 4×10^{-7} s × 2×10^9 bytes/cell/s ≅ **200 Gb/s**
- **γγ → hadrons:**
  3×10^4 events/s × 10 tracks/event × 130 cells/track × 4×10^{-7} s × 2×10^9 bytes/cell/s ≅ **30 Gb/s**
- **Bhabha:**
  5×10^4 events/s × 2 tracks/event × 0 cells/track × 4×10^{-7} s × 2×10^9 bytes/cell/s ≅ **0 Gb/s**
- **Beam noise** (assume 2.5% occupancy):
  2×10^4 events/s × 1.5×10^3 cells/event × 4×10^{-7} s × 2×10^9 bytes/cell/s ≅ **25 Gb/s**
- **Isolated peaks** (assume 2.5% occupancy):
  2×10^5 events/s × 1.5×10^3 cells/event × 4×10^{-7} s × 2×10^9 bytes/cell/s ≅ **250 Gb/s**

Transferring all digitized data (reading both ends of wires):

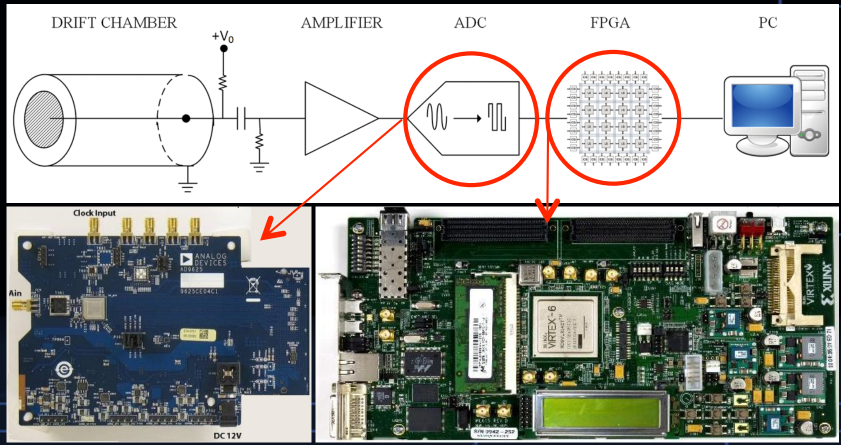
≥ 1 TB/s!

Example: the solution

The solution consists in transferring, for each hit drift cell, **instead of the full spectrum of the signal**, only the minimal information relevant to the application of the cluster timing/counting techniques, i.e. **the amplitude and the arrival time of each peak associated with each individual ionisation electron**.

This is accomplished by using a **FPGA** for the real time analysis of the data generated by the drift chamber and successively digitized by an ADC.

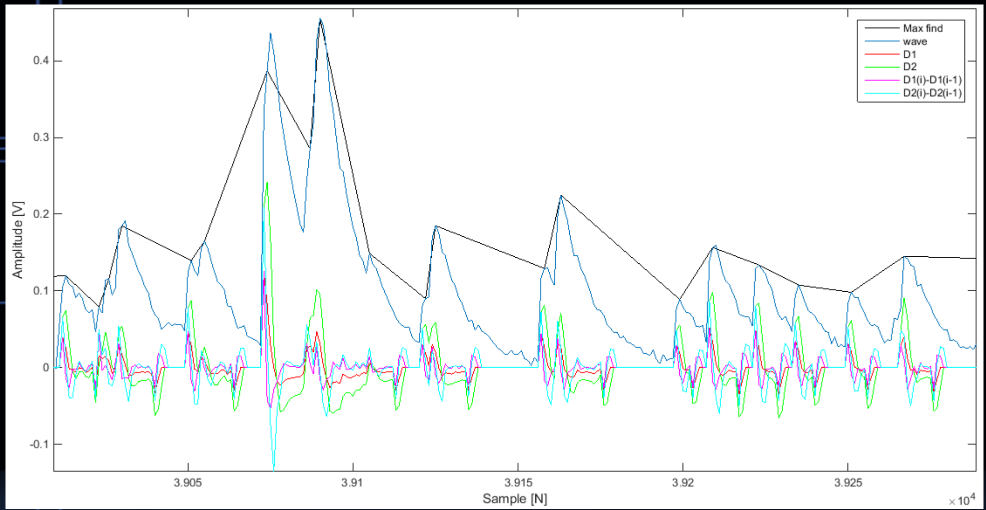
A fast readout algorithm (**CluTim**) for identifying, in the digitized drift chamber signals, the individual ionization peaks and recording their time and amplitude has been developed as **VHDL/Verilog** code implemented on a **Virtex 6 FPGA**, which allows for a maximum input/output clock switching frequency of **710 MHz**. The hardware setup includes also a 12-bit monolithic **pipeline sampling ADC** at conversion rates of up to **2.0 GSPS**.

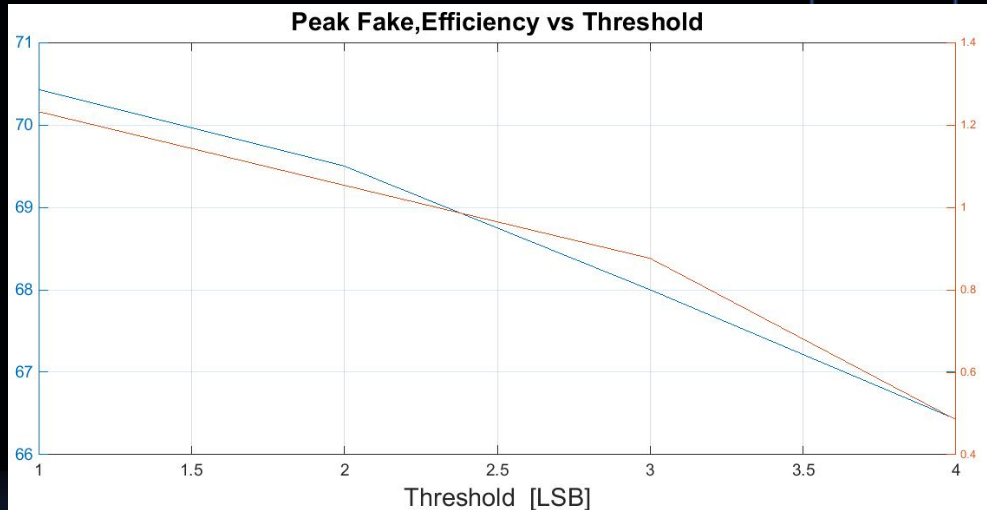


Example: CluTim algorithm

At the beginning of the signal processing procedure, a counter starts to count providing the timing information related to the signal under scrutiny.

The determination of a peak is done by relating the i-th sampled bin to a number n of preceding bins, where n is related to the rise times of the signal peak. Details of the algorithm can be found in next slide.





the input signal to the ADC, the peaks found, and the values of the auxiliary functions used and of their differences. Efficicency

The memories are continuously filled as new peaks are found. When a trigger signal occurs at time t_0, the reading procedure is enabled and only the data relative to the found peaks in the [t_0; $t_0 + t_{max}$] time interval are transferred to an external device

Example: CluTim data transfer

- **Z decays:**
  10^5 events/s × 20 tracks/event × 130 cells/track × 20 peaks/cell × 2 bytes/peak ≅ **10 Gb/s**
- **γγ → hadrons:**
  3×10^4 events/s × 10 tracks/event × 130 cells/track × 20 peaks/cell × 2 bytes/peak ≅ **1.6 Gb/s**
- **Bhabha:**
  5×10^4 events/s × 2 tracks/event × 0 cells/track × 20 peaks/cell × 2 bytes/peak ≅ **0 Gb/s**
- **Beam noise** (assume 2.5% occupancy):
  2×10^4 events/s × 1.5×10^3 cells/event × 0 peaks/cell × 2 bytes/peak ≅ **0 Gb/s**
- **Isolated peaks** (assume 2.5% occupancy):
  2×10^5 events/s × 1.5×10^3 cells/event × 0 peaks/cell × 2 bytes/peak ≅ **0 Gb/s**

Transferring only time and amplitude of each electron peak (reading both ends of wires):

≈ 25 GB/s!

Thin solenoid for the CTF detector placed in front of the identification system (option)

Alexey Bragin

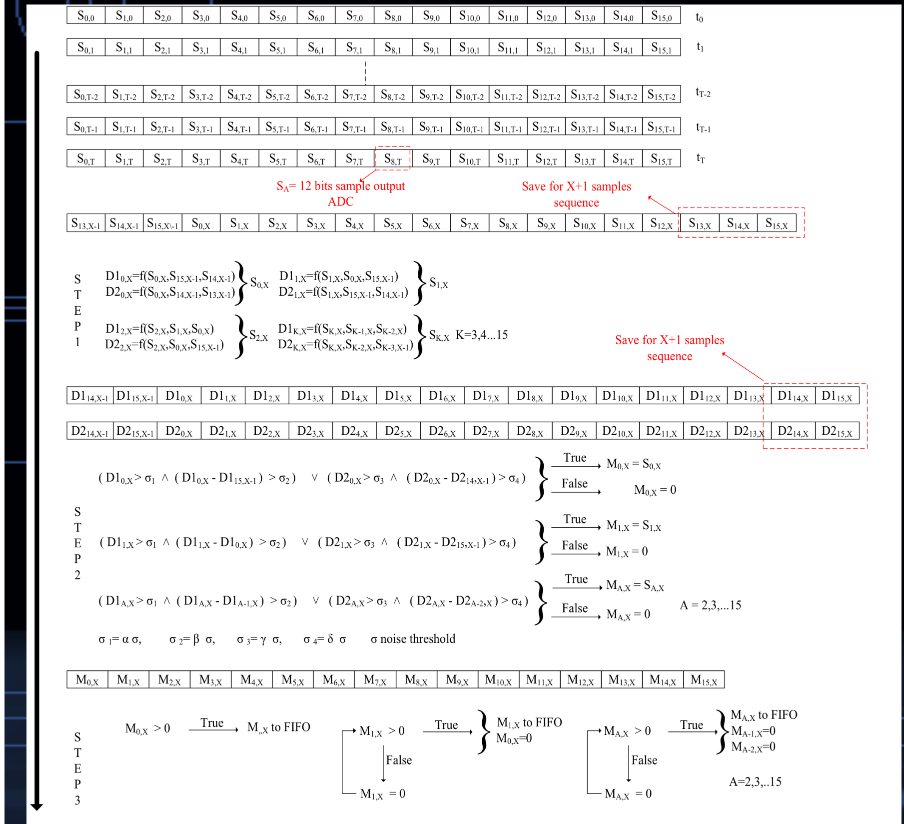
Budker Institute of Nuclear Physics,
Novosibirsk, Russia

May 2018

Thickness in radiation lengths

Materials	Thickness X, mm	Radiation length X_0 мм	X/X_0	Material ratio, %
SC wire, NbTi/Cu = 1/1	0.56	17.7	0.032	31.0
Carbon fibre (1.5 g/cm^3)	*1.5*	251	0.006	5.8
Epoxy compound (NB as filler)	*1.5*	*150**	0.010	9.7
Aluminum strips (2 x 0.5 mm)	1.0	88.9	0.011	10.7
Radiation shields, Al	2.0	88.9	0.022	21.4
Vacuum vessel, Al	2.0	88.9	0.022	21.4
Total, X_{tot}			0.103	100

Example: CluTim algorithm



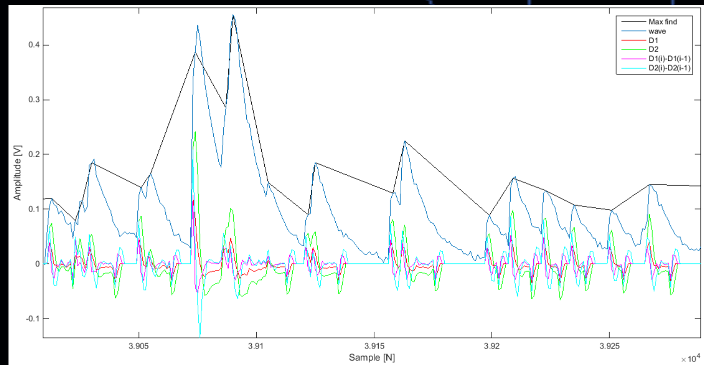
Sixteen samples $S_{K,X}$ at 125 MHz to the FPGA input.

STEP 1: Of the Sixteen samples $S_{K,X}$,where K is the sample number among those available, and X is the time instant at which they are present, the functions $D1_{K,X}$ e $D2_{K,X}$ are calculated with use of the following equations :

$D1_{K,X}=((2*S_{K,X}-S_{K-1,X}-S_{K-2,X})/16)*3$
$D2_{K,X}=((2*S_{K,X}-S_{K-2,X}-S_{K-3,X})/16)*5$

STEP 2: The values of $D1_{K,X}$ and $D2_{K,X}$ and the differences between $D1_{K,X}$ and $D1_{K-1,X}$ and between $D2_{K,X}$ and $D2_{K-1,X}$ are compared with the thresholds proportional to the level of noise present in the input signal.

STEP 3: In order to transfer the data in memory, the last step before being sent to an external device is to check that there are no adjacent peaks



Input signal to the ADC, peaks found, results of the functions D1, D2 and their differences

G. Chiarello, C. Chiri, G. Cocciolo, A. Corvaglia, F. Grancagnolo, M. Panareo, A. Pepino and G. Tassielli. "The Use of FPGA in Drift Chambers for High Energy Physics Experiments", Chapter 7 in "Field - Programmable Gate Array", book edited by George Dekoulis, ISBN 978-953-51-3208-0, Print ISBN 978-953-51-3207-3, Publ.: May 31, 2017 doi:10.5772/66853, http://dx.doi.org/10.5772/66853