Drift Chambers Challenges and Work Packages

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INFN – Lecce

DRD1 Community Meeting
CERN, 22–23 June 2023

Why a Drift Chamber?

Trackers at e^+e^- Colliders

past

SPEAR	**MARK2**	Drift Chamber
	MARK3	Drift Chamber
DORIS	**PLUTO**	MWPC
	ARGUS	Drift Chamber
CESR	**CLEO1,2,3**	Drift Chamber
VEPP2/4M	**CMD-2**	Drift Chamber
	KEDR	Drift Chamber
	NSD	Drift Chamber
PETRA	**CELLO**	MWPC + Drift Ch.
	JADE	Drift Chamber
	PLUTO	MWPC
	MARK-J	TEC + Drift Ch.
	TASSO	MWPC + Drift Ch.
TRISTAN	**AMY**	Drift Chamber
	VENUS	Drift Chamber
	TOPAZ	TPC

PEP	**MARK2**	Drift Chamber
	PEP-4	TPC
	MAC	Drift Chamber
	HRS	Drift Chamber
	DELCO	MWPC
BEPC	**BES1,2**	Drift Chamber
LEP	**ALEPH**	TPC
	DELPHI	TPC
	L3	Si + TEC
	OPAL	Drift Chamber
SLC	**MARK2**	Drift Chamber
	SLD	Drift Chamber
DAPHNE	**KLOE**	Drift Chamber
PEP2	**BaBar**	Drift Chamber
KEKB	**Belle**	Drift Chamber

present

VEPP2000	**CMD-3**	Drift Chamber
	KEDR	Drift Chamber
BEPC2	**BES3**	Drift Chamber
S.KEKB	**Belle2**	Drift Chamber

future

ILC	**ILD**	TPC
	SiD	Si
CLIC	**CLIC**	Si
FCC-ee	**CLD**	Si
	IDEA	Drift Chamber
CEPC	**Baseline**	TPC Si
	4th	Si + Drift Chamber
	IDEA	Drift Chamber
SCTF	**BINP**	Drift Chamber
STCF	**HIEPA**	Drift Chamber

Wire constraints

Electrostatic stability condition

$$\boxed{T_c \geq \frac{C^2 V_0^2}{4\pi\epsilon w^2} L^2}$$

T_c wire tension
w cell width
L wire length

C capacitance per unit length
V_0 voltage anode-cathode

For w = 1 cm, L = 4 m:

T_c > 26 g for 40 µm Al field wires (δ_{grav} = 260 μm)
T_c > 21 g for 20 µm W sense wires (δ_{grav} = 580 μm)

Elastic limit condition

$$T_c < YTS \times \pi \cdot r_w^2$$

YTS = 750 Mpa for W, *290 Mpa for Al*

T_c < 36 g for 40 µm Al field wires (δ_{grav} = 190 μm)
T_c < 24 g for 20 µm W sense wires (δ_{grav} = 510 μm)

The drift chamber length (**L = 4 m**) imposes
strong constraints on the drift cell size (**w = 1 cm**)
Very little margin left ⇒ increase wires radii or cell size
⇒ use different types of wires

Drift Chamber material budget

Increase cell size to *w* > *1.5 cm (+10%)*

(56,448 → 45,700 cells, 112 → 100 layers,

and replace **20 μm W and 40-50 μm Al** (5:1)

with **35 μm C wires** (10:1)

340,000 → 500,000 wires, 9 → 18 Ton)

Stability condition:

30 g < T_c < 87 g

corresponding to

270 (158) μm > δ_{grav} > 93 (54) μm

(safety factor within ample margin!)

Contribution to m. scatt. from wires:

1.3×10^{-3} X_0 → 0.9×10^{-3} X_0

current
Material budget estimates

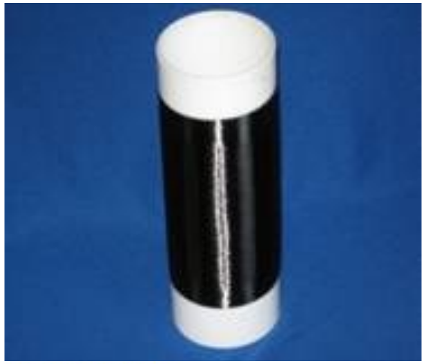
Inner wall (from CMD3 drift chamber)	**8.4×10^{-4} X_0**
200 μm Carbon fiber	
Gas (from KLOE drift chamber)	1.3×10^{-3} X_0
90% He – 10% iC_4H_{10}	
Wires (from MEG2 drift chamber)	1.3×10^{-3} X_0
20 μm W sense wires 6.8×10^{-4} X_0	
40 μm Al field wires 4.3×10^{-4} X_0	
50 μm Al guard wires 1.6×10^{-4} X_0	
Outer wall (from Mu2e I-tracker studies)	**1.2×10^{-2} X_0**
2 cm composite sandwich (7.7 Tons)	
End-plates (from Mu2e I-tracker studies)	**4.5×10^{-2} X_0**
wire cage + gas envelope incl. services (electronics, cables, ...)	

1^{st} CHALLENGES: wire types – Carbon monofilament

SPECIALTY MATERIALS, INC.

Manufacturers of Boron and SCS Silicon Carbide Fibers and Boron Nanopowder

CARBON MONOFILAMENT



TYPICAL PROPERTIES

Diameter:	0.00136 +/- 0.0001" (34.5 +/- 2.5 μm)	
Tensile Strength:	125 ksi (0.86 GPa)	0.65 GPa
Tensile Modulus:	6 msi (41.5 GPa)	
Electrical Resistivity:	3.6 x 10^{-3} ohm cm	37 KΩ/m
Density:	1.8 g/cc	

Specialty Materials, Inc.
1449 Middlesex Street
Lowell, Massachusetts 01851

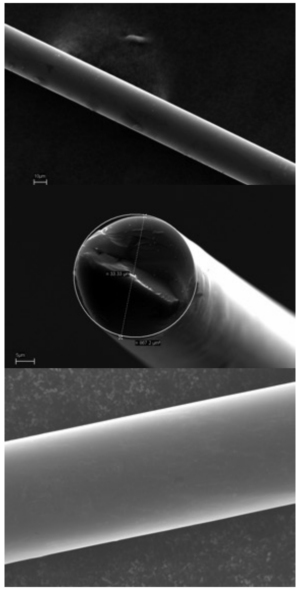
Phone: 978-322-1900
Fax: 978-322-1970

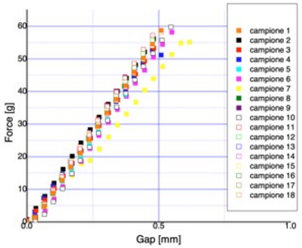
CARBON MONOFILAMENT PRODUCT PRICE LIST
Effective October 1, 2017

Product	Quantity	Price LF
CARBON MONOFILAMENT	1 Million LF	$0.02
	500,000 LF	$0.03
	1,000 LF	$0.93

CARBON MONOFILAMENT PRODUCT PRICE LIST EFFECTIVE APRIL 1, 2019

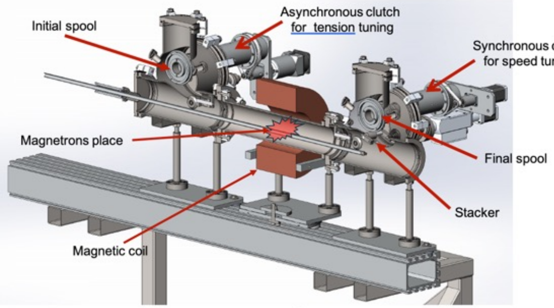
Product	Quantity	Price per LF	
CARBON MONOFILAMENT	1 Million LF	$0.02	60 €/Km
	500,000 LF	$0.03	
	1,000 LF	$0.94	

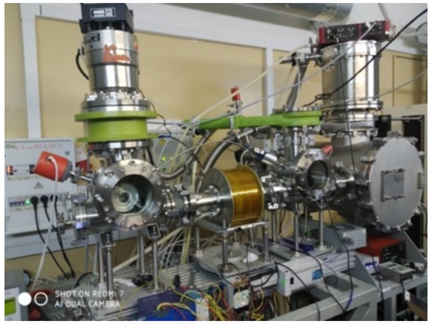


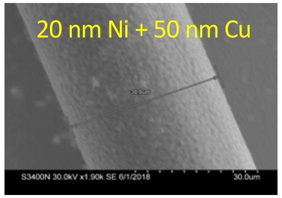


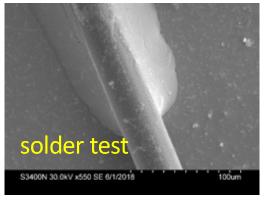
Metal coating by HiPIMS: High-power impulse magnetron sputtering

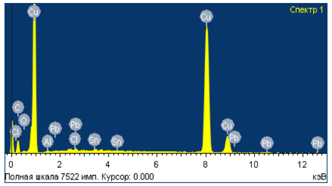
physical vapor deposition (PVD) of thin films based on magnetron sputter deposition (extremely high power densities of the order of kW/cm² in short pulses of tens of microseconds at low duty cycle <10%)

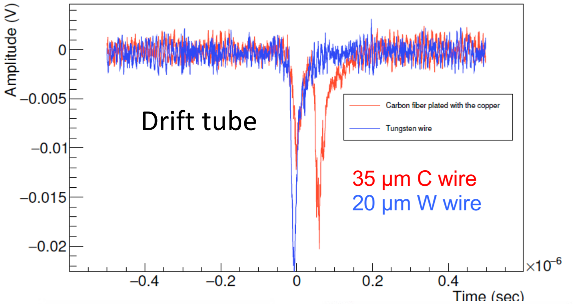




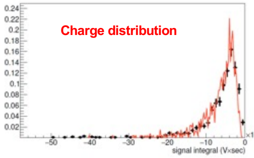

20 nm Ni + 50 nm Cu

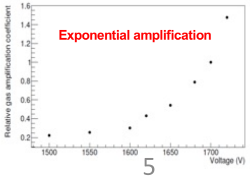

solder test




Drift tube

35 μm C wire
20 μm W wire

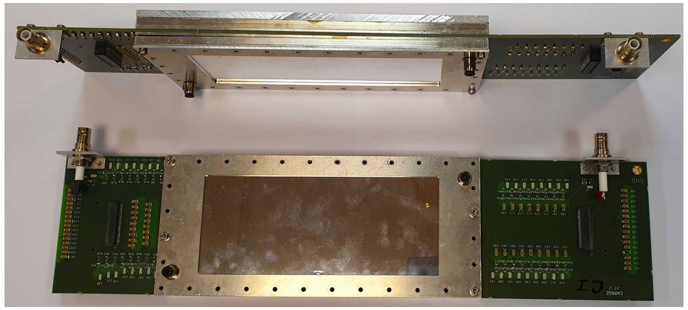

Charge distribution


Exponential amplification

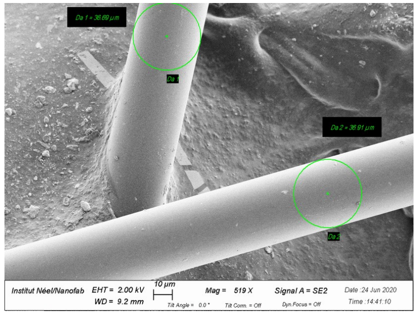
1^{st} CHALLENGES: wire types – Carbon monofilament

Blue Sky R&D at in2p3 to find new wire material

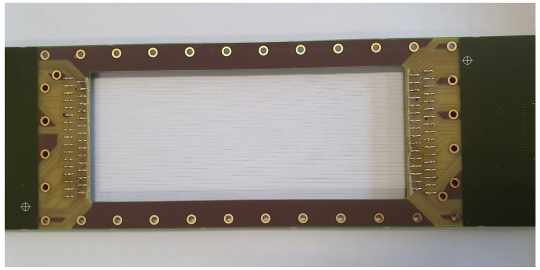
3 groups implied
2 with wiring
machines



Design a simple detector (active area 17x7 cm^2) to test different types of wires



Carbone wires seen from SEM



Carbon wire chamber soldered then glued

First results in 2017 *Carbon wire chamber at sub-atmospheric pressure, G. Charles et al., NIM A*

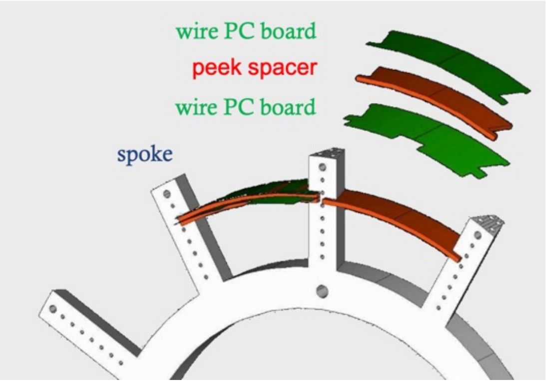
Tests with radioactive sources at 1 atm are on going for carbon wires and soldered AlMg5 wires.

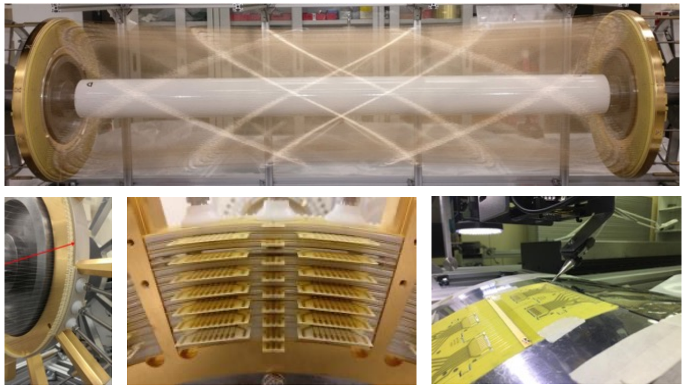
Next step will be beam tests and **internationalize the collaboration**.

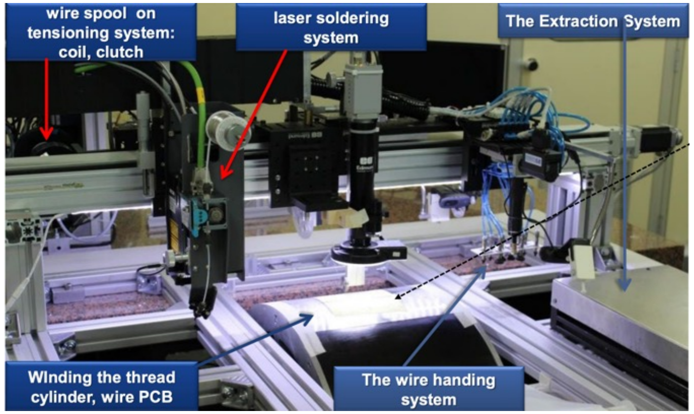
2nd CHALLENGE: 350,000 wires!

Need new wiring strategy!

Evolution of the MEG2 drift chamber wiring







Wiring robot at INFN Lecce:
32 wires at once

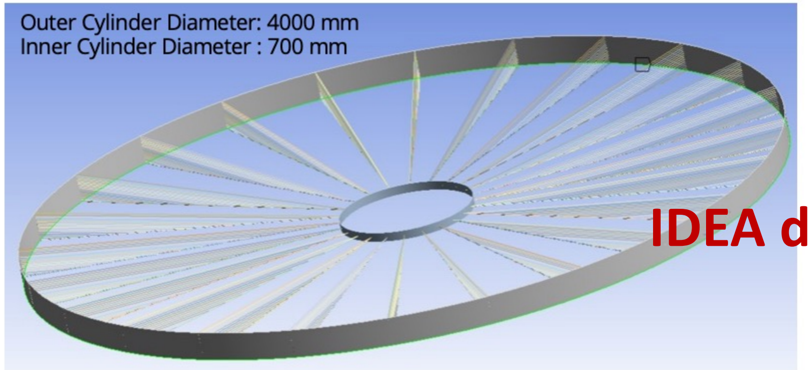
MEG2: 12 wires/cm^2
IDEA: 4 wires/cm^2

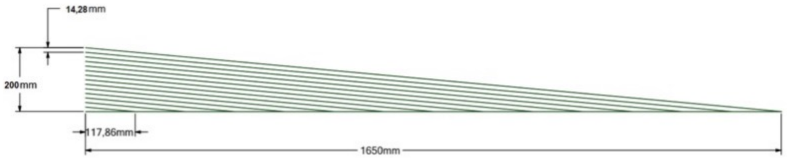
Very different dimensions!
+ tension recovery scheme

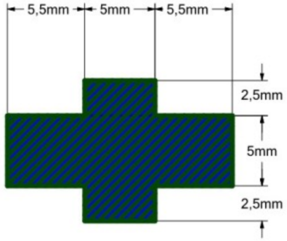
2nd CHALLENGE: mechanics and materials

IDEA drift chamber

Conceptual design under development



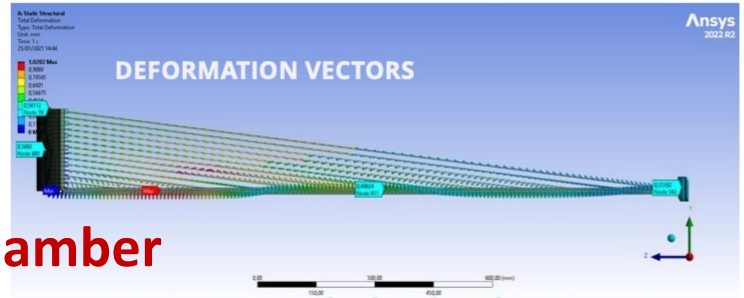




spoke profile
unidirectional
C-fiber

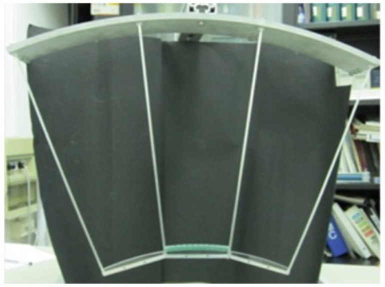
Cable/Stays: 3 mm dia.
(14 connected to each spoke)
Spokes: 16 x 10 mm (36)

Pre-stressed stays



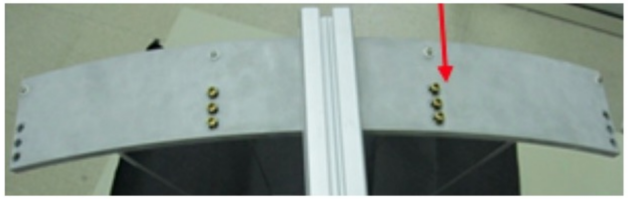
parameters optimization in progress

Test mockup (Al)



concept experimentally tested

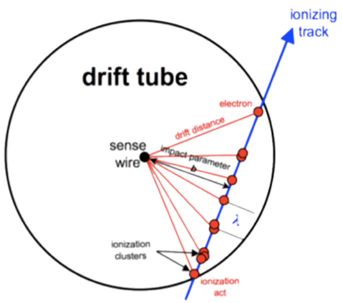
stays tension recovery screws



Choice of gas envelope shape profile and materials soon to be addressed

3rd CHALLENGE: Cluster counting/timing

PID with dN_{cl}/dx in the time domain: requirements



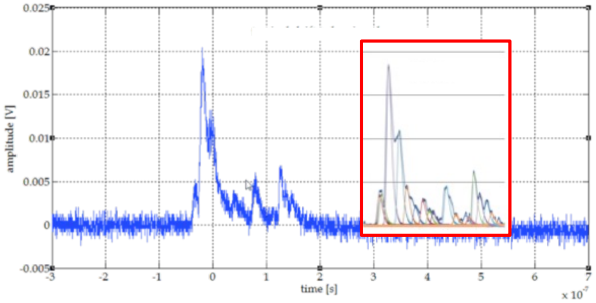
Determine, in the signal, the **ordered sequence of the electron arrival times**:

$$\left\{t_j^{el}\right\} \qquad j=1,n_{el}$$

Based on the dependence of **the average time separation between consecutive clusters** and on the **time spread due to diffusion**, as a function of the drift time, **define** the **probability function**, that the ***j***

the j^{th} **electron** belongs to the i^{th} **cluster**:

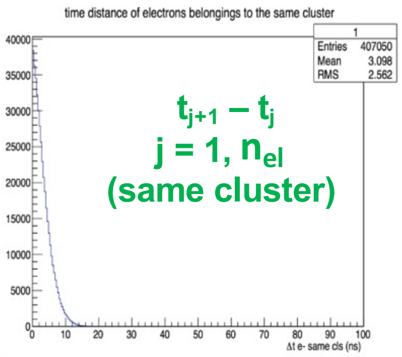
$$P(j,i) \qquad j=1,n_{el}, \quad i=1,n_{cl}$$



from this **derive** the most probable **time ordered sequence of the original ionization clusters**:

$$\left\{t_i^{cl}\right\} \qquad i=1,n_{cl}$$

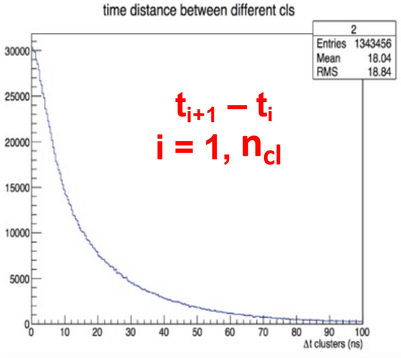
and the total number of clusters



$t_{j+1} - t_j$

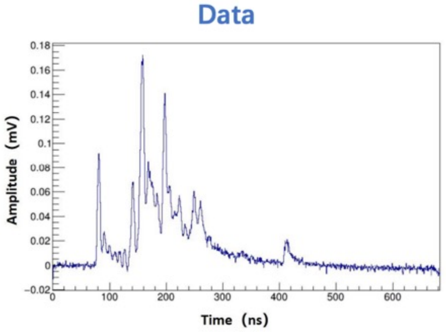
$j = 1, n_{el}$

(same cluster)



$t_{i+1} - t_i$

$i = 1, n_{cl}$



single electron
simulation:
rise time ≲ 0.5 ns
fall time ~ 2.0 ns

Requirements

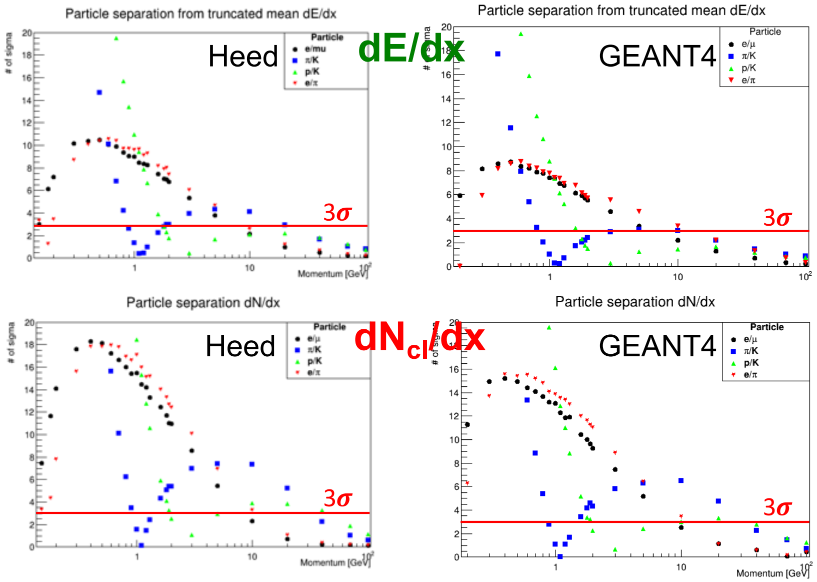
fast front-end electronics
(**bandwidth ~ 1 GHz**)

high sampling rate digitization
(**~ 2 GSa/s, 12 bits, >3 KB**)

PID with dN_{cl}/dx in the time domain: simulations

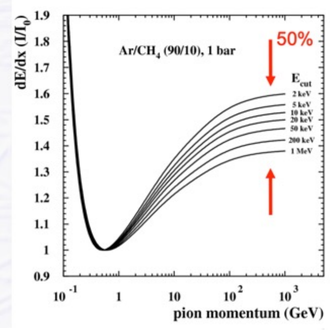
2.0 m long tracks in 90/10 He/iC_4H_{10}

full simulation



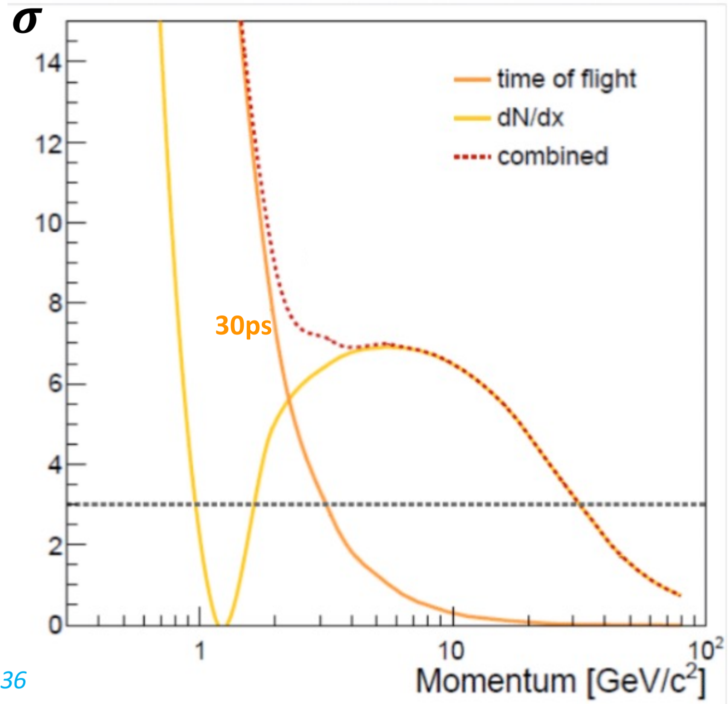
F. Cuna, N. De Filippis, F. Grancagnolo, G. Tassielli, Simulation of particle identification with the cluster counting technique, arXiv:2105.07064v1 [physics.ins-det] 14 May 2021

Geant4 uses the cluster density and the cluster size distributions derived from **Heed**, however, they **disagree**, most likely, due to a different choice of the **E_{cut}** parameter (the maximum energy of an electron still associated to a track in the simulation)



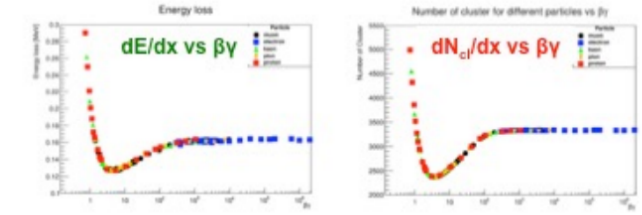
M. Hauschild Progress in dE/dx techniques used for particle identification NIM A379(1996) 436

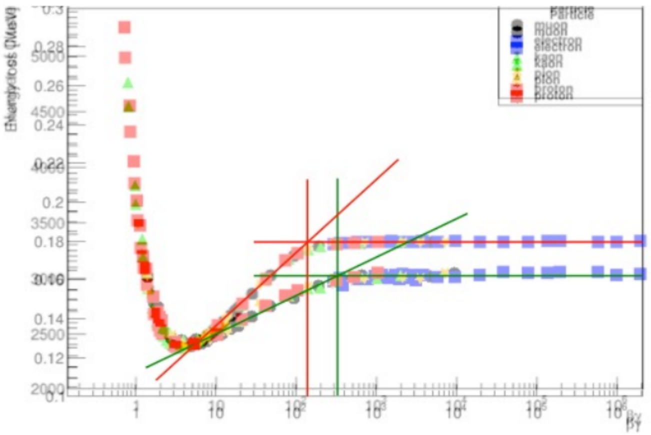
IDEA drift chamber expected π/K separation



3^{rd} CHALLENGE: simulation – experimental tests

GEANT4 with **HEED** clusterization model





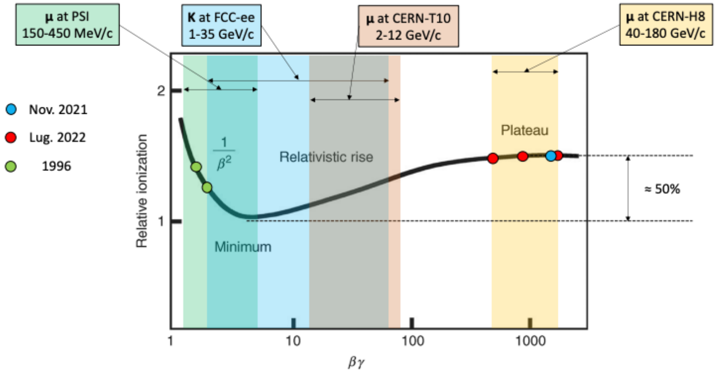
F. Cuna, N. De Filippis, F. Grancagnolo, G. Tassielli, Simulation of particle identification with the cluster counting technique, arXiv:2105.07064v1 [physics.ins-det] 14 May 2021

Higher values of Fermi plateau for dN_{cl}/dx w.r.t. dE/dx, yet reached at lower $\beta\gamma$ values and with a steeper slope

due to a choice of E_{cut} (the maximum energy of an electron still associated to a track in the simulation) parameter?

⇩

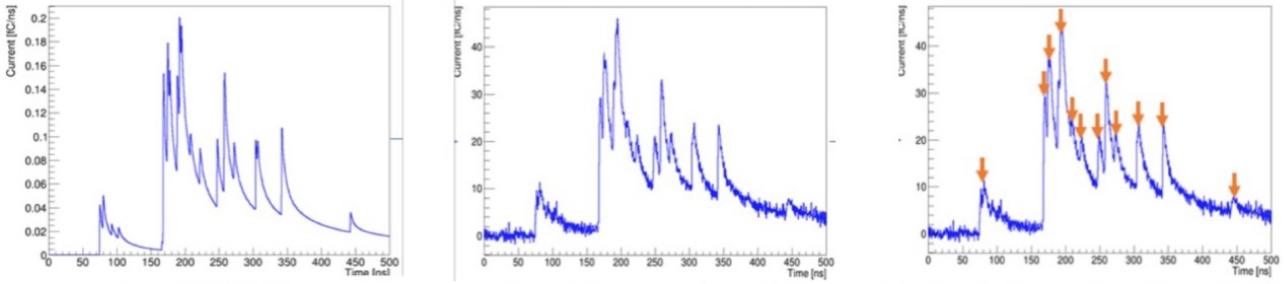
Experimental beam test campaign needed



Next beam test
21 June – 4 July
at CERN-T10
with muons
2-12 GeV/c

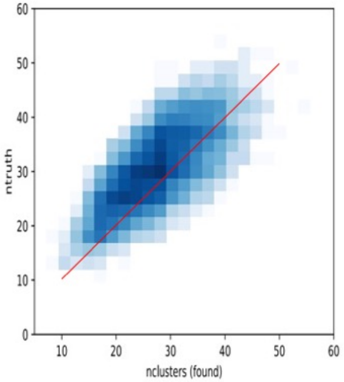
4th CHALLENGE: peak finding algorithms

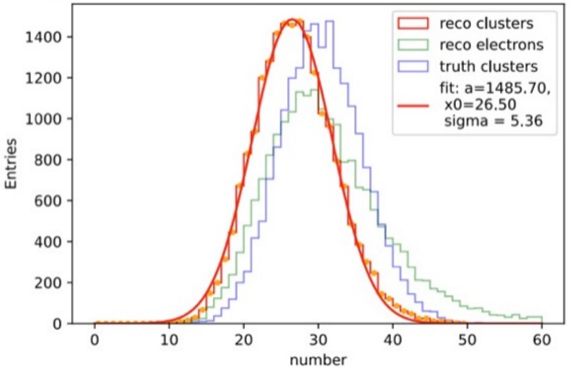
Simulation package (IHEP-Beijing contribution)



from GARFIELD++ | noise and pre-amp from data | (derivative) reconstruction algorithm

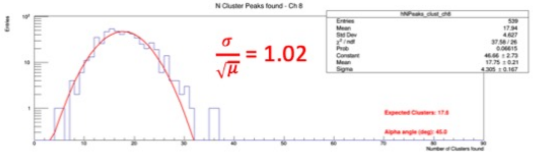
Peak reconstruction efficiency: eff = #reco peaks/ #truth peaks = 82%.
Cluster reconstruction efficiency: eff = #reco cls/ #truth cls = 92.5%,



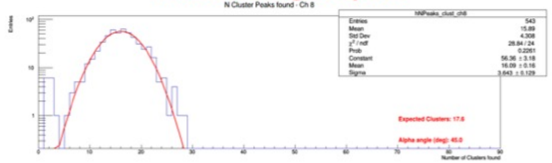


Alternative algorithms

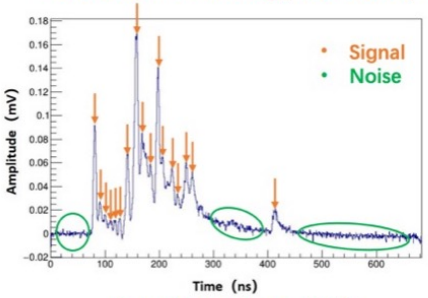
Lecce derivative



Lecce Running Template



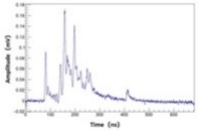
IHEP Machine Learning (RNN + CNN)



From Guang Zhao - IHEP

5th CHALLENGE: data reduction

The excellent performance of the **cluster finding** algorithms in offline analysis, relies on the assumption of being able to transfer the full spectrum of the digitized drift signals.
However …



according to the **IDEA drift chamber operating conditions**:

- 56448 drift cells in 112 layers (~130 hits/track)
- maximum drift time of 500 ns
- cluster density of 20 clusters/cm
- signal digitization 12 bits at 2 Gsa/s

… and to the **FCC-ee running conditions at the Z-pole**

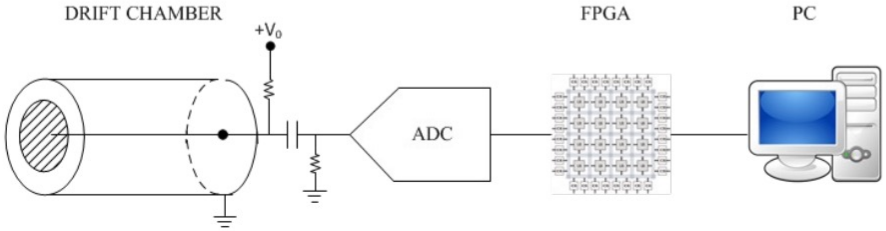
- 100 KHz of Z decays with 20 charged tracks/event multiplicity
- 30 KHz of $\gamma\gamma \longrightarrow$ hadrons with10 charged tracks/event multiplicity
- 2.5% occupancy due to beam noise
- 2.5% occupancy due to hits with isolated peaks

Reading both ends of the wires, ⇨ data rate ≥ 1 TB/s !

Solution consists in transferring, for each hit drift cell, instead of the full signal spectrum, 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.

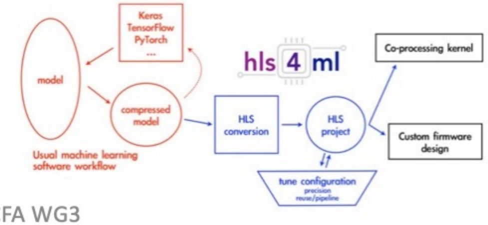
This can be accomplished by using a **FPGA** for the **real time analysis** of the data generated by the drift chamber and successively digitized by an ADC.

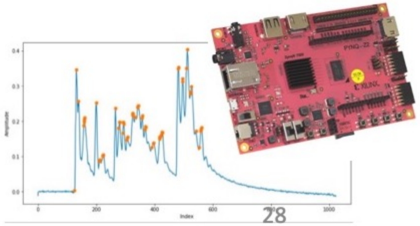


Single channel solution has been successfully verified.
G. Chiarello et al., The Use of FPGA in Drift Chambers for High Energy Physics Experiments May 31, 2017
DOI: 10.5772/66853

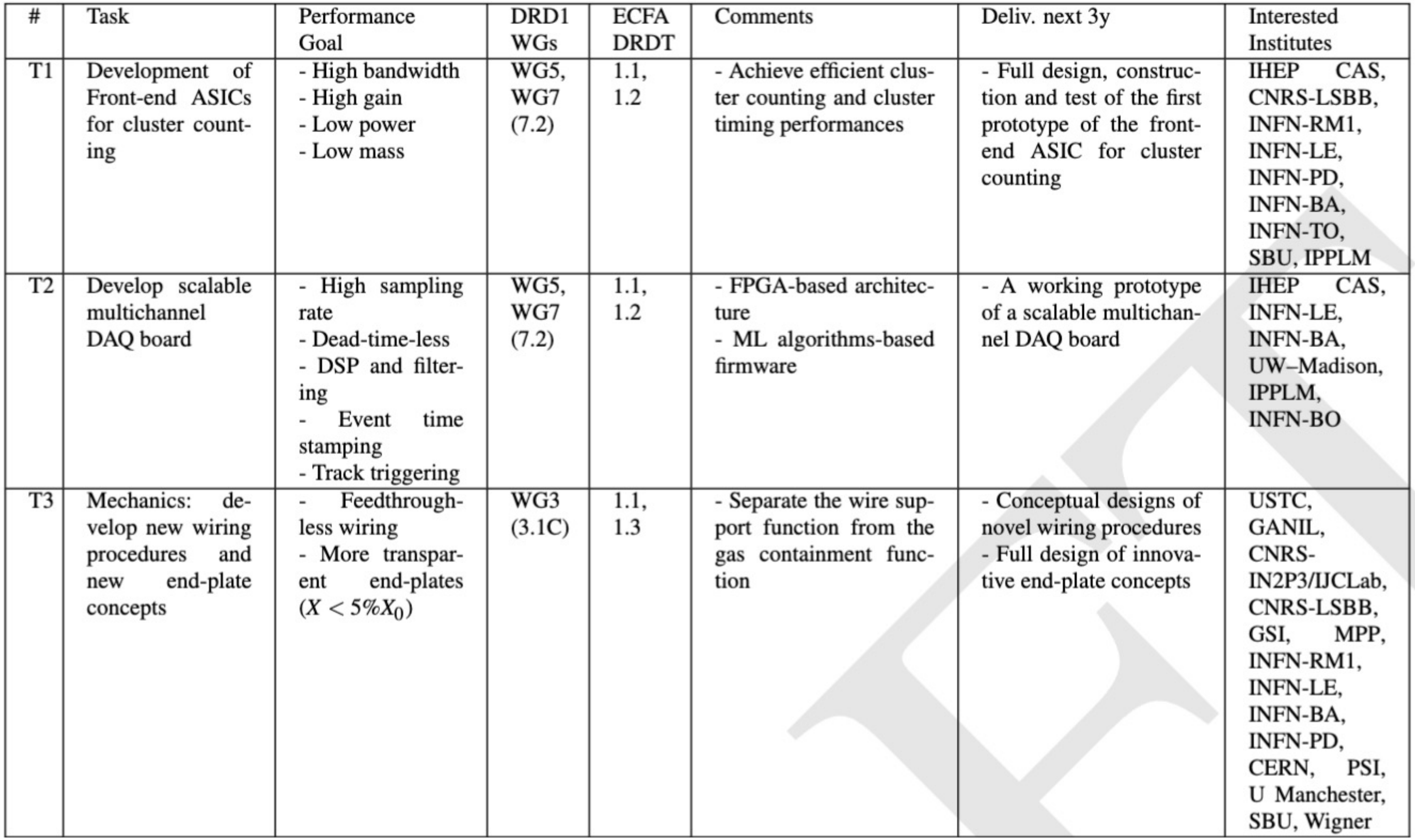
With this procedure **data transfer rate is reduced to ~ 25 GB/s**
Extension to a 4-channel board is in progress. Ultimate goal is a multi-ch. board (128 or 256 channels) to **reduce cost** and complexity of the system and to gain flexibility in determining the **proximity correlations** between hit cells for track **segment finding** and for **triggering** purposes.

Implementing ML algorithms on FPGA for peak finding

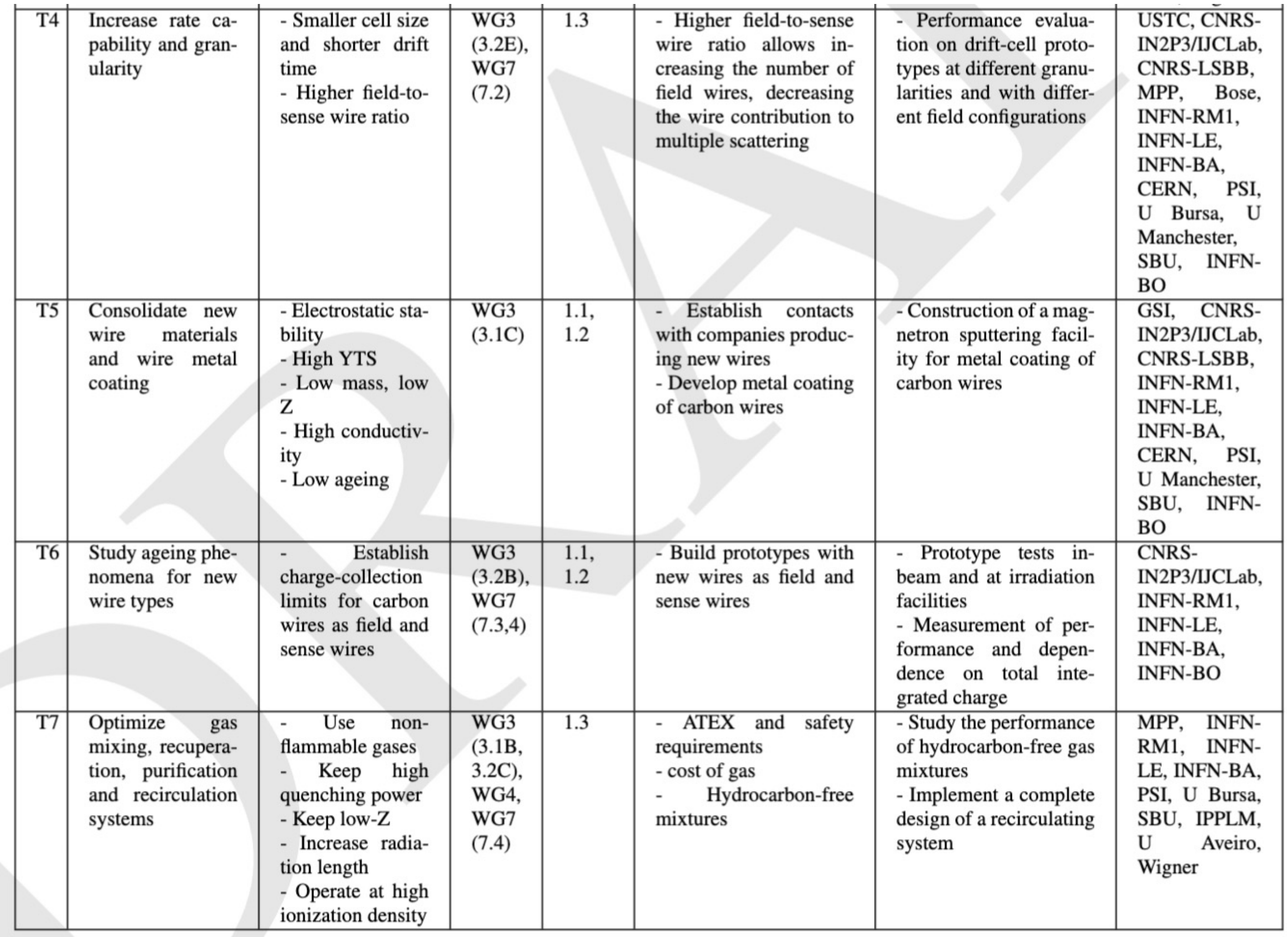




Work Package list



#	Task	Performance Goal	DRD1 WGs	ECFA DRDT	Comments	Deliv. next 3y	Interested Institutes
T1	Development of Front-end ASICs for cluster counting	- High bandwidth - High gain - Low power - Low mass	WG5, WG7 (7.2)	1.1, 1.2	- Achieve efficient cluster counting and cluster timing performances	- Full design, construction and test of the first prototype of the front-end ASIC for cluster counting	IHEP CAS, CNRS-LSBB, INFN-RM1, INFN-LE, INFN-PD, INFN-BA, INFN-TO, SBU, IPPLM
T2	Develop scalable multichannel DAQ board	- High sampling rate - Dead-time-less - DSP and filtering - Event time stamping - Track triggering	WG5, WG7 (7.2)	1.1, 1.2	- FPGA-based architecture - ML algorithms-based firmware	- A working prototype of a scalable multichannel DAQ board	IHEP CAS, INFN-LE, INFN-BA, UW–Madison, IPPLM, INFN-BO
T3	Mechanics: develop new wiring procedures and new end-plate concepts	- Feedthrough-less wiring - More transparent end-plates ($X < 5\% X_0$)	WG3 (3.1C)	1.1, 1.3	- Separate the wire support function from the gas containment function	- Conceptual designs of novel wiring procedures - Full design of innovative end-plate concepts	USTC, GANIL, CNRS-IN2P3/IJCLab, CNRS-LSBB, GSI, MPP, INFN-RM1, INFN-LE, INFN-BA, INFN-PD, CERN, PSI, U Manchester, SBU, Wigner



T4	Increase rate capability and granularity	- Smaller cell size and shorter drift time - Higher field-to-sense wire ratio	WG3 (3.2E), WG7 (7.2)	1.3	- Higher field-to-sense wire ratio allows increasing the number of field wires, decreasing the wire contribution to multiple scattering	- Performance evaluation on drift-cell prototypes at different granularities and with different field configurations	USTC, CNRS-IN2P3/IJCLab, CNRS-LSBB, MPP, Bose, INFN-RM1, INFN-LE, INFN-BA, CERN, PSI, U Bursa, U Manchester, SBU, INFN-BO
T5	Consolidate new wire materials and wire metal coating	- Electrostatic stability - High YTS - Low mass, low Z - High conductivity - Low ageing	WG3 (3.1C)	1.1, 1.2	- Establish contacts with companies producing new wires - Develop metal coating of carbon wires	- Construction of a magnetron sputtering facility for metal coating of carbon wires	GSI, CNRS-IN2P3/IJCLab, CNRS-LSBB, INFN-RM1, INFN-LE, INFN-BA, CERN, PSI, U Manchester, SBU, INFN-BO
T6	Study ageing phenomena for new wire types	- Establish charge-collection limits for carbon wires as field and sense wires	WG3 (3.2B), WG7 (7.3,4)	1.1, 1.2	- Build prototypes with new wires as field and sense wires	- Prototype tests in-beam and at irradiation facilities - Measurement of performance and dependence on total integrated charge	CNRS-IN2P3/IJCLab, INFN-RM1, INFN-LE, INFN-BA, INFN-BO
T7	Optimize gas mixing, recuperation, purification and recirculation systems	- Use non-flammable gases - Keep high quenching power - Keep low-Z - Increase radiation length - Operate at high ionization density	WG3 (3.1B, 3.2C), WG4, WG7 (7.4)	1.3	- ATEX and safety requirements - cost of gas - Hydrocarbon-free mixtures	- Study the performance of hydrocarbon-free gas mixtures - Implement a complete design of a recirculating system	MPP, INFN-RM1, INFN-LE, INFN-BA, PSI, U Bursa, SBU, IPPLM, U Aveiro, Wigner