

# Preliminary beam test results

F. Grancagnolo

Dec. 15, 2021

RD\_FCC Collaboration Meeting

# The test

## Purpose

- **Demonstrate the ability to count clusters at a fixed  $\beta\gamma$  (e.g. muons at a fixed momentum – 165 GeV/c) by changing:**
  - the cell size (1 – 3 cm)
  - the track angle (0° to 60°)
  - the gas mixture (90/10: 12 cl/cm, 80/20: 20 cl/cm, for m.i.p.)
- **Establish the limiting parameters for an efficient cluster counting:**
  - cluster density as a function of impact parameter
  - space charge (by changing gas gain, sense wire diameter, track angle)
  - gas gain stability
- **Train different cluster counting algorithms**

S  
H  
I  
L  
T  
E  
R  
S

Claudio CAPUTO

Federica CUNA

Nicola DE FILIPPIS

Francesco GRANCAGNOLO

Matteo GRECO

Sergey GRIBANOV

Kurtis JOHNSON

Sasha POPOV

Angela TALIERCIO

Shuiting XIN

UC Louvain

INFN Lecce

INFN Bari

INFN Lecce

INFN Lecce

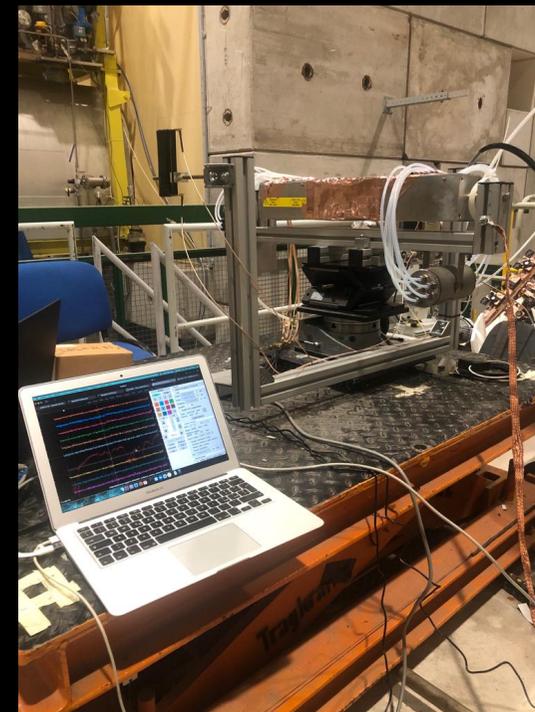
BINP Novosibirsk

U of Florida

BINP Novosibirsk

UC Louvain

IHEP Beijing



# Drift tubes schematics

10cm x 10cm  
165 GeV/c  
 $\mu$  beam



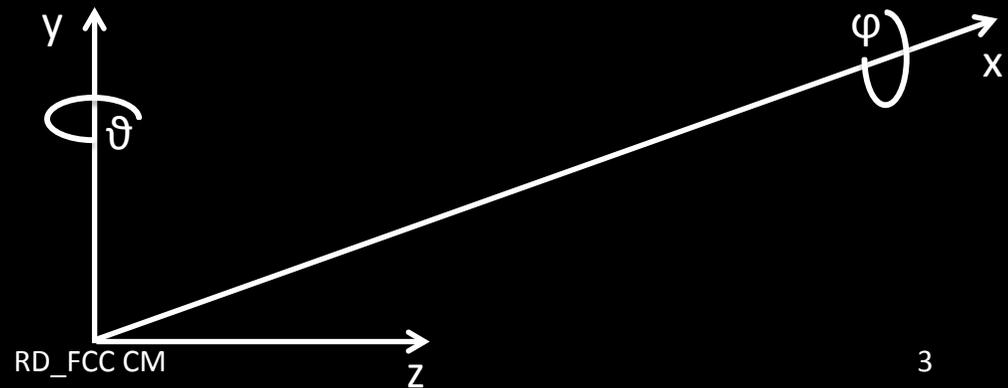
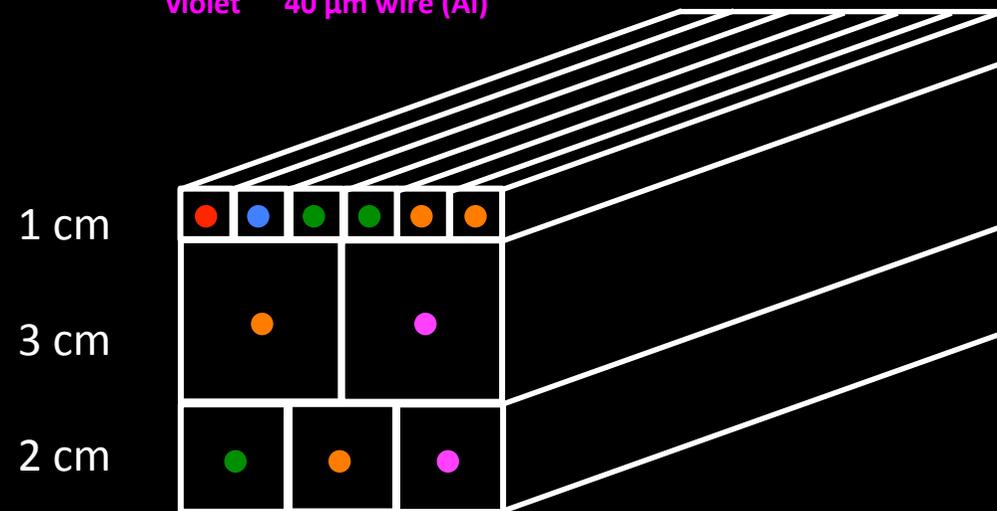
1500  $\mu$  /spill

trigger  
coverage



80  $\mu$  /spill  
to DAQ

red 10  $\mu$ m wire (Mo)  
blue 15  $\mu$ m wire (Mo)  
green 20  $\mu$ m wire (W)  
orange 25  $\mu$ m wire (W)  
violet 40  $\mu$ m wire (Al)



# Advantages of this setup

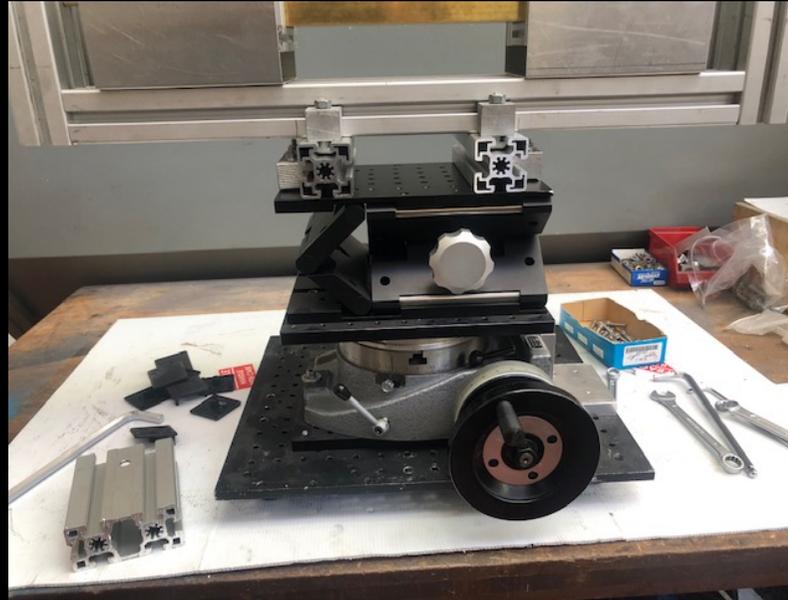
- no need of **external trackers**: only interested in **path length** inside the drift tube active volume
- no need of **internal tracking** (time-to-distance and  $t_0$  **calibrations**, alignment, track finding and fitting algorithms, ...)
- no need to convert **time to distance** (just count clusters in the **time domain**)
- no worry of **multiple scattering** (irrelevant for path length differences)
- no need of **particle tagging** in hadron beams: use only **muon beams** at different momenta (**different  $\beta\gamma$** )
- use selected **commercial amplifiers** (adapting tube impedance to  $50 \Omega$ ) to minimize electronics performance limitations (**bandwidth, gain, noise, ...**) and neglecting **power consumption**
- use only **fully integrated digitizers** (**O-scope, 16-ch. WDB**) for ease of readout

# The Hardware

The drift tubes



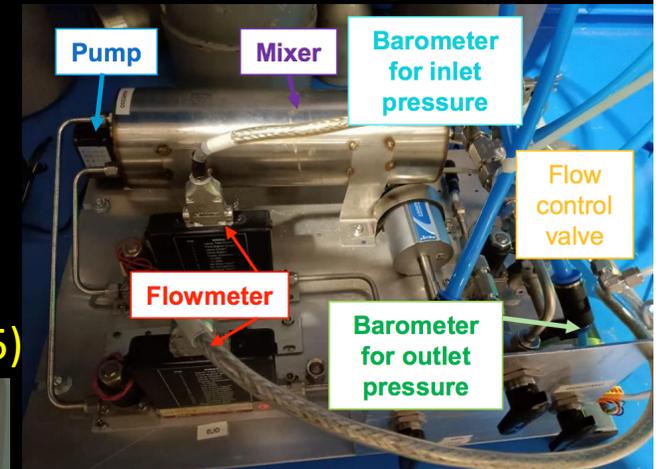
The rotating table



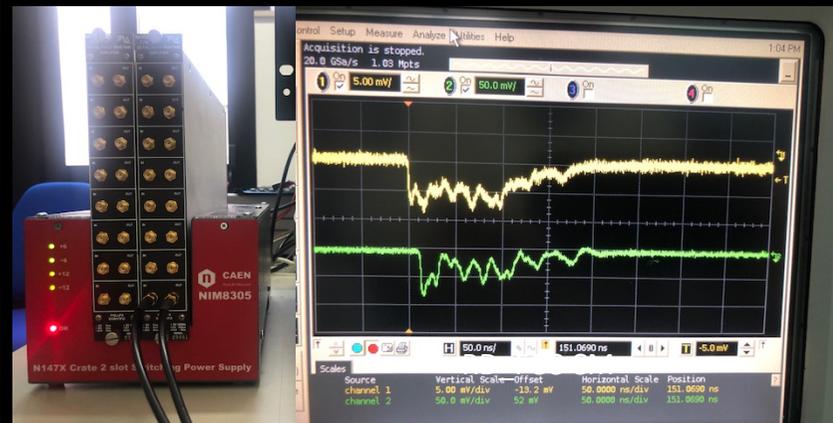
The HV system



The portable gas system



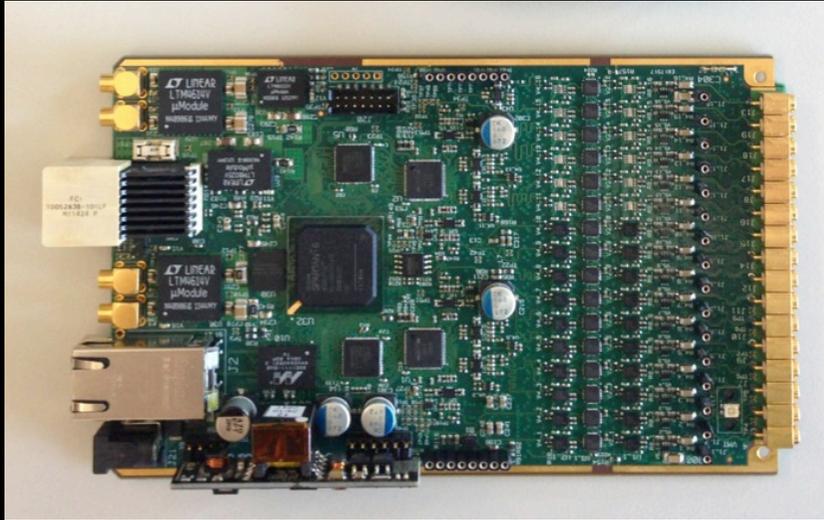
The gain 10 - 1.7 GHz amplifier (Phillips 775)



The gas controllers



# DRS4 DAQ board and Trigger



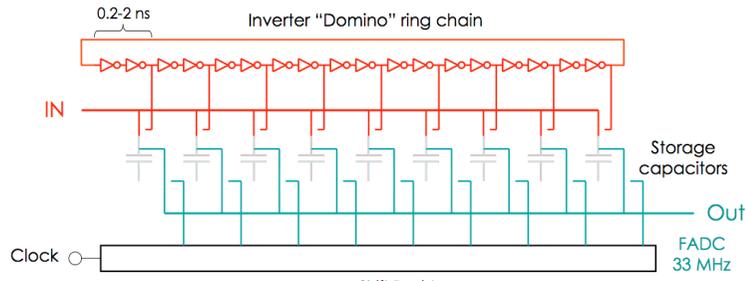
16 channels data acquisition board designed and used by the MEG2 experiment at PSI ( $\mu \rightarrow e + \gamma$ )  
(credit to S. Ritt, Paul Scherrer Institute, Zurich, Switzerland)



12cm x 6cm upstream and downstream  
scintillator tiles (designed and used as timing  
counter of the MEG2 experiment at PSI) used in  
coincidence and readout by SiPM's

# The DAQ board

## DRS4 chip

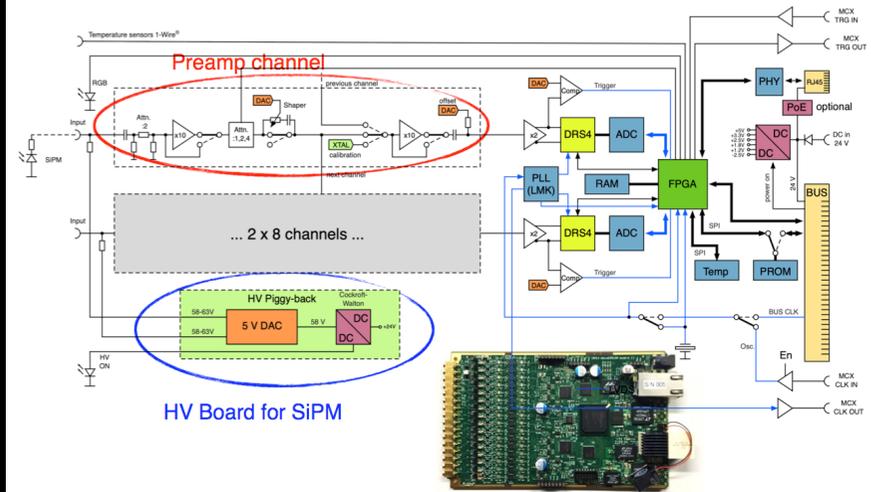


\* **Analog switched capacitor array:** analog memory with a depth of 1024 sampling cells developed at PSI, perform a "sliding window" sampling.

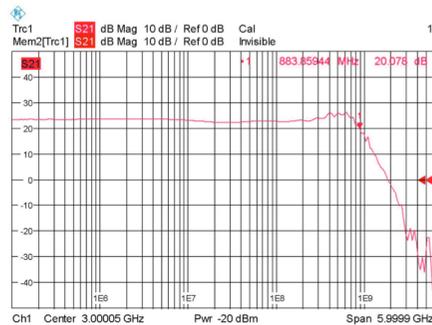
\* **500MSPS  $\leftrightarrow$  5GSPS sampling speed** with 11.5 bit signal-noise ratio  
 \* 8 analog channels + 1 clock-dedicated channel for sub 50ps time alignment

\* Pile-up rejection  $O(\sim 10 \text{ ns})$   
 \* Time measurement  $O(10 \text{ ps})$   
 \* Charge measurement  $O(0.1\%)$

## WaveDREAM Board (WDB)



## Preamp channel



Gain	BW <sub>3db</sub> (MHz)	Noise (mV)
1	940	0.37
10	880	0.40
100	300	1.2
100	500	1.7
100	800	3.3

Different compensations



Chn	Pol	P00	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12	P13	P14	P15	P16	P17
CH0	+																		
CH1	+																		
CH2	+																		
CH3	+																		
CH4	+																		
CH5	+																		
CH6	+																		
CH7	+																		
CH8	+																		
CH9	+																		
CH10	+																		
CH11	+																		
CH12	+																		
CH13	+																		
CH14	+																		
CH15	+																		
EXT	+																		

trigger patterns

Chn	Gain	PZC	Trigger Level	HV	Current
0	5		-19 mV	0 V	0 uA
1	5		-19 mV	0 V	0 uA
2	5		-19 mV	0 V	0 uA
3	5		-19 mV	0 V	0 uA
4	5		-19 mV	0 V	0 uA
5	5		-19 mV	0 V	0 uA
6	5		-19 mV	0 V	0 uA
7	5		-19 mV	0 V	0 uA
8	5		-19 mV	0 V	0 uA
9	5		-19 mV	0 V	0 uA
10	5		-19 mV	0 V	0 uA
11	5		-19 mV	0 V	0 uA
12	5		-19 mV	0 V	0 uA
13	5		-19 mV	0 V	0 uA
14	5		-19 mV	0 V	0 uA
15	5		-19 mV	0 V	0 uA

channels settings

# Data format

## WDS: Binary format

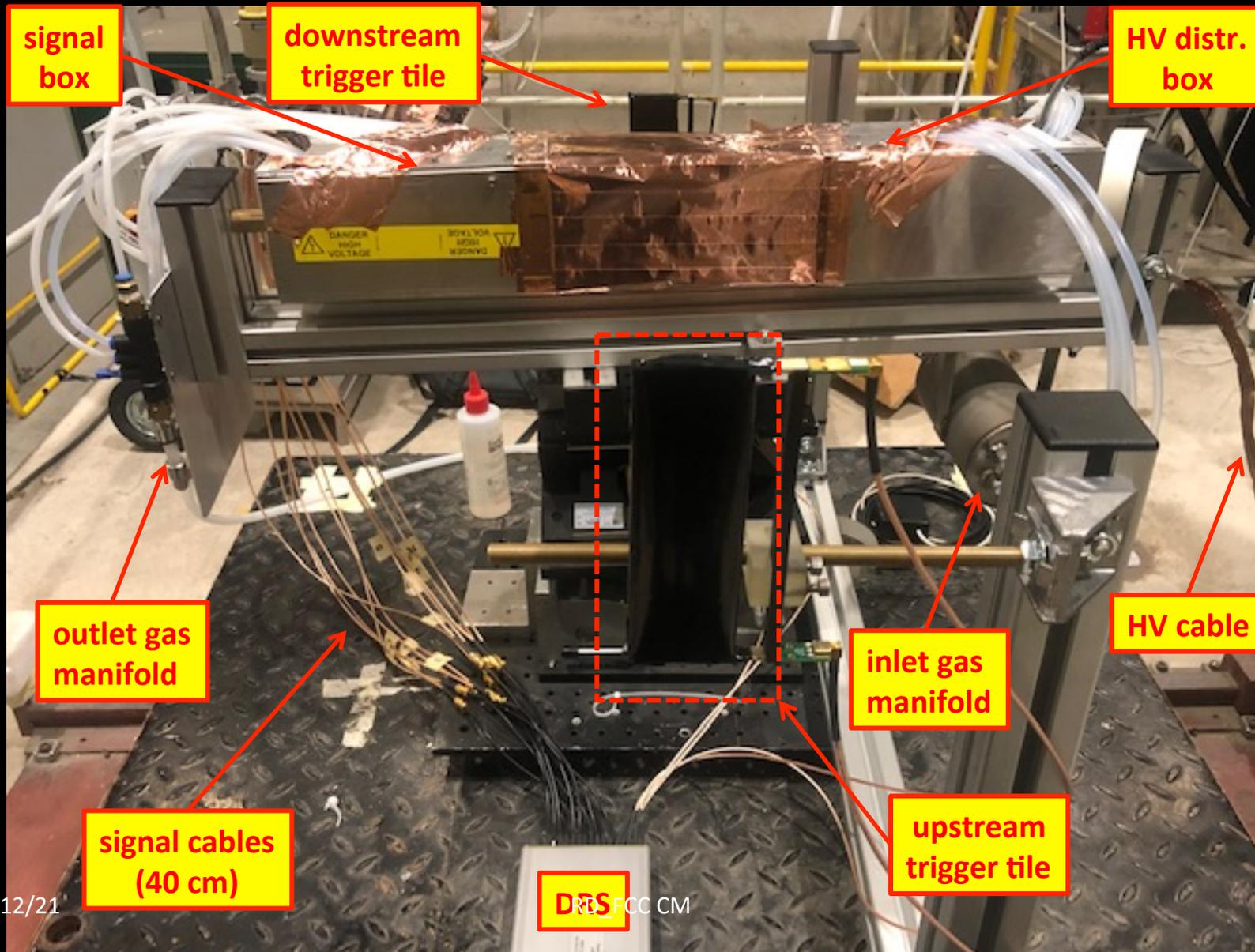
- \* Header relating to the board consisting of the words:
  - \* DRS8
  - \* TIME
  - \* B#XXX (XXX represents the card number and changes according to the WDB, in this case 033)
  - \* Calibration information

- \* Header EVENT
  - \* Serial. Number
  - \* Time information
  - \* Channel Information

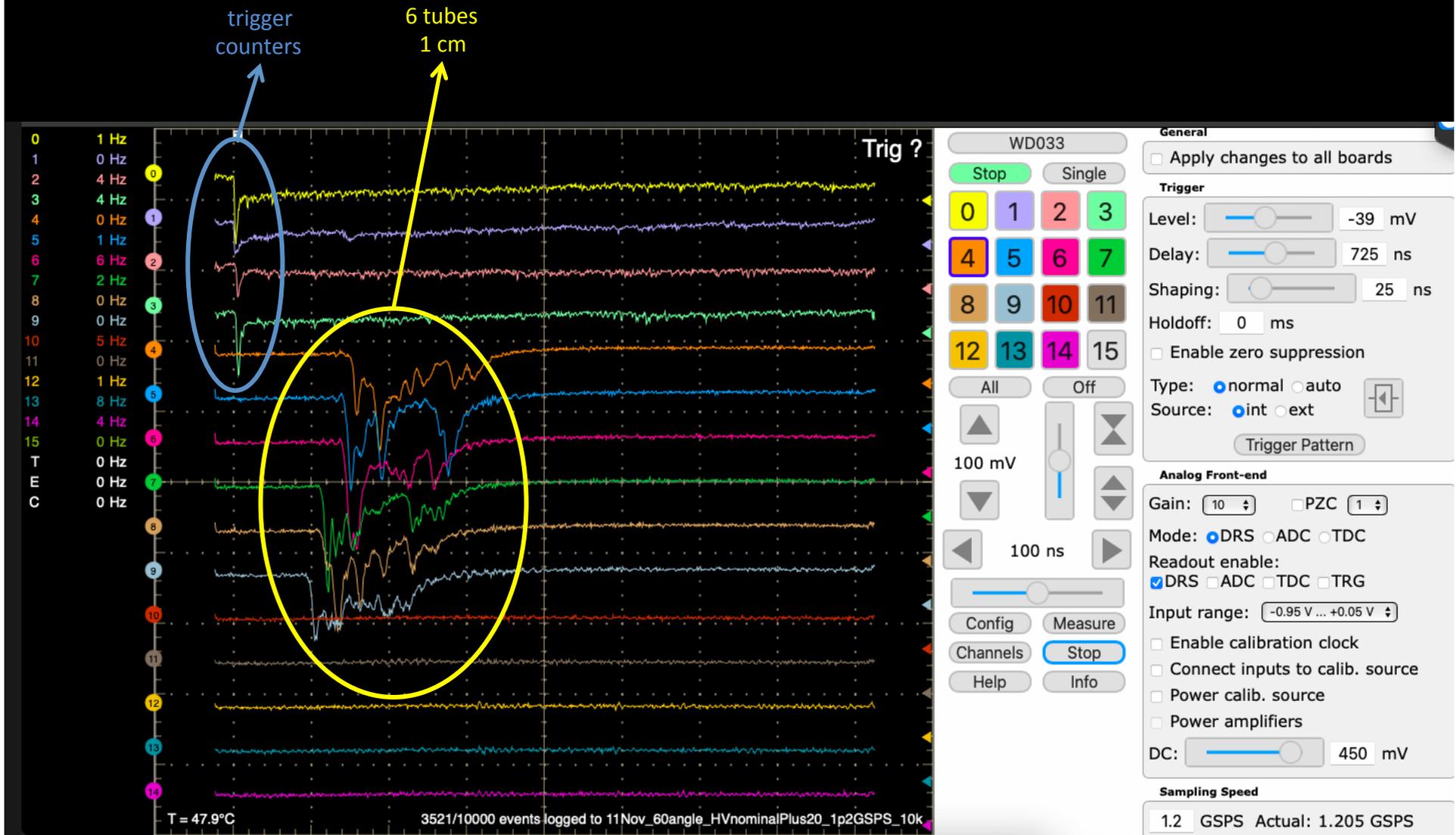
The macro for converting binary files to root files is ready.

Word	Byte 0	Byte 1	Byte 2	Byte 3	Contents
0	'D'	'R'	'S'	'8'	File header, Byte 3 = version
1	'T'	'I'	'M'	'E'	Time Header
2	'B'	'#'	Board number		Board serial number
3	'C'	'0'	'0'	'0'	Channel 0 header
4	Time Bin Width #0				Effective time bin width in ns for channel 0 encoded in 4-Byte floating point format
5	Time Bin Width #1				
...	...				
1027	Time Bin Width #1023				
1028	'C'	'0'	'0'	'1'	
1029	Time Bin Width #0				Effective time bin width in ns for channel 1 encoded in 4-Byte floating point format
1030	Time Bin Width #1				
...	...				
2052	Time Bin Width #1023				
2053	'E'	'H'	'D'	'R'	
2054	Event Serial Number				Serial number starting with 1
2055	Year		Month		Event date/time 16-bit values
2056	Day		Hour		
2057	Minute		Second		
2058	Millisecond		Range		
2059	'B'	'#'	Board number		Board serial number
2060	'C'	'0'	'0'	'0'	Channel 0 header
2061	Scaler #1				Scaler for channel 0 in Hz
2062	'T'	'#'	Trigger cell		Channel 0 first readout cell
2063	Voltage Bin #0		Voltage Bin #1		Channel 0 waveform data encoded in 2-Byte integers. 0=RC-0.5V and 65535=RC+0.5V. RC see header.
2064	Voltage Bin #2		Voltage Bin #3		
...	...		...		
2574	Voltage Bin #1022		Voltage Bin #1023		
2575	'C'	'0'	'0'	'1'	Channel 1 header
2576	Scaler #2				Scaler for channel 1 in Hz
2077	'T'	'#'	Trigger cell		Channel 1 first readout cell
2578	Voltage Bin #0		Voltage Bin #1		Channel 1 waveform data encoded in 2-Byte integers. 0=RC-0.5V and 65535=RC+0.5V. RC see header.
2579	Voltage Bin #2		Voltage Bin #3		
...	...		...		
3089	Voltage Bin #1022		Voltage Bin #1023		
3090	'E'	'H'	'D'	'R'	Next Event Header
...	...				

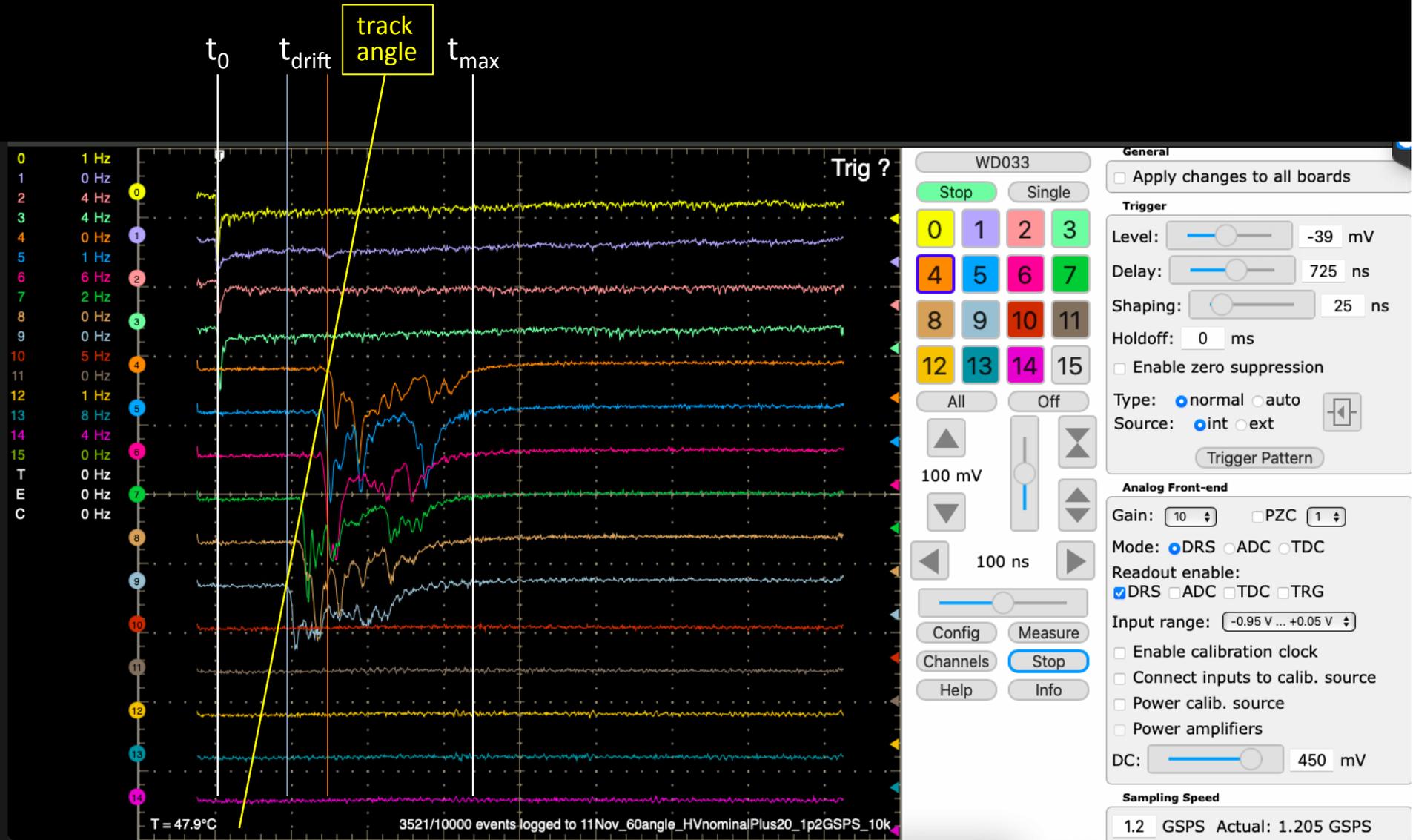
# The setup



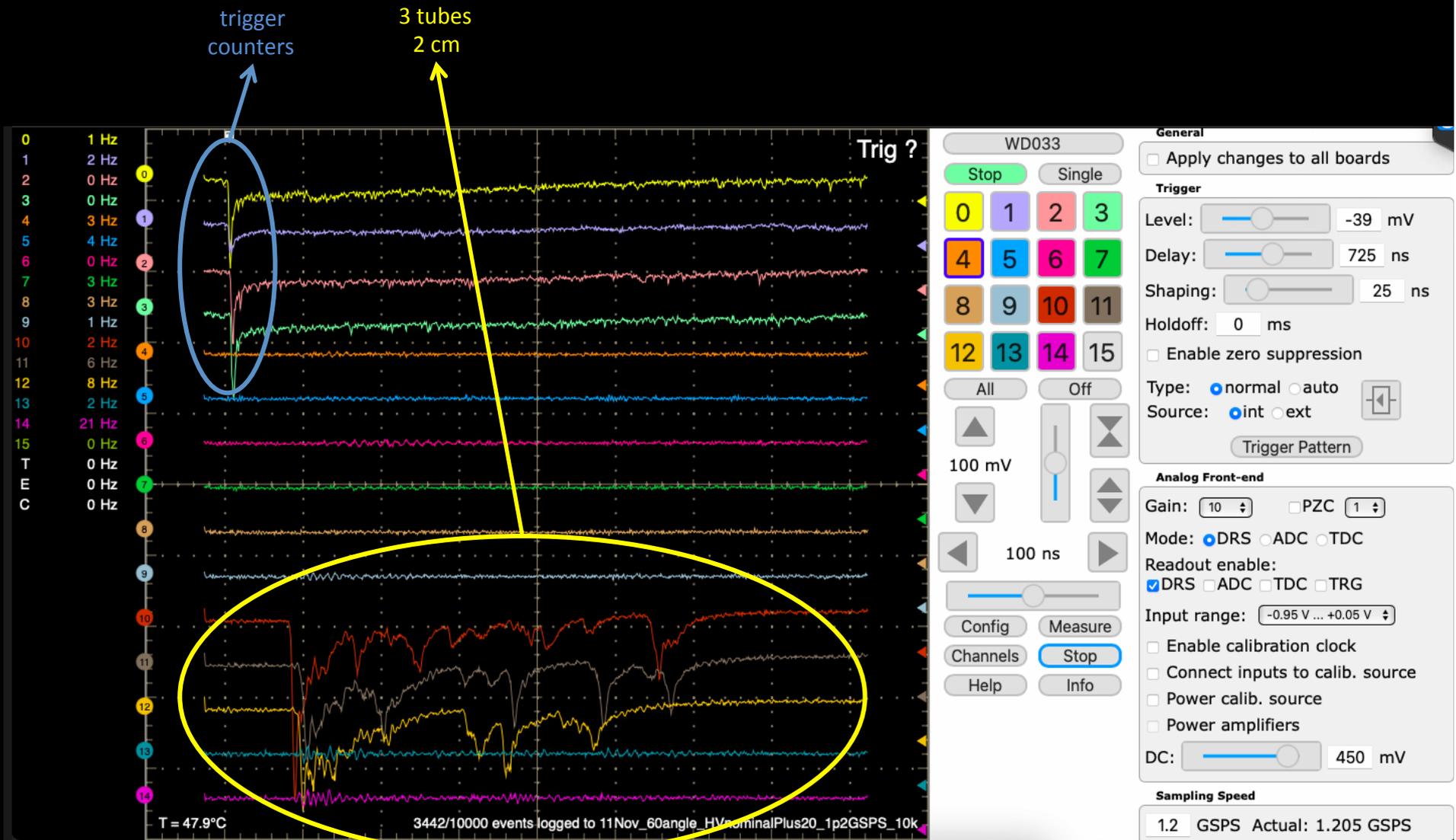
# Event display



# Event display



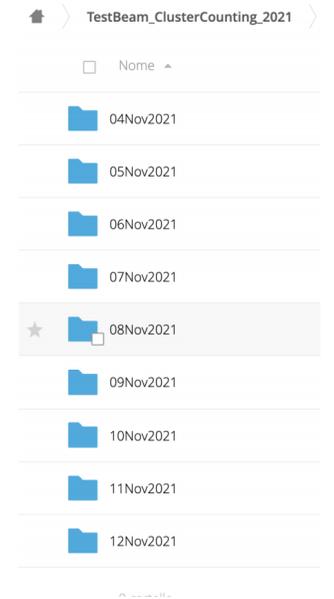
# Event display



# Data storage

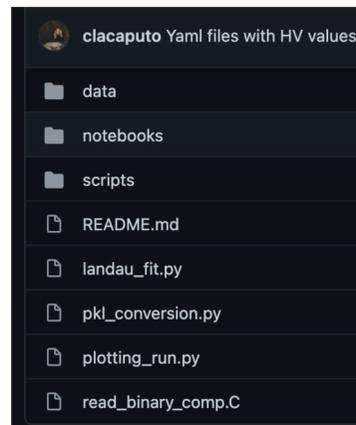
- Raw data stored on CERNBox: <https://cernbox.cern.ch/index.php/s/lz16PygC4tx1DCE>
  - Public accessible; you can download it
  - Only binary files provided
- Github with online analysis code and preliminary offline code: [https://github.com/clacaputo/drifftubes\\_analysis](https://github.com/clacaputo/drifftubes_analysis)
  - Code for converting RAW data to ROOT and PKL files is provided in the repository
  - Basic Runs database, based on YAML files, is provided
- Log Book (To be Updated): <https://codimd.web.cern.ch/9UXozxEwRK6vsJ4ilia9BA>

- <https://cernbox.cern.ch/index.php/s/lz16PygC4tx1DCE>
- One folder for each day of data taking, each folder should contain:
  - txt file with informations about the run (To be moved in the log book)
  - RAW files (binary),
  - ROOT and pkl files can be easily created with the code provided in my repo (more in next slides)



- Github: [https://github.com/clacaputo/drifftubes\\_analysis](https://github.com/clacaputo/drifftubes_analysis)

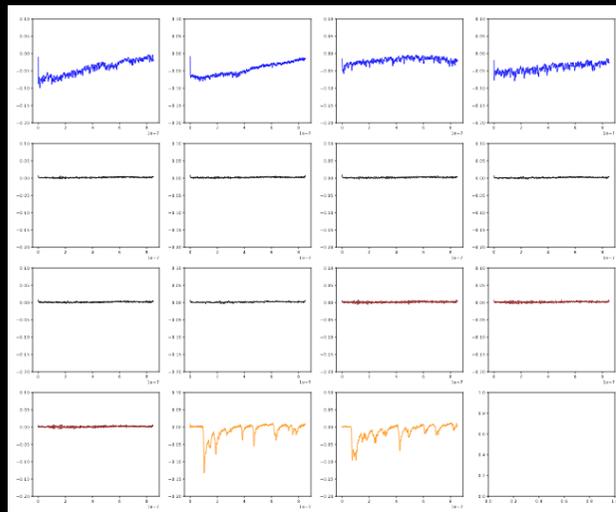
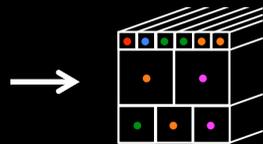
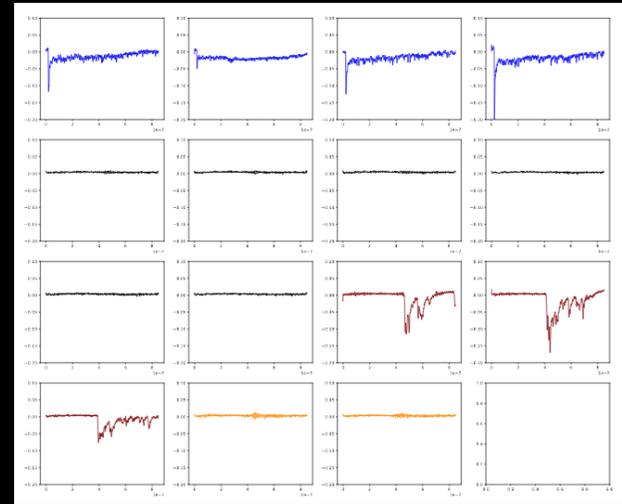
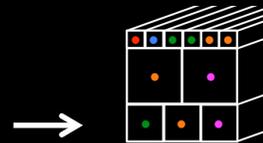
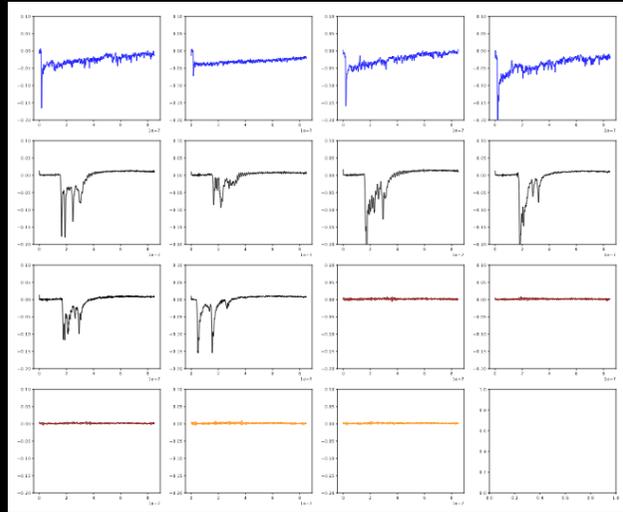
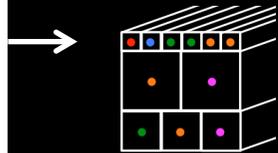
- **YAML** config files for the different runs
- Decoding code (Thanks to Gianluigi!)
- Conversion code to ROOT, pkl files, parallellized on HTCCondor
- script for submitting on HPC facilities, easily customisable
- code for online Landau fit, plus plot productions
- Peak finding (BETA version)



- YAML config files for the different runs, example at this link

```
78 lines (74 sloc) | 3.27 KB
Raw Blame
1 GasMixture: 90.10
2 MuonEnergy: 165 #GeV
3 GSPS: 1.2
4 delay: 725 #ns
5 NumberEvents: 5000
6 HV:
7 nominal: {"ch4": 1200, "ch5": 1245, "ch6": 1300, "ch7": 1300, "ch8": 1340, "ch9": 1340, "ch10": 1495, "ch11": 1550, "ch12": 1720, "ch13": 1670, "ch14": 1810}
8 main_path: /eos/user/c/clacaputo/TestBeam_ClusterCounting/11Nov/
9 Measurements:
10 Voltage_m20:
11 voltage: "m20"
12 angle_scan:
13 angle_15:
14 file_bin: "11Nov_15angle_HVnominalMinus20_1p2GSPS_5k"
15 file_root: "11Nov_15angle_HVnominalMinus20_1p2GSPS_5k.root"
16 file_pkl: "11Nov_15angle_HVnominalMinus20_1p2GSPS_5k.pkl"
17 angle_30:
18 file_bin: "11Nov_30angle_HVnominalMinus20_1p2GSPS_5k"
19 file_root: "11Nov_30angle_HVnominalMinus20_1p2GSPS_5k.root"
20 file_pkl: "11Nov_30angle_HVnominalMinus20_1p2GSPS_5k.pkl"
21 angle_45:
22 file_bin: "11Nov_45angle_HVnominalMinus20_1p2GSPS_5k"
23 file_root: "11Nov_45angle_HVnominalMinus20_1p2GSPS_5k.root"
24 file_pkl: "11Nov_45angle_HVnominalMinus20_1p2GSPS_5k.pkl"
25 angle_60:
26 file_bin: "11Nov_60angle_HVnominalMinus20_1p2GSPS_10k"
27 file_root: "11Nov_60angle_HVnominalMinus20_1p2GSPS_10k.root"
28 file_pkl: "11Nov_60angle_HVnominalMinus20_1p2GSPS_10k.pkl"
29 voltage_nominal:
30 voltage: "nominal"
31 angle_scan:
32 angle_15:
```

# Data converted



# Analysis plan

this talk

- Determine **gas gain** for the different (9) configurations and for different gas mixtures
- Study the **space charge** limitations for an efficient cluster collection

- Train different **cluster counting algorithms** by direct comparisons among them (and to PeakFit)
- Check **Poisson nature** of cluster counting (tube size, track angle, gas mixture)

next talk

# Some considerations on gas gain

Capacitance per unit length (cylinder approximation):

$$C_L = 2\pi\epsilon_0/\ln(R/r_w) \quad C_{\text{tube}} = C_L \times L$$

Inductance per unit length (cylinder approximation):

$$L_L = 2 \times 10^{-7} \ln(R/r_w) \mu\text{H/m}$$

our drift tubes:  $L = 30, 40 \text{ cm}$      $R = 0.4, 0.9, 1.4 \text{ cm}$   
 $r_w = 5.0, 7.5, 10.0, 12.5, 20.0 \mu\text{m}$

Characteristic Impedance:  $Z = \sqrt{L/C}$

At **gas gain =  $10^5$** , one single electron deposits a charge

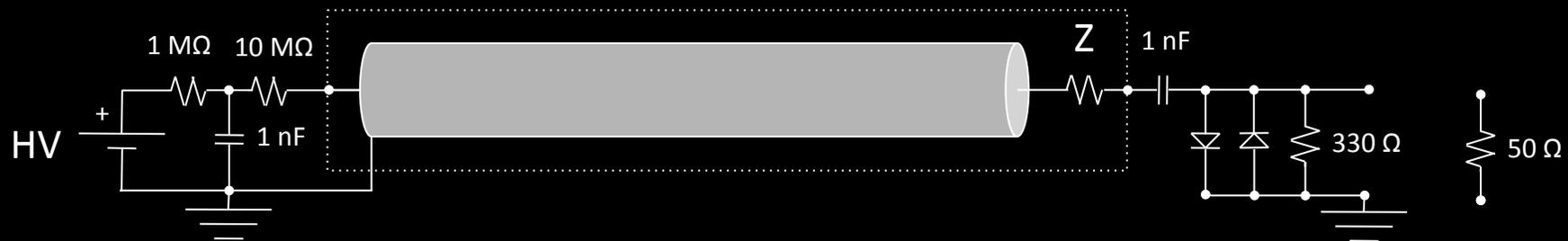
$$Q_0 = 1.6 \times 10^{-19} \times 10^5 \text{ Coul} = \mathbf{16 \text{ fCoul}}$$

and the pulse height generated by a single electron would be:

$$\Delta V = Q_0 / C_{\text{tube}}$$

# Charge distribution

equivalent circuit



Impedance mismatch:  $\Delta V_{\text{reflect}} = (Z-330)/(330+Z) \times \Delta V$        $\Delta V_{\text{transmit}} = 660/(330+Z) \times \Delta V$

Current divider:  $\Delta V' = 330/(330+50) \times \Delta V_{\text{transmit}} = 0.87 \times \Delta V_{\text{transmit}}$

combined result:  $\Delta V' = 330/(330+50) \times 660/(330+Z) \times Q_0/C_{\text{tube}}$

# A few numbers

configuration number	R	$2 \times r_w$	L	$C_L$	$L_L$	$C_{\text{tube}}$	Z	$\Delta V$ ( $10^5$ gain)	$\Delta V'$ ( $10^5$ gain)
1	0.4 cm	10 $\mu\text{m}$	0.4 m	8.37 pF/m	1.34 $\mu\text{H/m}$	3.35 pF	400 $\Omega$	4.78 mV	3.75 mV
3	0.4 cm	15 $\mu\text{m}$	0.4 m	8.91 pF/m	1.26 $\mu\text{H/m}$	3.56 pF	376 $\Omega$	4.49 mV	3.65 mV
5 - 7	0.4 cm	20 $\mu\text{m}$	0.4 m	9.33 pF/m	1.20 $\mu\text{H/m}$	3.73 pF	359 $\Omega$	4.29 mV	3.57 mV
9 - 11	0.4 cm	25 $\mu\text{m}$	0.4 m	9.69 pF/m	1.15 $\mu\text{H/m}$	3.88 pF	344 $\Omega$	4.12 mV	3.50 mV
13	0.9 cm	20 $\mu\text{m}$	0.3 m	8.22 pF/m	1.36 $\mu\text{H/m}$	2.47 pF	407 $\Omega$	6.48 mV	5.04 mV
15	0.9 cm	25 $\mu\text{m}$	0.3 m	8.50 pF/m	1.32 $\mu\text{H/m}$	2.55 pF	394 $\Omega$	6.27 mV	4.96 mV
17	0.9 cm	40 $\mu\text{m}$	0.3 m	9.15 pF/m	1.22 $\mu\text{H/m}$	2.75 pF	365 $\Omega$	5.82 mV	4.80 mV
19	1.4 cm	25 $\mu\text{m}$	0.3 m	7.96 pF/m	0.94 $\mu\text{H/m}$	2.39 pF	344 $\Omega$	6.69 mV	5.02 mV
21	1.4 cm	40 $\mu\text{m}$	0.3 m	8.54 pF/m	0.85 $\mu\text{H/m}$	2.56 pF	315 $\Omega$	6.25 mV	5.30 mV

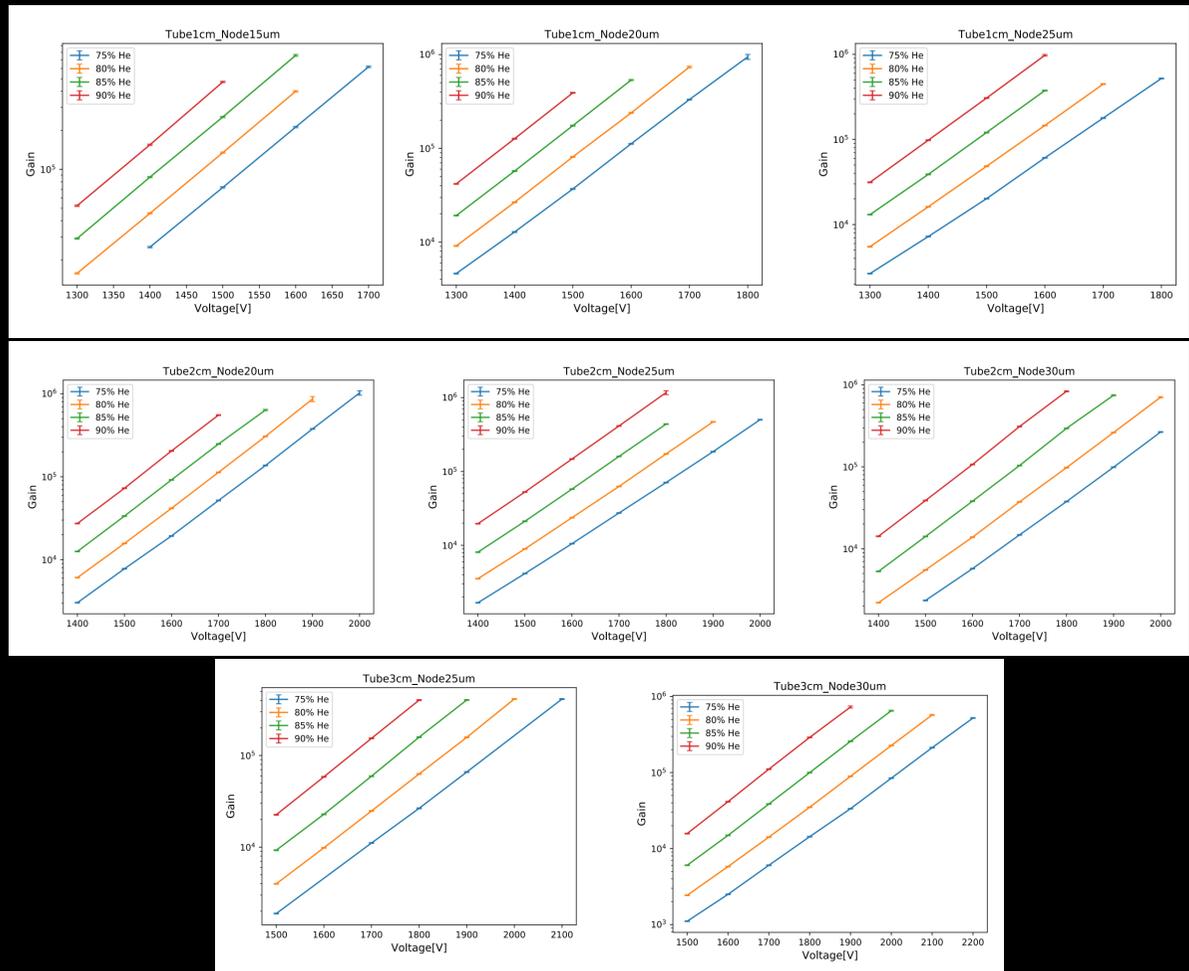
**$\Delta V'$ ( $10^5$  gain)** = single electron pulse height at readout, for an HV producing a **reduced electric field: E/P**, corresponding to a gas gain of  **$10^5$**

# Determining HV ( $10^5$ gain)

Garfield run on different configurations by Shuiting for  $P = 760$  torr,  $T = 20^\circ\text{C}$

renormalized for  $P = 725$  torr and extrapolated for 10 and 40  $\mu\text{m}$  wires

and readjusted by observing average maximum pulse height



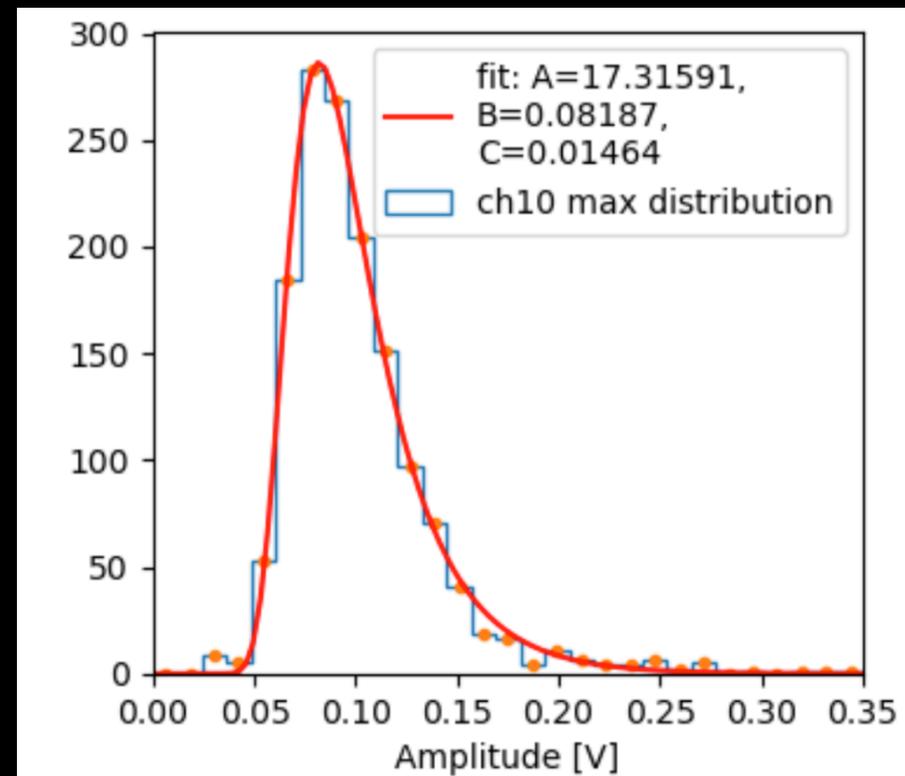
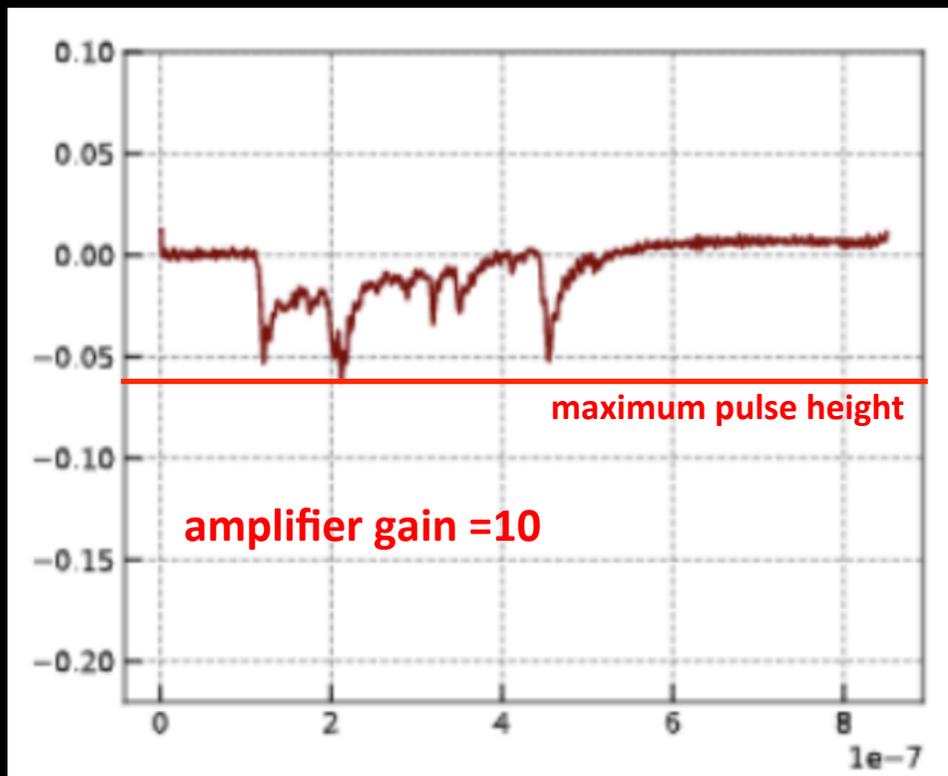
# HV table (He/iC<sub>4</sub>H<sub>10</sub> = 90/10, P = 725 torr)

## 1<sup>st</sup> attempt (from Garfield)

configuration number	HV	relative gas gain ( $\Delta V$ )
1	1230 V	2.6
3	1255 V	1.4
5 - 7	1305 V	1.3
9 - 11	1330 V	0. ...
13	1470 V	0.6
15	1545 V	0.9
17	1670 V	0. ...
19	1620 V	0. ...
21	1765 V	0. ...

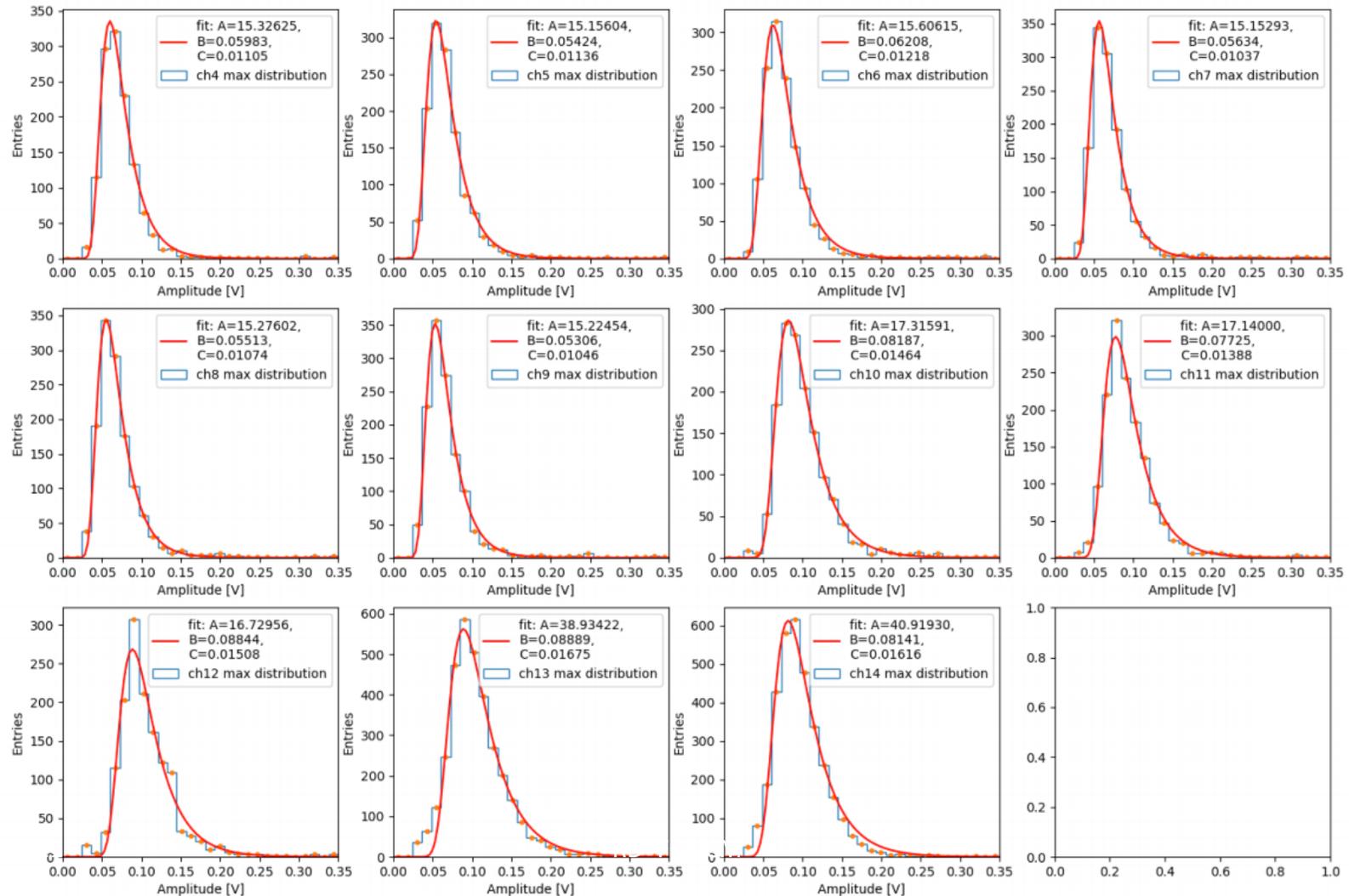
# Average maximum pulse height

Assume that the average maximum pulse height  $\cong$   
single electron pulse height  
and fit to a Landau distribution by taking into account the  
amplifier gain (x 10)



# Average maximum pulse height

- Max amplitude/ per channel distribution, fitted with a landau - **11Nov\_45angle\_HVnominal\_1p2GSPS\_10k\_LANDAU**
  - [https://github.com/clacaputo/drifftubes\\_analysis/blob/main/landau\\_fit.py](https://github.com/clacaputo/drifftubes_analysis/blob/main/landau_fit.py)
- More of these plots: <https://cernbox.cern.ch/index.php/s/yjoJLkgUbPCiELG>



# HV table (He/iC<sub>4</sub>H<sub>10</sub> = 90/10, P = 725 torr)

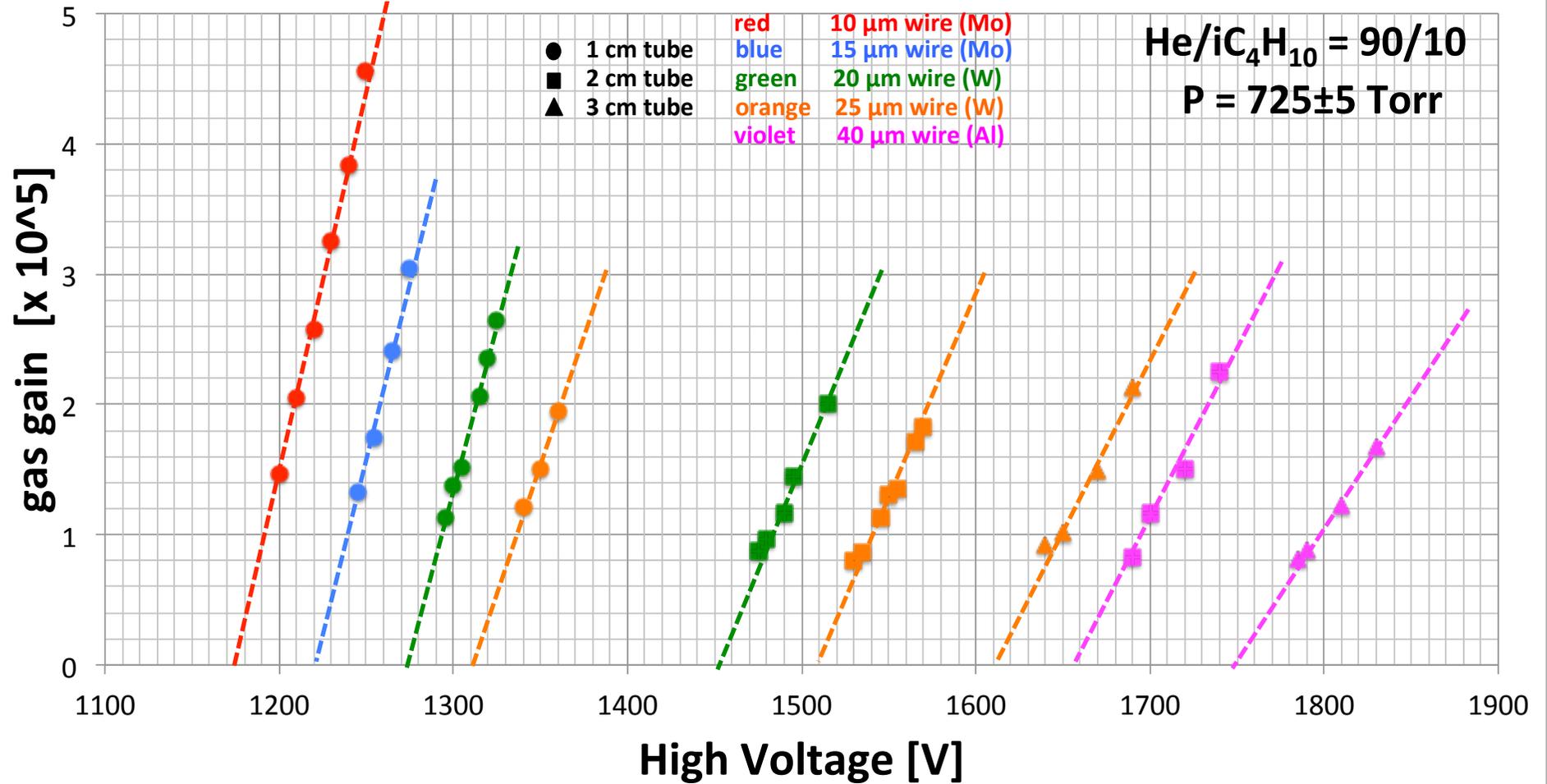
## 1<sup>st</sup> attempt (from Garfield)

## 2<sup>nd</sup> attempt (corrections to Garfield)

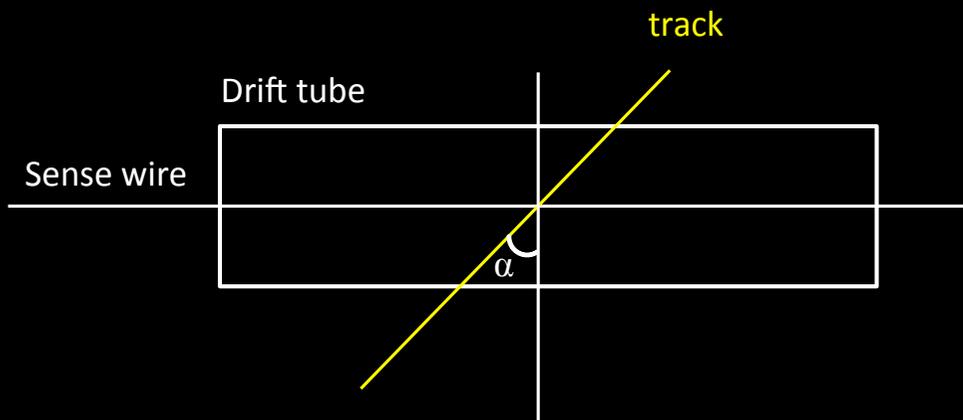
configuration number	HV	relative gas gain ( $\Delta V$ )	HV	relative gas gain ( $\Delta V$ )	actual gas gain ( $\Delta V'$ )
1	1230 V	2.6	1230 V - 30 V	1.2	1.47
3	1255 V	1.4	1255 V - 10 V	1.1	1.29
5 - 7	1305 V	1.3	1305 V - 5 V	1.1	1.31
9 - 11	1330 V	0. ...	1330 V + 10 V	1.1	1.27
13	1470 V	0.6	1470 V + 25 V	1.1	1.57
15	1545 V	0.9	1545 V + 5 V	1.0	1.49
17	1670 V	0. ...	1670 V + 50 V	1.2	1.92
19	1620 V	0. ...	1620 V + 50 V	1.1	2.00
21	1765 V	0. ...	1765 V + 45 V	1.0	1.73

# Gas gain

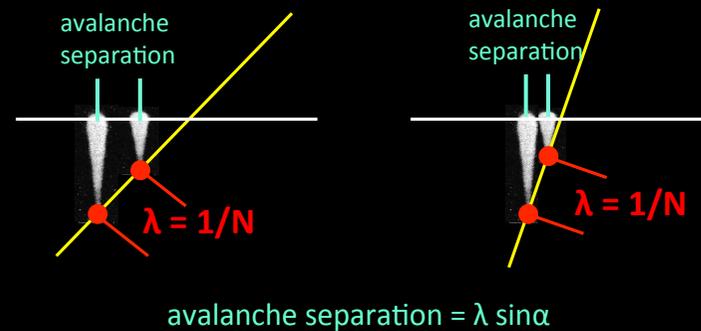
## measured gas gain vs HV (normal incidence)



# Space Charge Effect



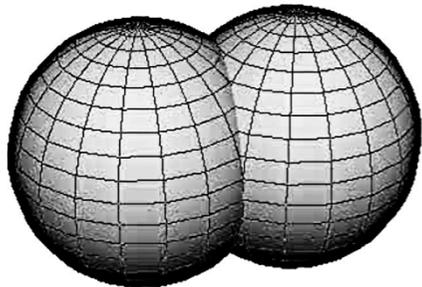
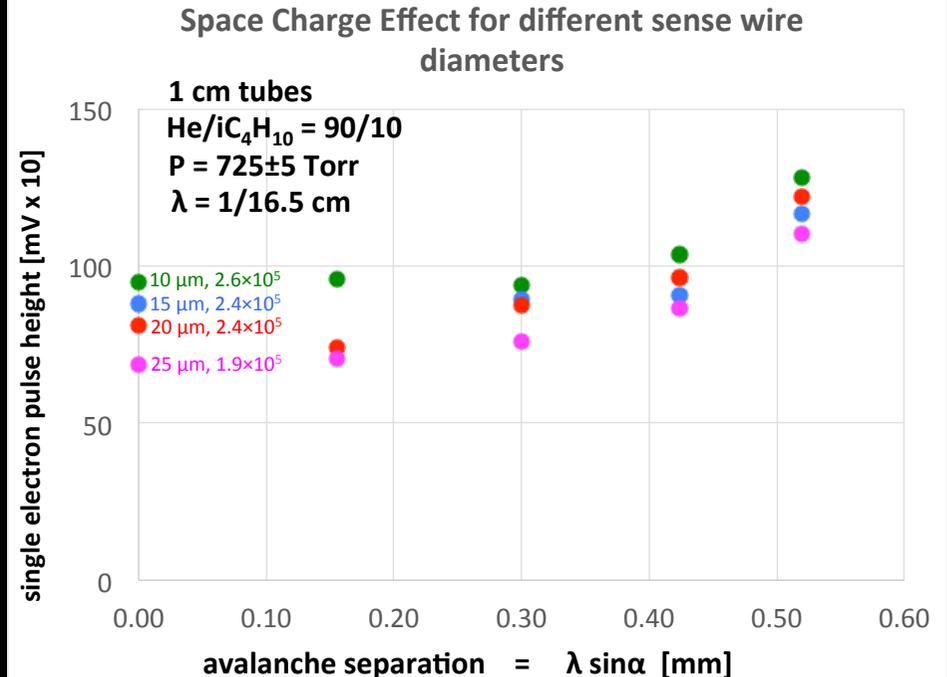
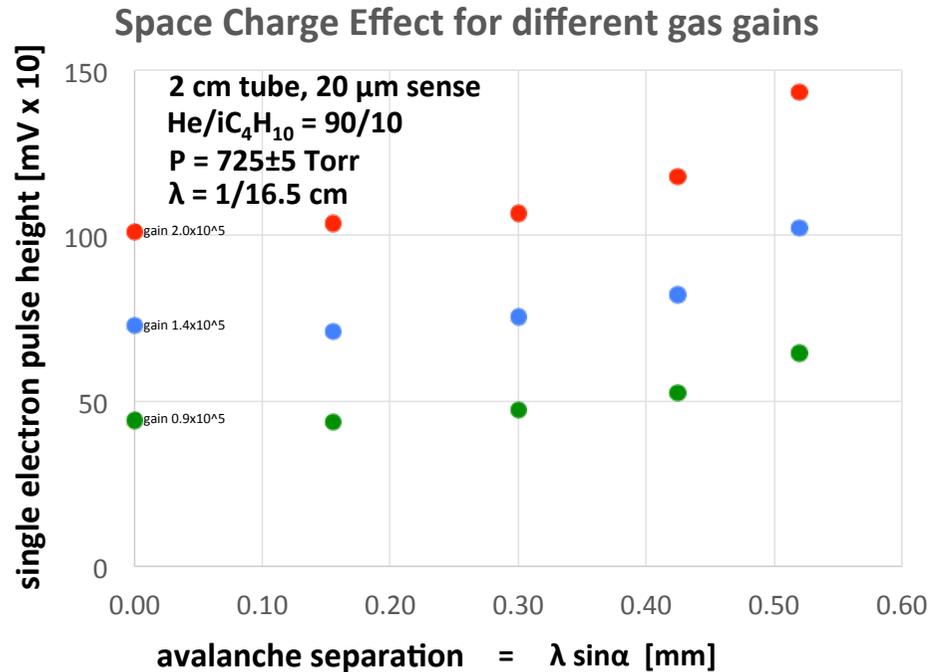
Study avalanche overlap as a function of the track angle



Space charge effect, at any given angle, results in reducing the effective gas gain (or, equivalently the average single electron pulse height) with respect to a configuration at a larger angle.

At 165 GeV/c, we expect  $N \sim 16.5/\text{cm} \rightarrow \lambda \sim 600 \mu\text{m}$ .

# Space Charge Effects



A naive model based on spherical avalanche gives, for this particular configuration, an **avalanche radius** of  $r_v \approx 450 \mu\text{m}$ .

assuming  $\lambda \geq r_v$ , on the Fermi plateau  
 $N \leq 22/\text{cm}$  or  $N_{\text{max}} = 15/\text{cm}$  for m.i.p.

Space charge effects, in this range of gas gain do not seem to depend on gas gain or, surprisingly enough, on sense wire diameter. The maximum **avalanche suppression**, for this gas mixture, amounts to  $\approx 70\%$ , at  $0^\circ$ .

$N = 15/\text{cm}$  for m.i.p.  $\rightarrow \text{He}/\text{iC}_4\text{H}_{10} = 85/15$   
 $(N = 12/\text{cm}$  for  $\text{He}/\text{iC}_4\text{H}_{10} = 90/10)$