WP5: An ultra-low mass tracking chamber with particle identification capabilities for SCTF

F. Grancagnolo, INFN Lecce
N. De Filippis, Politecnico/INFN Bari
on behalf of the full team

CREMLINplus Kick-off Workshop
February 19-20, 2020

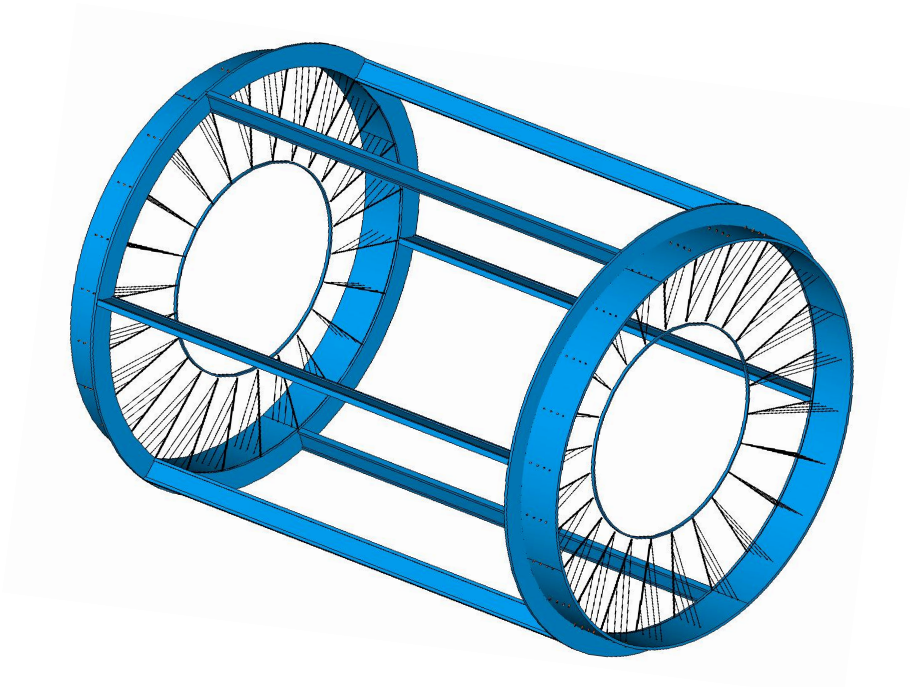
Development of a central tracker for SCTF

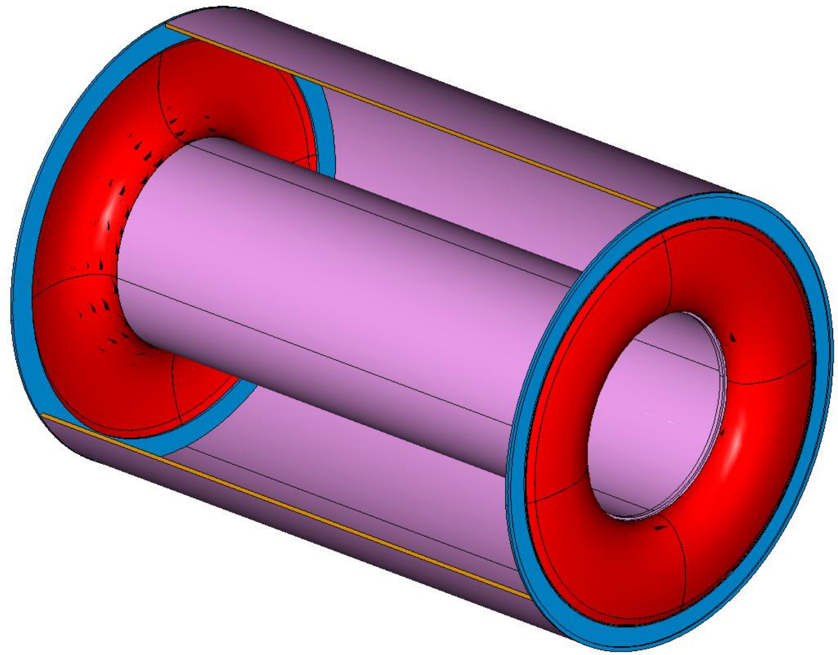
An ultra-low mass Tracking Chamber with Particle Identification capabilities (TraPId) concept (INFN Lecce) based on:

- **Low material**
- **Improved identification with cluster counting**
- **Synergy with MEG2 DC and the IDEA DC project for FCC-ee and CEPC**
- **New drift chamber for the CMD3 experiment as a prototype for the SCT central tracker**

Mechanical design of the prototype (1)

"Wire Cage" and "Gas Envelope"





Wire support:

Wire cage structure not subject to differential pressure can be light and feed-through-less.

Gas containment:

Gas envelope can freely deform without affecting the internal wire position and tension.

Development of new wire material (1)

Electrostatic stability condition $$T > \frac{C^2 V_0^2 L^2}{4\pi\varepsilon w^2}$$

T = wire tension
C = capacitance per unit length
V_0 = anode-cathode voltage
L = wire length, w = cell width

IDEA Drift Chamber: C = 10 pF/m, V_0 = 1500 V, L = 4.0 m, w = 1.0 cm

T > 0.32 N

- **20 µm W sense wire (Y.S. ≈ 1200 MPa): T_{max} = 0.38 N (marginal)**
- **40 µm Al field wire (Y.S. ≈ 300 MPa): T_{max} = 0.38 N (marginal)**

=> shorten chamber (loss of acceptance)
=> widen cell size (increase occupancy)
=> increase wire diameter (increase multiple scattering and endplate load)

or,

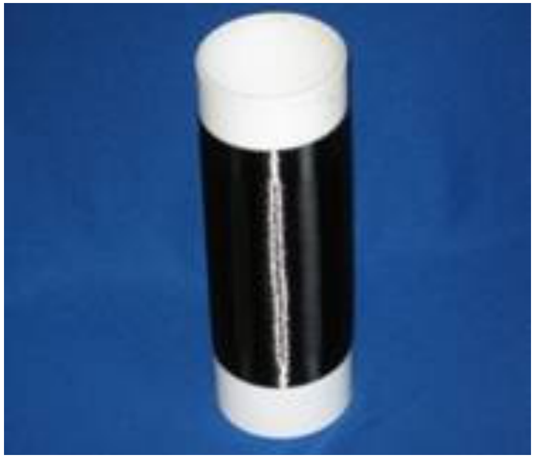
replace 40 µm Al with 35 µm Carbon monofilament
(Y.S. > 860 MPa): T_{max} > 0.83 N

New wire material (2): carbon monofilaments

SPECIALTY MATERIALS, INC.

Manufacturers of Boron and SCS Silicon Carbide Fibers and Boron Nanopowder

CARBON MONOFILAMENT



TYPICAL PROPERTIES

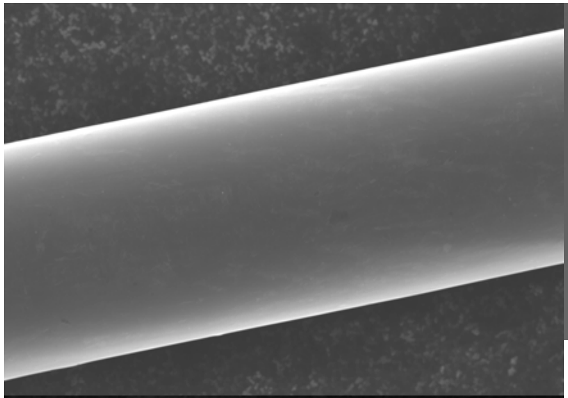
Diameter:	0.00136 +/- 0.0001" (34.5 +/- 2.5 µm)
Tensile Strength:	125 ksi (0.86 GPa)
Tensile Modulus:	6 msi (41.5 GPa)
Electrical Resistivity:	3.6 x 10^{-3} ohm cm
Density:	1.8 g/cc

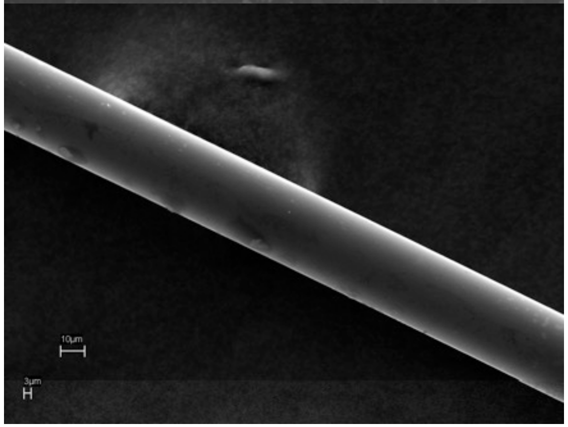
Specialty Materials, Inc.
1449 Middlesex Street
Lowell, Massachusetts 01851

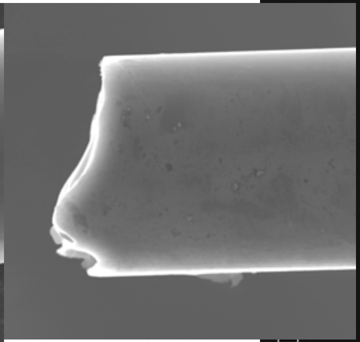
Phone: 978-322-1900
Fax: 978-322-1970

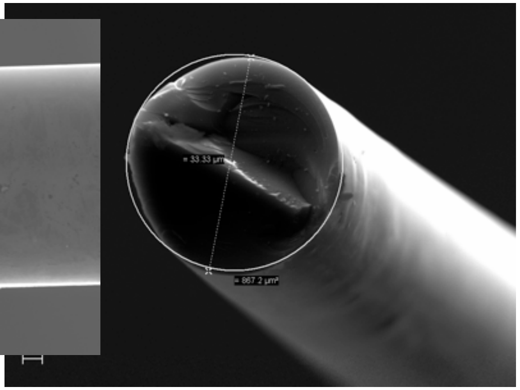
CARBON MONOFILAMENT PRODUCT PRICE LIST
Effective October 1, 2017

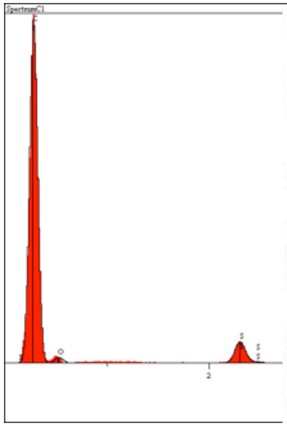
Product	Quantity	Price LF
CARBON MONOFILAMENT	1 Million LF	$0.02
	500,000 LF	$0.03
	1,000 LF	$0.93











Component	Type	Mole Conc.	Conc.		
O	Calc	5.592	7.248	wt.%	
C	Calc	93.865	91.340	wt.%	
S	Calc	0.543	1.412	wt.%	
		100.000	100.000	wt.%	Total

Elt.	Line	Atomic %	Conc		
C	Ka	93.865	91.340	wt.%	
O	Ka	5.592	7.248	wt.%	
S	Ka	0.543	1.412	wt.%	
		100.000	100.000	wt.%	Total

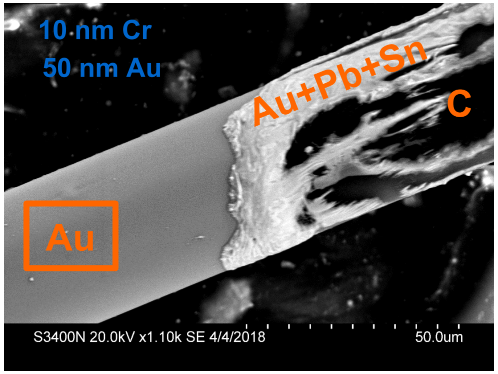
kV	20.0
Takeoff Angle	35.0°
Esc	On
Sum Peak	On

New wire material (3): C wire metal coating

HiPIMS: High-power impulse magnetron sputtering

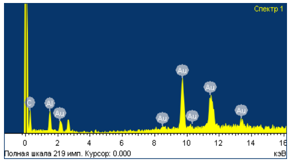
physical vapor deposition (PVD) of thin films based on magnetron sputter deposition (extremely high power densities of the order of kW/cm^2 in short pulses of tens of microseconds at low duty cycle <10%)

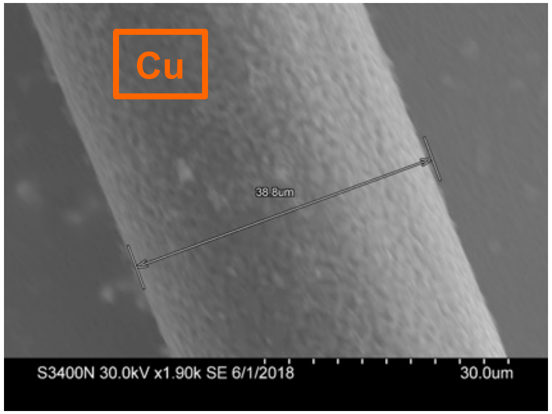
BINP
A. Popov
V. Logashenko



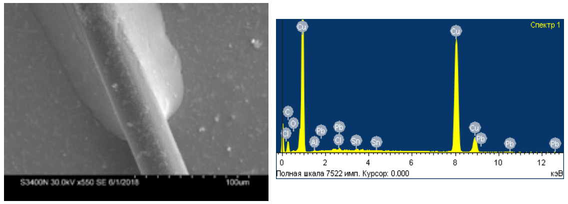
soldering attempt

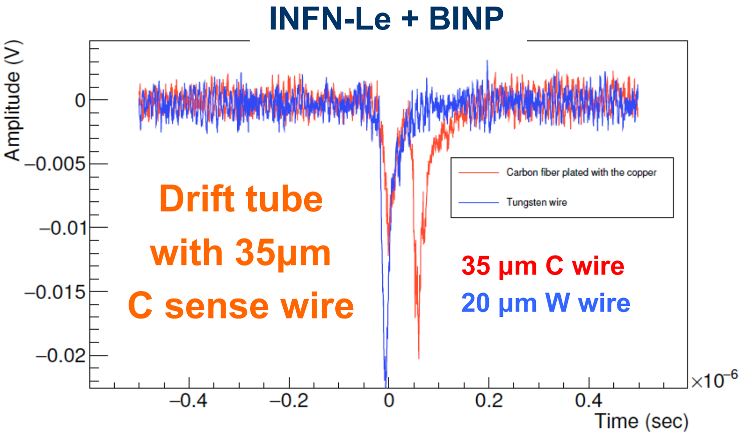
Lead forms intermetallic compound with gold and completely dissolves the 50 nm Au layer.

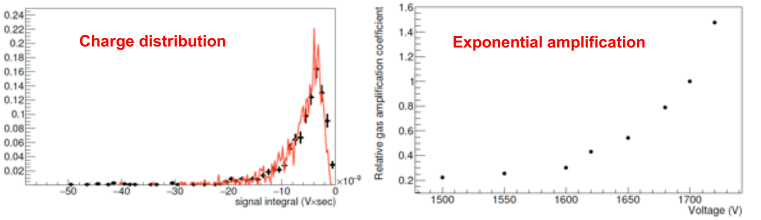




good solder wettability on Cu



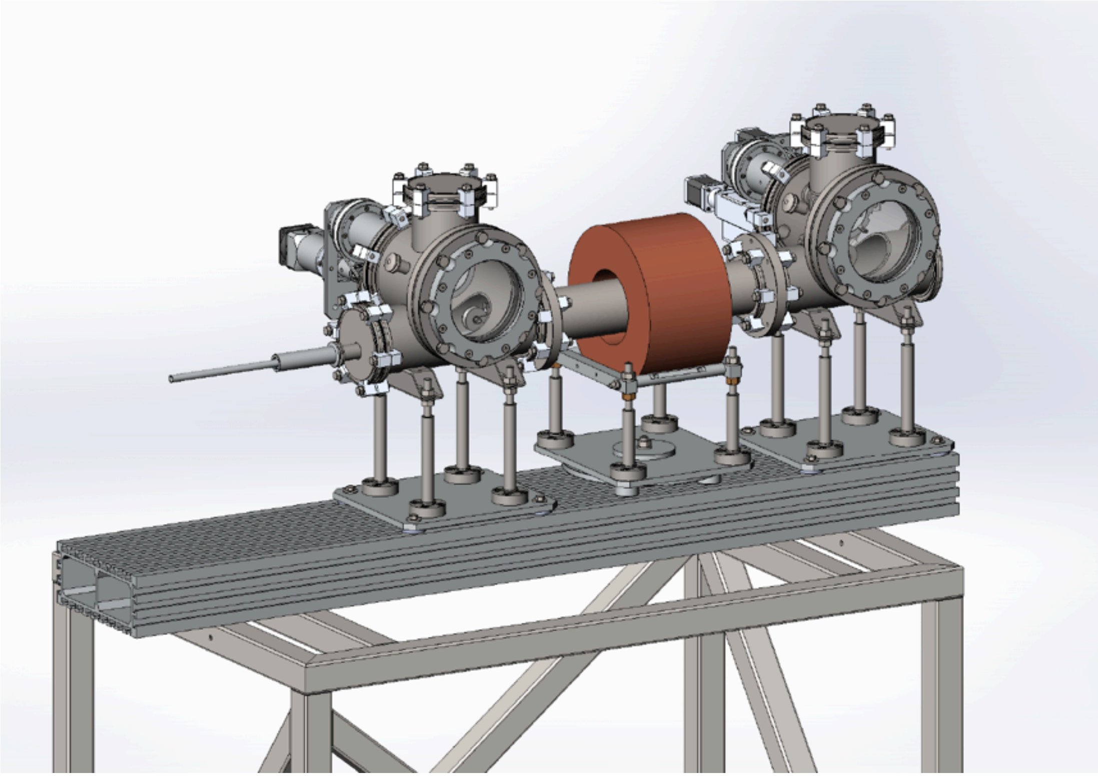


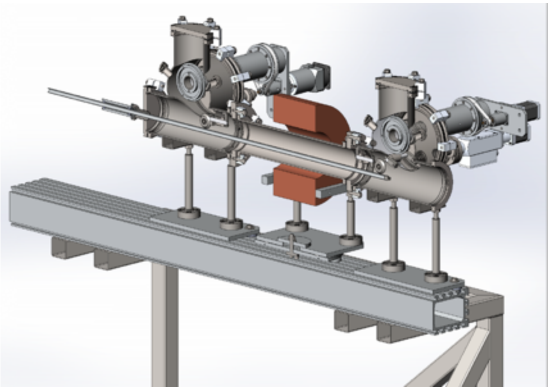


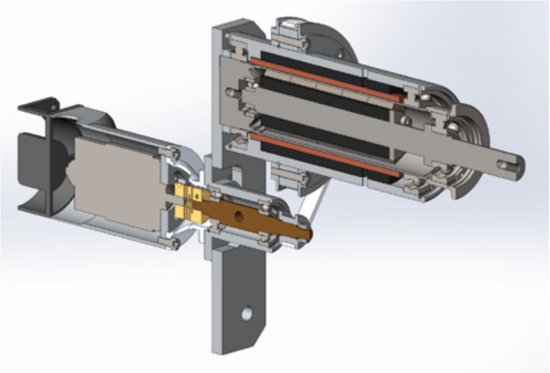
- Cu coating test of 35 μm carbon monofilament very successful on short samples with HiPIMS at BINP, Novosibirsk
- Investigation of magnetron sputtering facilities elsewhere (INFN LNL?)
- Industrialization of process for coating continuous spooled monofilament under study

New wire material (4): C wire metal coating (BINP)

BINP
A. Popov
V. Logashenko







C wire soldering without metal coating (1)

Soldering of Carbon Materials Using Transition Metal Rich Alloys

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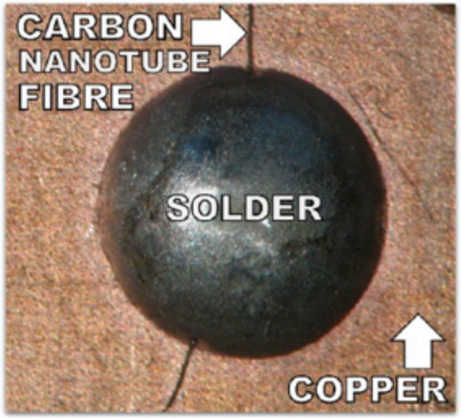
Marek Burda,[*,†] Agnieszka Lekawa-Raus,[†] Andrzej Gruszczyk,[‡] and Krzysztof K. K. Koziol[*,†]

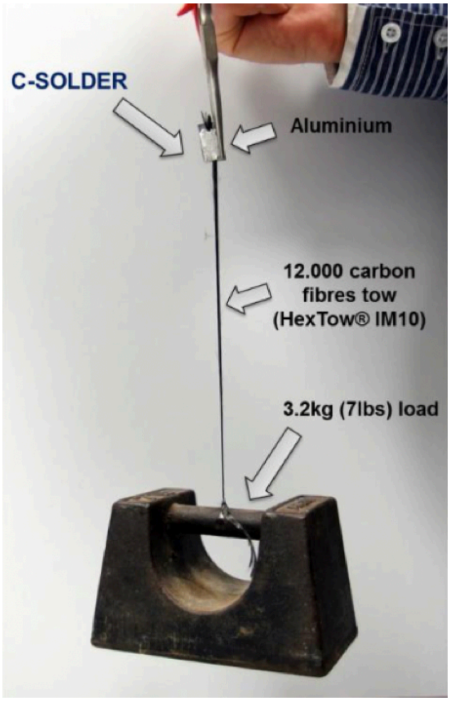
[†]Department of Materials Science and Metallurgy, University of Cambridge, 27 Charles Babbage Road, CB3 0FS, Cambridge, U.K. and [‡]Welding Department, Silesian University of Technology, Konarskiego 18a, 44-100 Gliwice, Poland

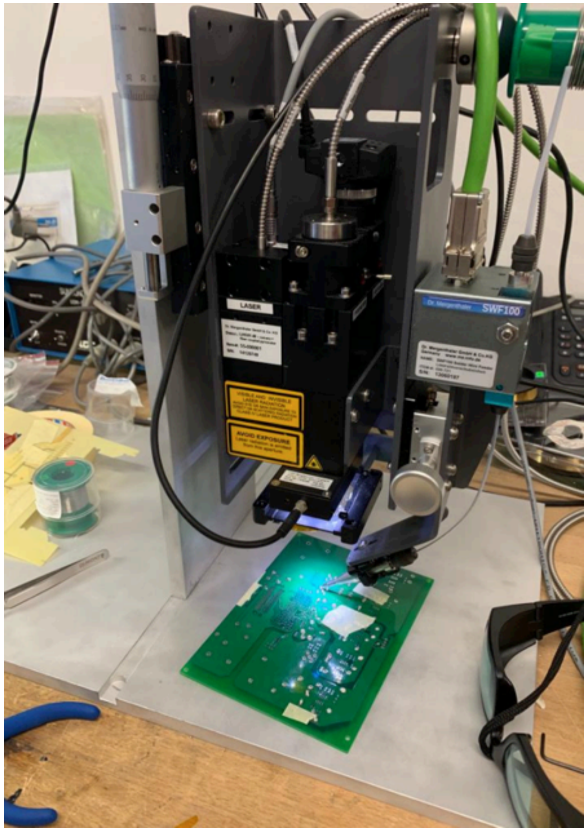
ABSTRACT Joining of carbon materials *via* soldering has not been possible up to now due to lack of wetting of carbons by metals at standard soldering temperatures. This issue has been a severely restricting factor for many potential electrical/electronic and mechanical applications of nanostructured and conventional carbon materials. Here we demonstrate the formation of alloys that enable soldering of these structures. By addition of several percent (2.5–5%) of transition metal such as chromium or nickel to a standard lead-free soldering tin based alloy we obtained a solder that can be applied using a commercial soldering iron at typical soldering temperatures of approximately 350 °C and at ambient conditions. The use of this solder enables the formation of mechanically strong and electrically conductive joints between carbon materials and, when supported by a simple two-step technique, can successfully bond carbon structures to any metal terminal. It has been shown using optical and scanning electron microscope images as well as X-ray diffraction patterns and energy dispersive X-ray mapping that the successful formation of carbon–solder bonds is possible, first, thanks to the uniform nonreactive dispersion of transition metals in the tin-based matrix. Further, during the soldering process, these free elements diffuse into the carbon–alloy border with no formation of brazing-like carbides, which would damage the surface of the carbon materials.



C wire soldering <u>without</u> metal coating (2)

- We verified successfully the possibility of soldering manually the C wire on copper with the C-solder
- We are testing the usage of a infrared-laser soldering system already available in Lecce in order to guarantee uniformity and reproducibility.





TraPId: A proposal for SCTF

$R_{in} - R_{out}$ [mm]		200 – 800
active L – service area [mm]		1800 – 200
inner cylindrical wall		
C-fiber/C-foam sandwich	2×80 μm / 5 mm	0.036 g/cm^2 – 8×10^{-4} X/X_0
outer cylindrical wall		
C-fiber/C-foam sandwich	2×5 mm / 10 mm	0.512 g/cm^2 – 1.2×10^{-2} X/X_0
end plate		
gas envelope	160 μm C-fiber	0.021 g/cm^2 – 6×10^{-4} X/X_0
instrumented wire cage	wire PCB, spacers, HV distr. and cables, limiting R, decoupling C and signal cables	0.833 g/cm^2 – 3.0×10^{-2} X/X_0

cell	
shape	square
size [mm]	7.265 – 9.135
layer	
8 super-layers	8 layer each
64 layer total	
stereo angles	66 – 220 mrad
n. sense wires [20μm W]	23,040
n. field wires [40/50μm Al]	116,640
n. total (incl. guard)	141,120
gas + wires [600 mm]	
90%He – 10%iC_4H_{10}	4.6×10^{-4}
W + 5 Al ➔ Ti + 5 C	(13.1 ➔ **2.5**)$\times10^{-4}$

TraPId: Tracking performance

Expected Performance: **Track parameters resolutions**

n = 64, B = 1.5 T, R_{out} = 0.8 m, L = 2.0 m, $(0.8+1.8)\times10^{-3}$ X/X_0, σ_{xy} = 100 μm, σ_z = 0.8 mm

measurement	multiple scattering (gas + wires + inner wall)

$$\frac{\Delta p_\perp}{p_\perp} = 2.0\times10^{-3},\ \Delta\phi = 0.70\ mrad, \Delta\theta = 0.78\ mrad$$

$$\text{at } p = 1\ GeV/c$$

$$\frac{\Delta p_\perp}{p_\perp} = 7.8\times10^{-4}\, p_\perp \oplus 1.8\times10^{-3}$$

(7.8 → 6.6 with cluster timing)

$$\Delta\phi = 1.1\times10^{-4} \oplus \frac{6.9\times10^{-4}}{p}$$

$$\Delta\theta = 3.8\times10^{-4} \oplus \frac{6.9\times10^{-4}}{p}$$

TraPId: Pid performance

$$\frac{\sigma_{dE/dx}}{(dE/dx)} = 0.41 \cdot n^{-0.43} \cdot \left(L_{track}[m] \cdot P[atm]\right)^{-0.32}$$

from *Walenta parameterization (1980)*

$L_{track} = 0.6\ m$
$P = 1\ atm$
$n = 64$

$$\frac{\sigma_{dE/dx}}{(dE/dx)} = 8.1\%$$

6.9% for $L_{track} = 1\ m$

$$\frac{\sigma_{dN_{cl}/dx}}{(dN_{cl}/dx)} = \left(\delta_{cl} \cdot L_{track}\right)^{-1/2}$$

from *Poisson distribution*

$L_{track} = 0.6\ m$
$\delta_{cl} = 12.5/cm$

$$\frac{\sigma_{dN_{cl}/dx}}{(dN_{cl}/dx)} = 3.6\%$$

2.8% for $L_{track} = 1\ m$

Summary of performance

	$\frac{\Delta p_t}{p_t} \times 10^3$	at $p_t = 1 GeV$	$\frac{dE}{dx} \Big/ \frac{dN}{dx}$	
KLOE	$0.5 p_t \oplus 2.6$	2.6×10^{-3}	5%	**still best world performance**
BaBar	$1.3 p_t \oplus 4.5$	4.7×10^{-3}	7.5%	
Belle	$2.8 p_t \oplus 3.5$	4.5×10^{-3}	6.9%	
BelleII	$1.9 p_t \oplus 2.9$	3.5×10^{-3}	6.4%	
BESIII	$2.7 p_t \oplus 4.7$	5.1×10^{-3}	$6 - 7\%$	
Cleo3	$1.0 p_t \oplus 9.0$	9.1×10^{-3}	5%	
SCTF (Todyshev)	$2.6 p_t \oplus 5.1$	5.7×10^{-3}	7%	
TraPId (this proposal)	$0.78 p_t \oplus 1.8$	2.0×10^{-3}	$8.1 / 3.6\%$	
TraPId (this proposal)	$0.66 p_t \oplus 1.4$	1.6×10^{-3}	$6.9 / 2.8\%$	**C wires + cluster timing** **1 m track length**

Conclusions

I. **An ultra-low mass drift chamber for SCTF** with a material budget **$<1.5\times10^{-2}$ X/X_0** in the radial direction and **$<5\times10^{-2}$ X/X_0** in the forward and backward directions (including HV and FEE services) **can be built** with the novel technique adopted for the successful construction of the MEG2 drift chamber

II. **$\Delta p_t/p_t = 2.0\times10^{-3}$, $\Delta\theta = 0.70$ mrad, $\Delta\phi = 0.78$ mrad at $p = 1$ GeV/c**.

III. Particle identification at the level of **3.6%** with **cluster counting** allowing for **π/K separation ≥ 3σ** over a wide range of momenta.

IV. Further gain in momentum and angular resolutions and in particle identification, will be obtained by
   - applying **cluster timing** techniques,
   - exploiting the possibilities of large scale implementation of **C wires**
   - **operating the chamber at lower than atmospheric pressures**, with moderate degradation of particle identification performance

Backup

C wire soldering without metal coating (2)

Up to now it has not been possible to apply soldering to graphitic materials as they are not wetted by the commercially available alloys.

C-SOLDER is a trade name for a group of new tin-based lead-free low-temperature soldering alloys which enable joining of various carbon materials including carbon fibres or carbon nanotube fibres in both carbon-carbon and carbon-metal arrangements.

The use of these alloys allows fast formation of mechanically strong bonds which are electrically conductive simultaneously.

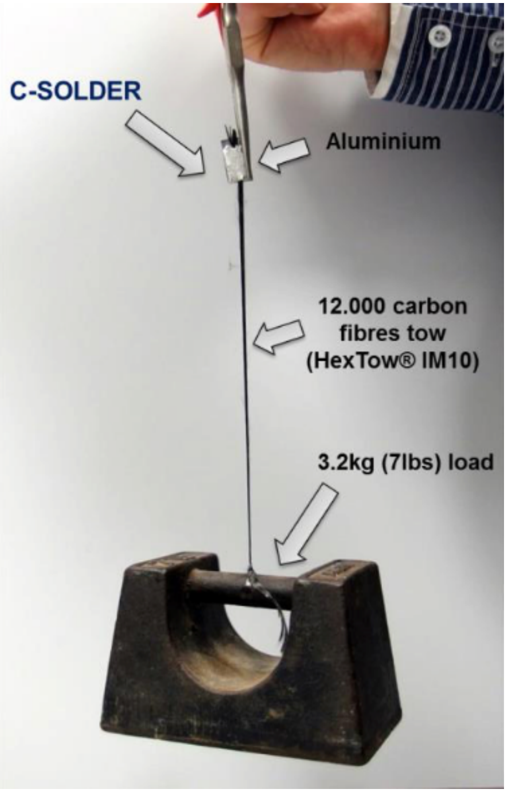
C-SOLDER Type: SAC-1B:

- Excellent wetting of carbon materials: graphite, carbon fibres, carbon nanotube fibres, graphene, etc.
- Suitability for bonding in carbon-carbon and carbon-metal systems.
- Soldering temperatures below 450°C.
- Good mechanical and electrical properties.
- Lead free.
- Flux free.

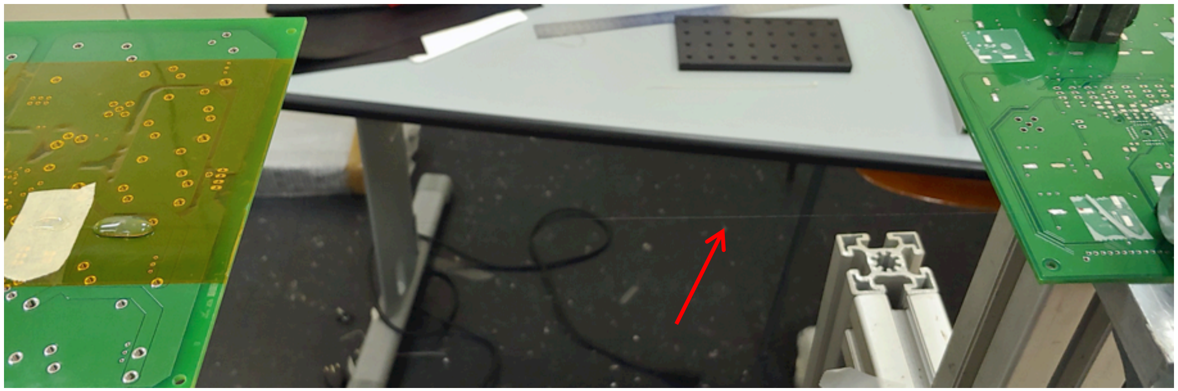
Cametics CAMBRIDGE ADVANCED METALS LTD.

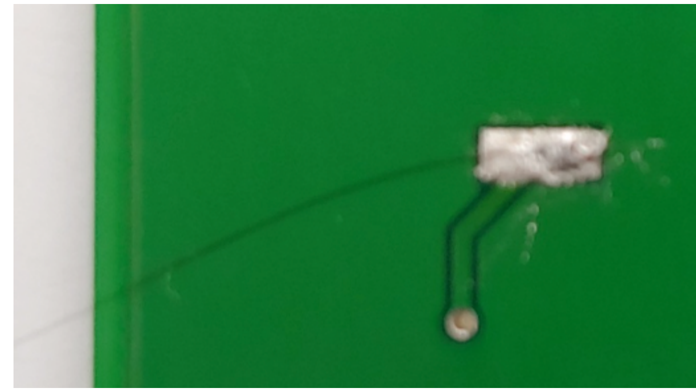
C-SOLDER

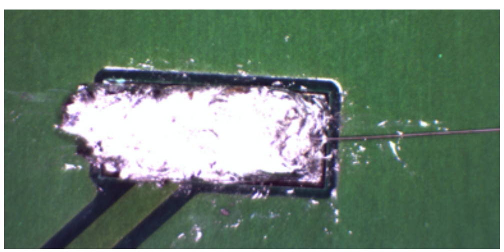
TYPE: SAC-1B

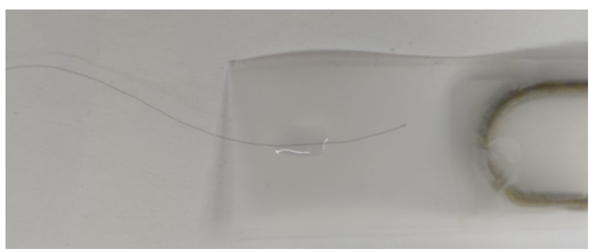


C wire without metal coating: hand soldering

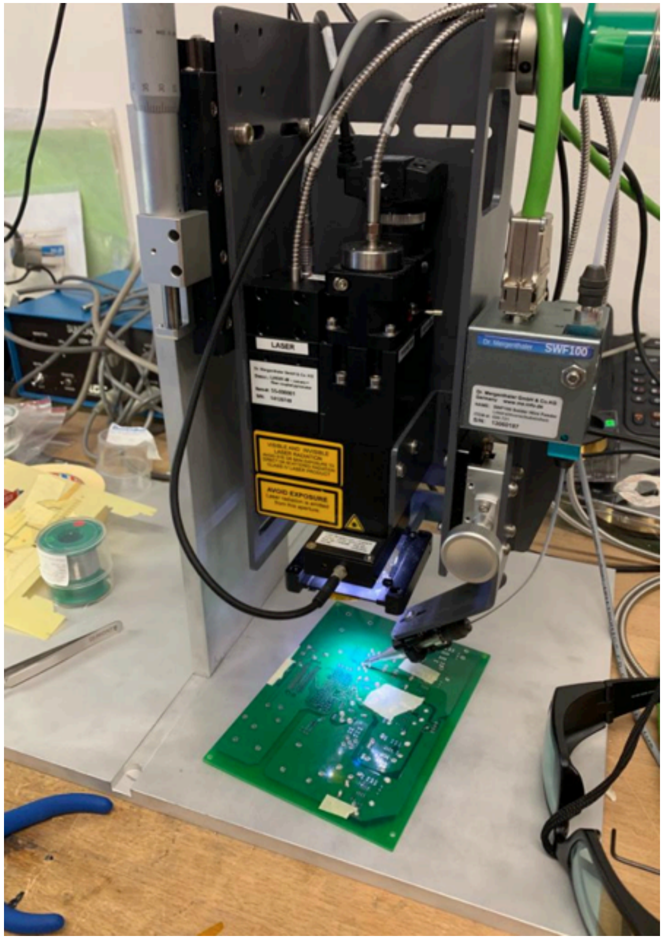








C wire without metal coating (3): laser soldering



The Infrared laser system

of the MEG2 wiring robot

makes use of 0.5 mm

soldering wire

Cametics
CAMBRIDGE ADVANCED METALS LTD.

For 3Kg we will make 0.5 mm. We can also give it a try to go below 0.5 mm with no extra fee.

2-3 Kg at the cost ~ £1500/500g (4 times cheaper as compared to £122.00/10g offered by Goodfellow).