CREMLIN PLUS
Connecting Russian and European Measures for Large-scale Research Infrastructures

INFN
Istituto Nazionale di Fisica Nucleare

CREMLINplus WP5 General Meeting:
Task 5.5-Drift Chamber Prototyping

F. Grancagnolo

for the INFN (Bari and Lecce) and BINP groups

8-9 July 2021

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 871072

A reminder …

Task 5.5: Development and design of Central Tracker for the SCT detector (BINP, INFN).

TraPId (Tracking and Particle Identification), **the Central Tracker proposed by the Bari and Lecce INFN groups for the detector at SCT is an ultra-light drift chamber equipped with cluster counting/timing readout techniques**. **The TraPId R&D program spans over three different topics**.

1. **Mechanical design of the drift chamber end plates with a novel tension recovery scheme to minimize the amount of material in front of the end-plate crystal calorimeter.**
2. **Development of a new type of field wires based on carbon monofilaments coated with a thin metal sheet to allow for ease of soldering.**
3. **Development of a fast digitizer coupled to a FPGA for fast filtering and pre-analysis of the signal spectra, aiming at strongly reducing the amount of data transfer.**

Deliverables

D5.3 **M24 (Feb. 2022)**. **Status report on R&D work on Central Tracker for the SCT detector**. This report is supposed to describe joint EU – Russia activities around central tracker of the SCT detector

D5.8 **M44 (Oct. 2023)**. **Final report on R&D work on Central Tracker for the SCT detector**. This report is supposed to describe the advanced stage of activities of SCT collaboration related to central tracker of the SCT detector, including the construction and test of prototype.

Mile no.	Milestone name	Related Work package(s)	Due date[1]	Means of verification[2]
5	Construction and test of the drift chamber prototype for SCT detector	5	42	Conference contribution

CMD-3 new drift chamber

Sub-task 1:

Mechanical design of the drift chamber end plates with a novel tension recovery scheme to minimize the amount of material in front of the end-plate crystal calorimeter.

- The **general layout** of **TraPId**, the SCTF drift chamber, has been completed. *slide*
- The **general layout** of its prototype, the CMD-3 drift chamber, has been completed. *slide*
- The **conceptual mechanical design** of the CMD-3 drift chamber has been completed, including the novel wire tension recovery scheme. *slide*
- The detailed **FEA** of the mechanical design has just started (long delayed because of the pandemic) with the collaboration of the Computational Mechanics group of the Bari Politecnico (new entry).
- As soon as we have the results from the FEA, we intend to build a **three sectors mock-up** of the mechanics to validate the computed stress-strain relations and the tension recovery scheme.

The INFN team

INFN Bari

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G. Tassielli
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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/cm² – 8×10⁻⁴ X/X_0
outer cylindrical wall		
C-fiber/C-foam sandwich	2×5 mm / 10 mm	0.512 g/cm² – 1.2×10⁻² X/X_0
end plate		
gas envelope	160 μm C-fiber	0.021 g/cm² – 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/cm² – 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 → Mo + 5 C	(13.1 → 2.7)×10⁻⁴

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

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

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

(7.8 → 6.6 with cluster timing)

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

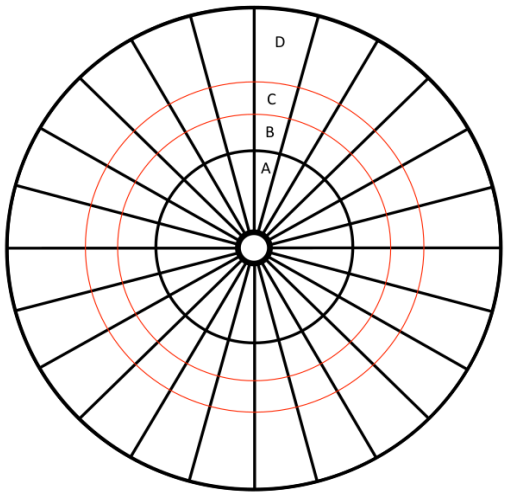
$$\Delta\theta = 3.8\times10^{-4} \oplus \frac{6.9\times10^{-4}}{p}$$

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

at $p = 1\ GeV/c$

CMD3 drift chamber layout

24 sectors:	2304 sense wires	20 µm sense wires
A: 12 cells/sector axial	28 layers radially	40-50-90 µm field wires
B: 4x4 cells/sector +/- stereo	16,000 total wires	50-120 µm guard wires
C: 5x4 cells/sector +/- stereo	85-200 mrad stereo	430 Kg total wire load
D: 6x8 cells/sector +/- stereo		18 Kg per sector



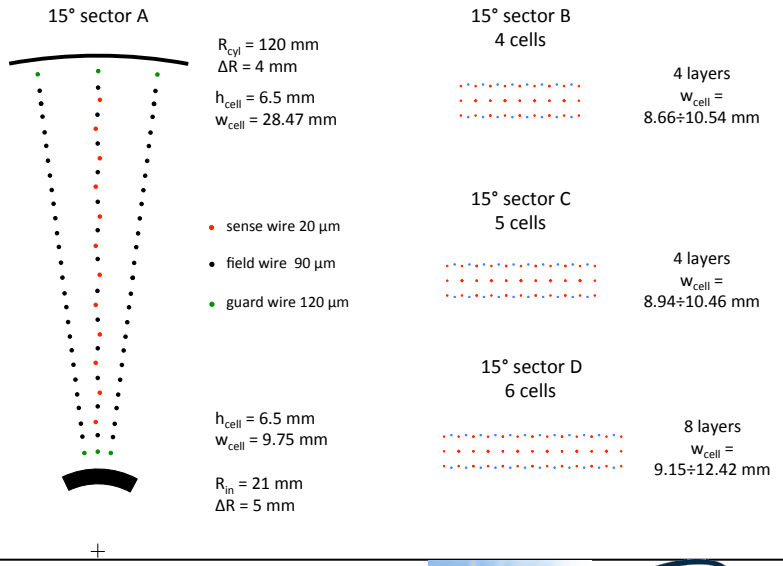
SPIDER WEB STRUCTURE

A:
jet cell axial-layer
12 sense per cell
1 cell per sector

B:
4 single wire cell
±stereo-layers
4 cells per sector

C:
4 single wire cell
±stereo-layers
5 cells per sector

D:
8 single wire cell
±stereo-layers
6 cells per sector



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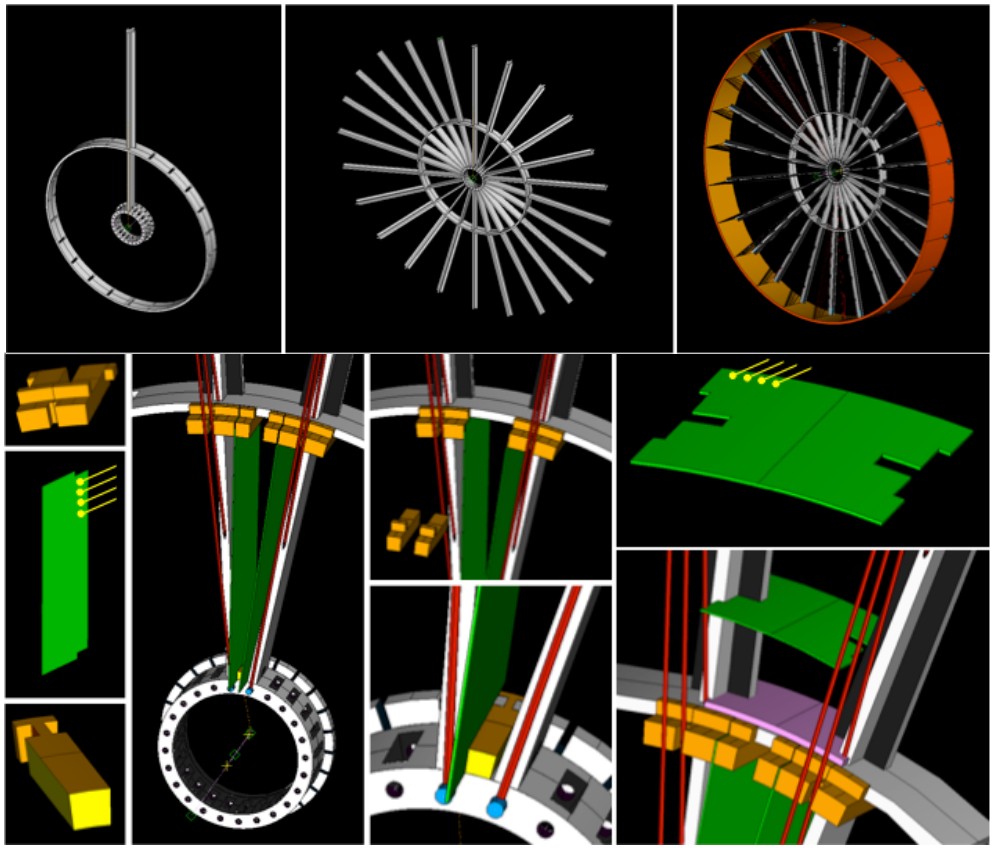
CMD3 drift chamber mechanical design



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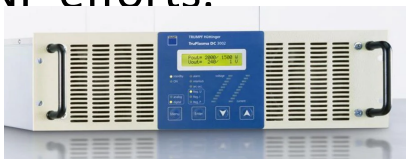
Sub-task 2:

Development of a new type of field wires based on carbon monofilaments coated with a thin metal sheet.

- Magnetron test have continued, despite the pandemic restrictions, which have impeded however a direct participation of INFN to the BINP efforts.
- INFN has acquired a TRUMPF Hüttinger TruPlasma DC 3002 air-cooled power supply to be shipped to BINP.

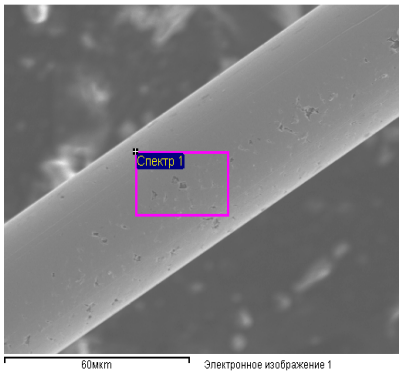


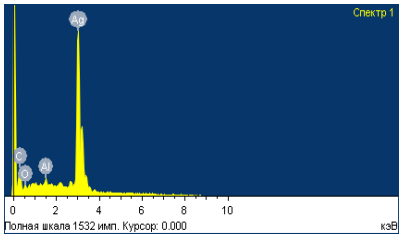
- More spools of carbon monofilament and of 40 and 50 µm bare (not coated) aluminum wires to optimize coating procedures will soon be shipped to BINP.
- Silver coated 40 µm wires have been successfully gold coated without affecting the wire mechanical properties. *slides*
- A stable coating process with Nickel has been reached for long pieces (3 m) of carbon monofilament. *slide*

40 micron silver aluminum wire from CFW

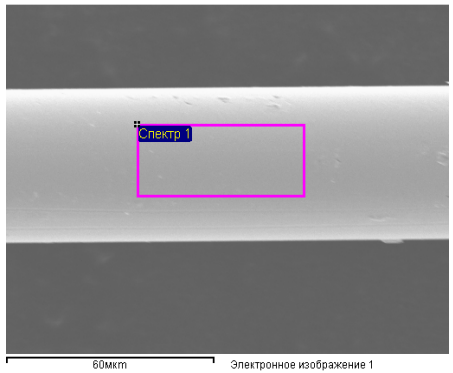
from A. Popov, BINP

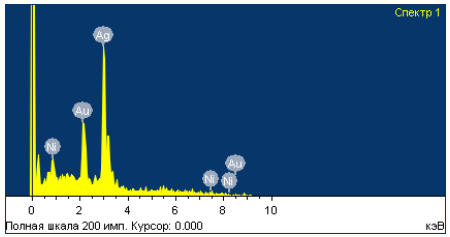
Before (Ag plated)



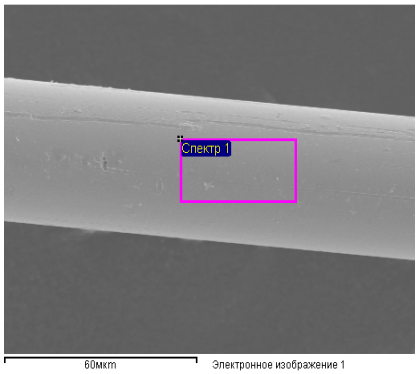


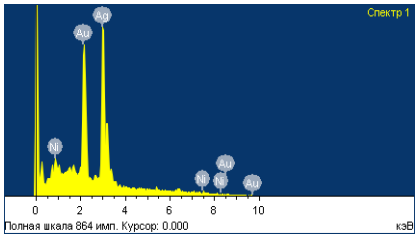
10-15 nm of gold



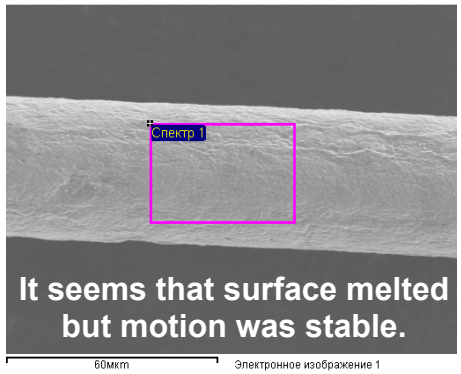


20-30 nm of gold

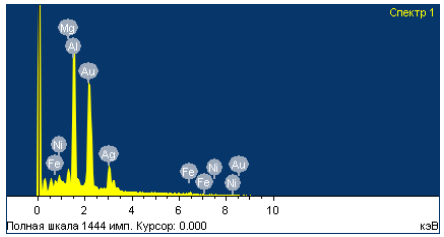




50-60 nm of gold



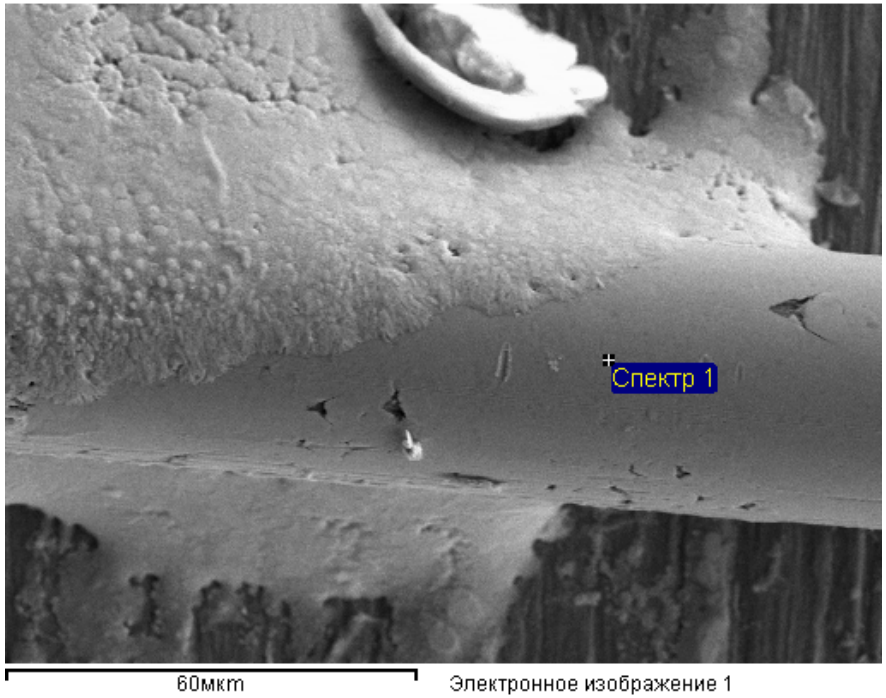
It seems that surface melted but motion was stable.



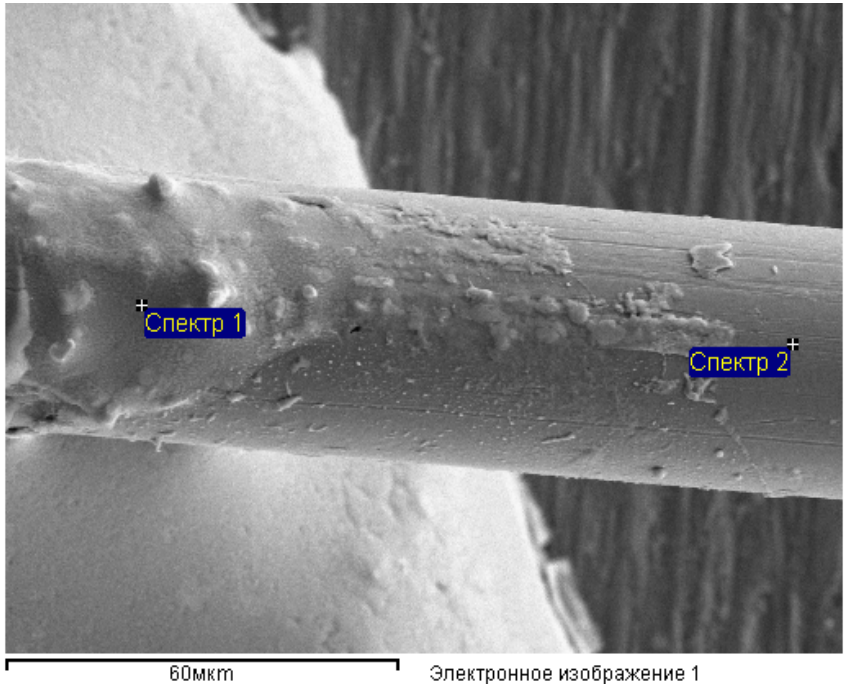
Soldering tests

from A. Popov, BINP

10-15 nm of gold

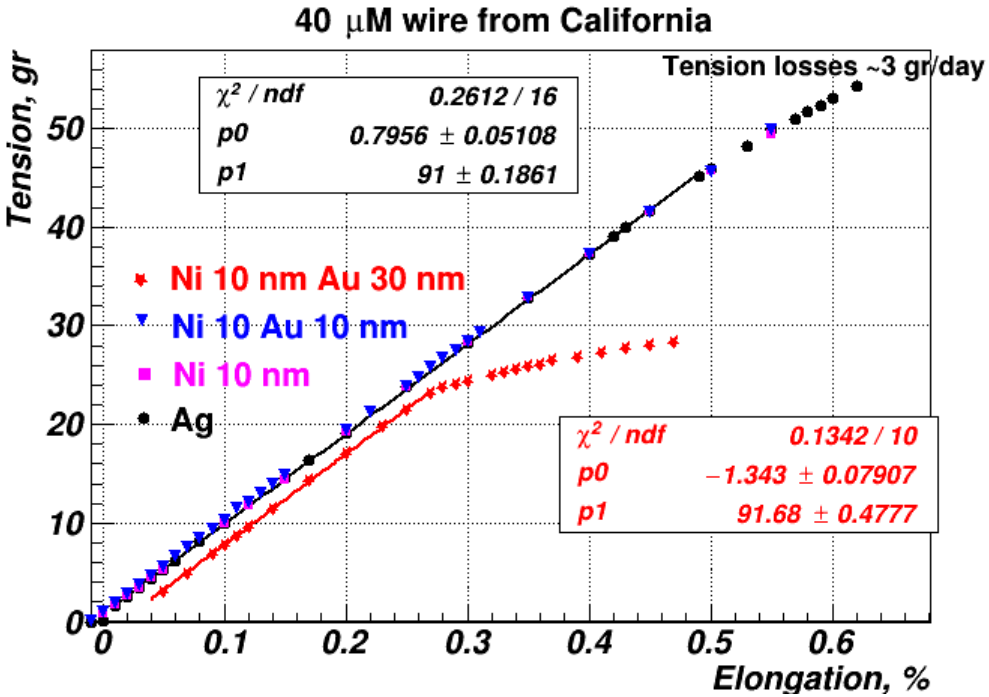


20-30 nm of gold



It looks like that 10 nm of gold is sufficient for soldering

Mechanical tests

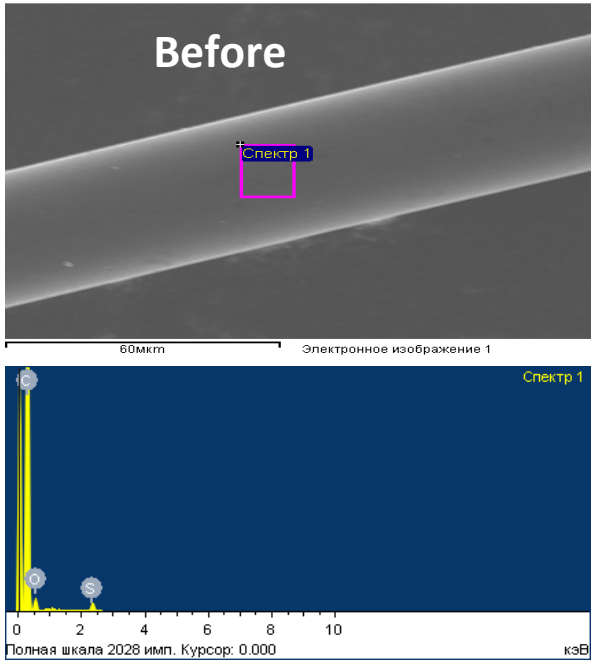


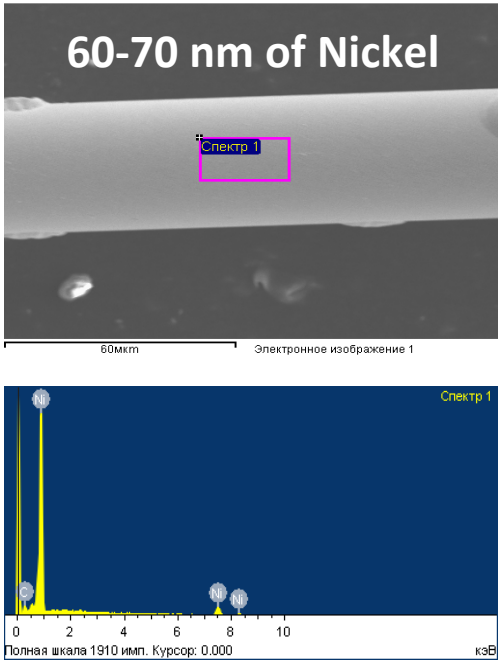
The mechanical properties do not change significantly for a thickness of 10 nm.

Test 40-um Carbon fiber coating by Nickel

from A. Popov, BINP

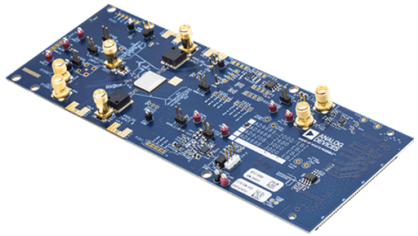
1. Stable coating process with 0.3 m/min of speed gas been reached.
2. Measured linear resistivity: 100 Om/cm.
3. Copper cathode process under same conditions would give 10 Om/cm.





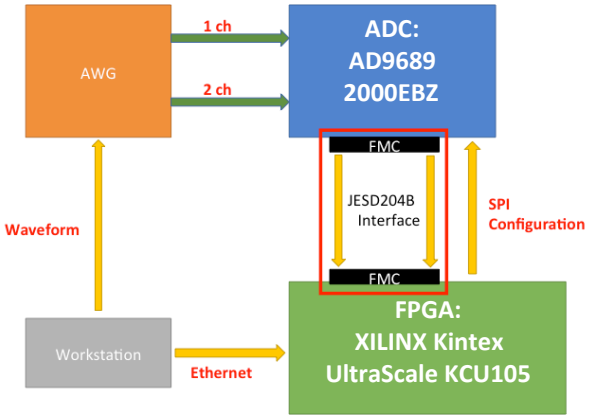
Sub-task 3:

Development of a fast digitizer coupled to a FPGA for fast filter, pre-analysis of the signal spectra and reduction of the amount of data transfer.



Dual channel ADC: AD9689 - 2000EBZ

FPGA: Xilinx Kintex UltraScale KCU105

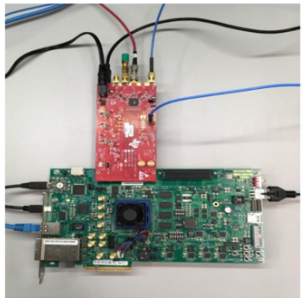


New hardware under test for a new **2ch board**

Dual channel ADC: AD9689 - 2000EBZ
FPGA: Xilinx Kintex UltraScale KCU105

Considering also

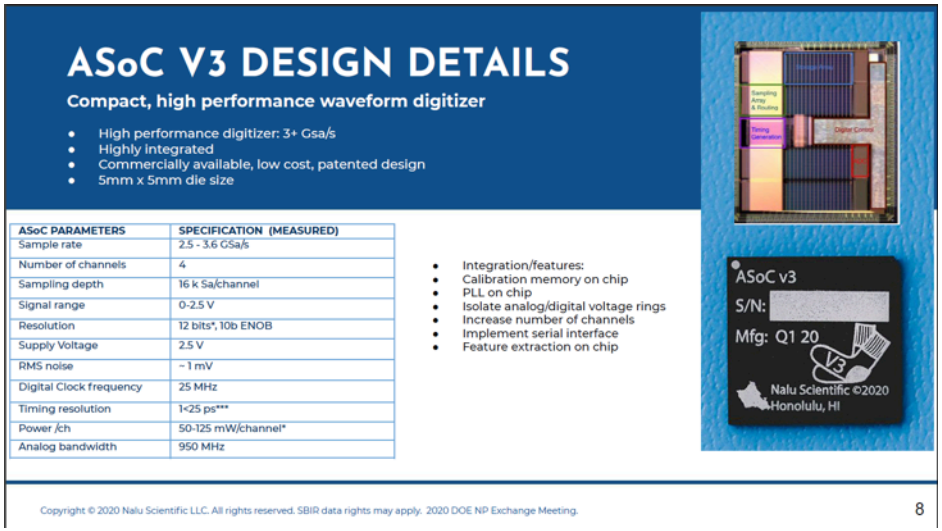
Dual-Channel ADC: ADC32RF45, 14-Bit, 3GSPS from TEXAS INSTRUMENT directly compatible with **KCU105**, offering better performance in terms of
- noise,
- ENOB,
- channels isolation

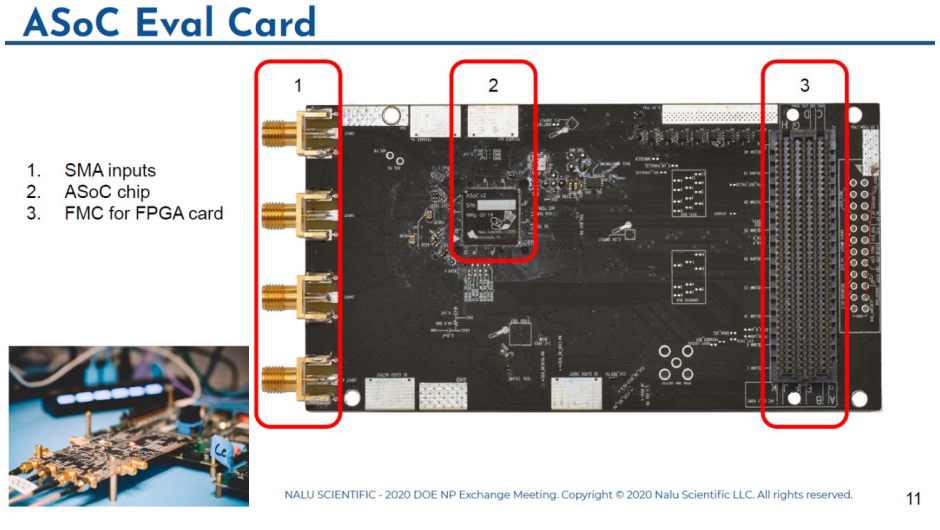


ASOC alternative

Nalu Scientific (the SiRead Chip manufacturers) is testing a new digitizer (**ASoC**) with better performance (4-channel) than SiRead and complying with our requests.

After contacts with the Nalu Scientific, we have been promised a demo board at the conclusions of their quality tests (this summer).





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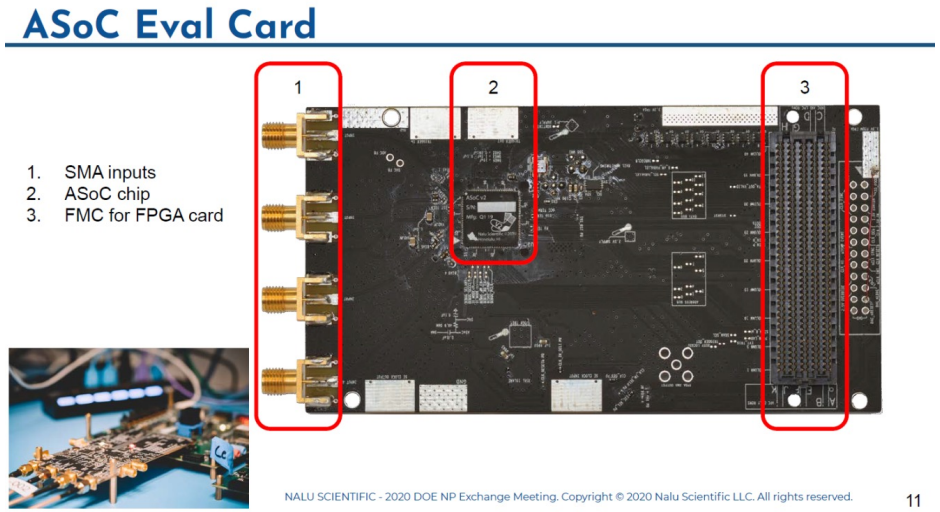
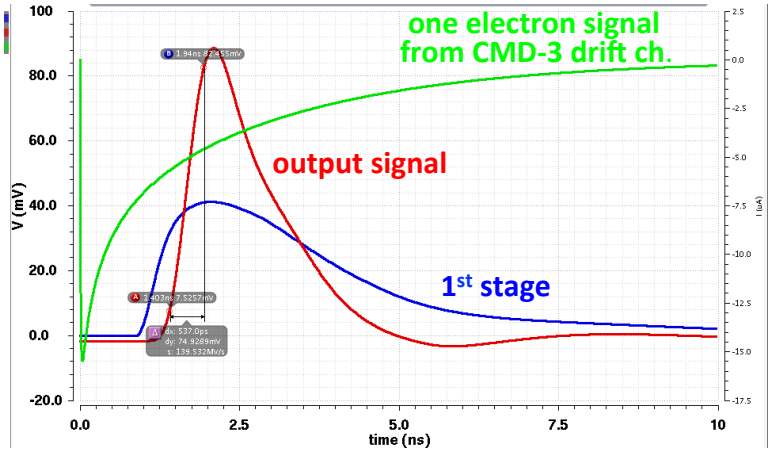
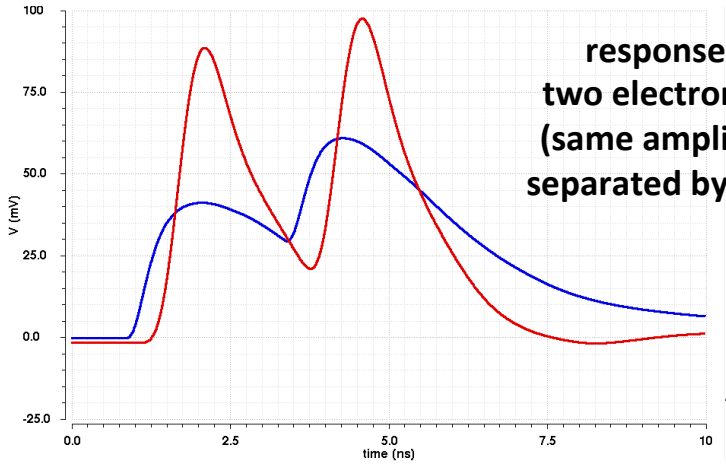
ASoC PARAMETERS	SPECIFICATION (MEASURED)
Sample rate	2.5 - 3.6 GSa/s
Number of channels	4
Sampling depth	16 k Sa/channel
Signal range	0-2.5 V
Resolution	12 bits*, 10b ENOB
Supply Voltage	2.5 V
RMS noise	~ 1 mV
Digital Clock frequency	25 MHz
Timing resolution	1<25 ps***
Power /ch	50-125 mW/channel*
Analog bandwidth	950 MHz



A two stage amplifier for Cluster Counting/Timing: possible ASIC implementation

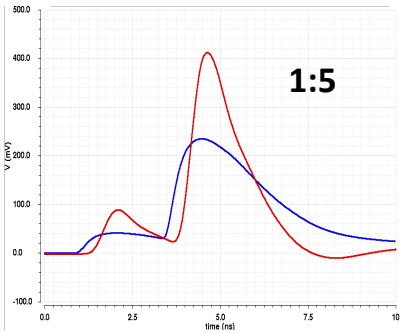
from V. Aulchenko, BINP

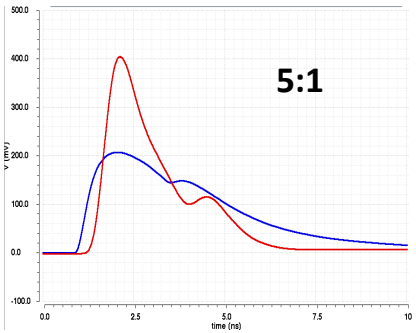




from BINP
Aulchenko V. M

Output signal parameters:
- leading edge **0.6 ns**;
- width at the half of amplitude **1.4 ns**;
- width at 10% of amplitude **2.9 ns**;
- noise (RMS) **3 mV;**
- S/N **30.**





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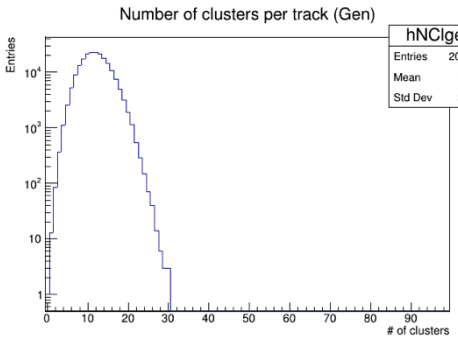
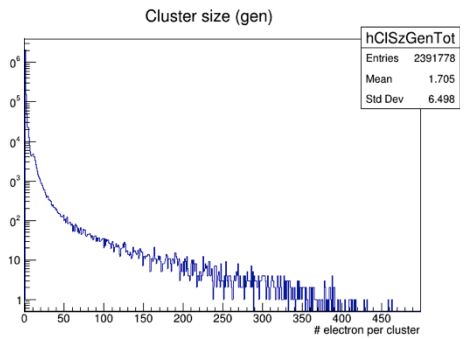
PID full simulation with cluster counting

- **Garfield++ (Heed)** simulates in deep detail the ionization processes in the gas, but it would be extremely cumbersome to follow an ionization particle inside the large volume of a tracking detector.
- **GEANT4** simulates the interaction of a particle with all the materials of a large detector but it doesn't simulate the ionization clustering process which is essential for cluster counting.
- **Define a model** for a fast simulation of the cluster density and the cluster size distribution according to the predictions of **Heed**, to be used taking into account the results of the particle interactions calculated by **GEANT4**.

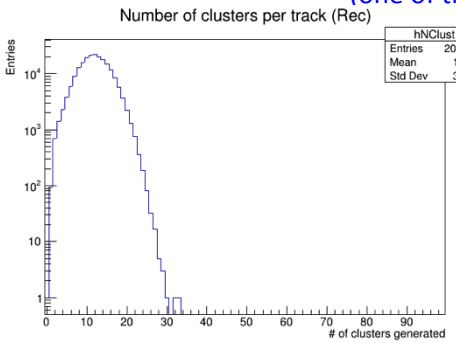
Heed

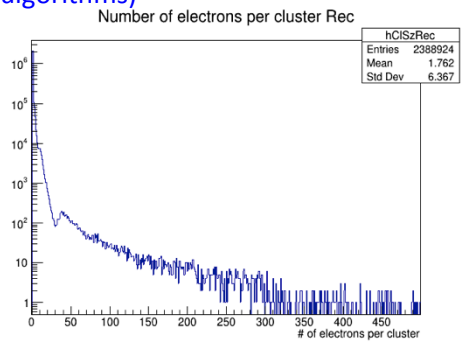




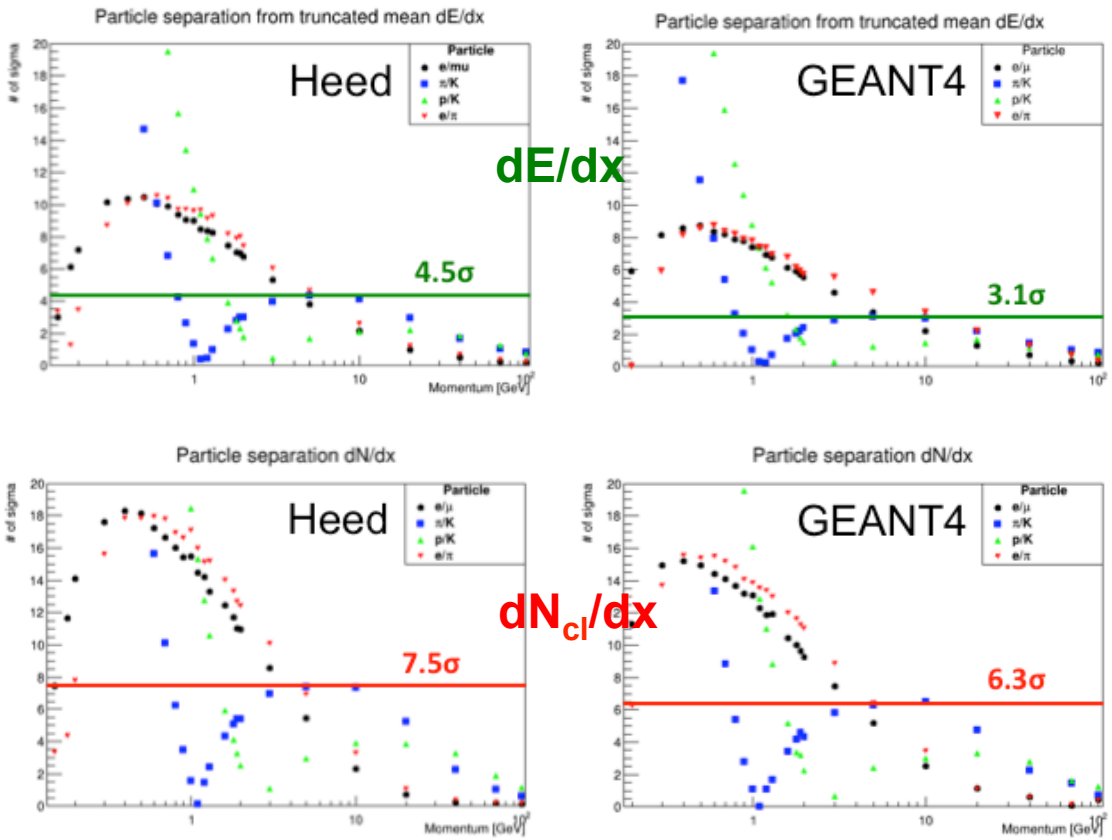
model

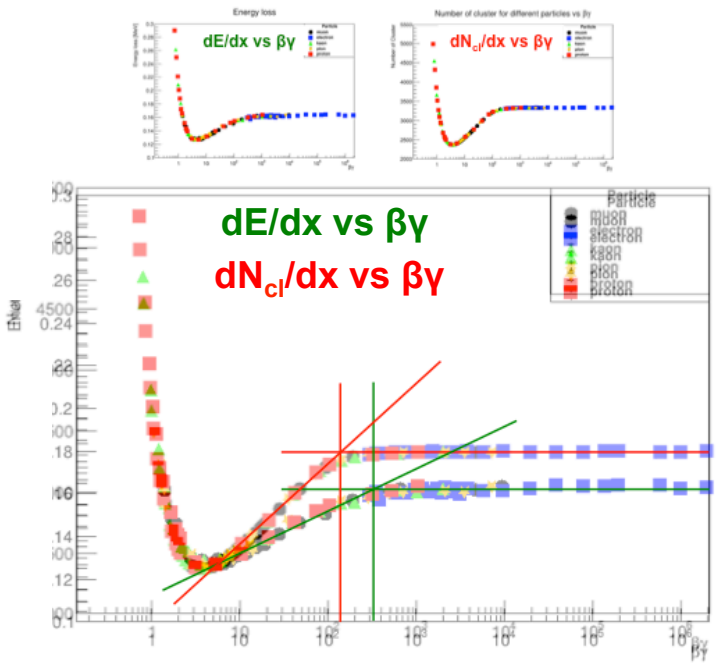
(one of the algorithms)





PID full simulation with cluster counting





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PID full simulation with cluster counting

Open questions:

1. **Lack of experimental data** on cluster density and cluster population for He based gas. Particularly in the relativistic rise region to compare predictions.
2. Despite the fact that the Heed model in GEANT4 reproduces reasonably well the Heed predictions, why particle separation, both with dE/dx and with dN_{cl}/dx, **in GEANT4 is** considerably **worse than in Heed**?
3. Despite a higher value of the dN_{cl}/dx Fermi plateau with respect to dE/dx, why this is reached at **lower values of βγ with a steeper slope**?
4. We are still waiting for answers from Heed and Geant4 developers to try to shed light on these questions
5. These questions are crucial for establishing the particle identification performance at **FCCee**, **CEPC** and **SCTF**
6. However, **the only way to ascertain these issues is an experimental measurement!**

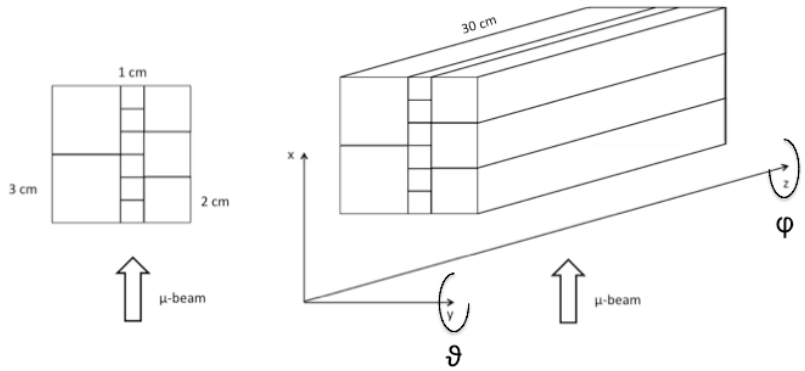
Motivations for a beam test

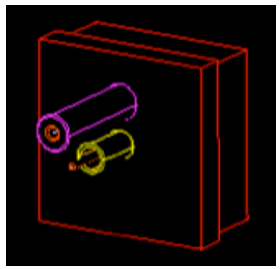
Beam test plans:

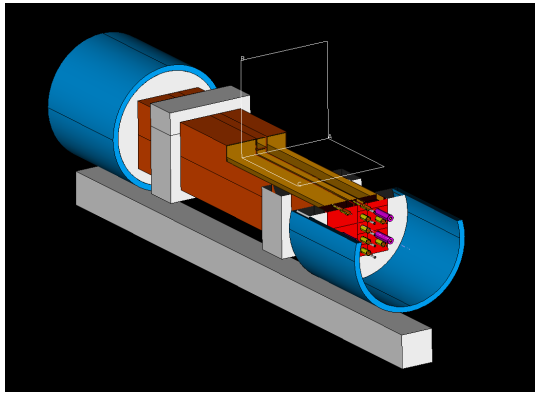
1. First of all, need to demonstrate the **ability to count clusters**:
   at a fixed βγ (e.g. muons at a fixed momentum) count the clusters by
   - doubling and tripling the track length and changing the track angle;
   - changing the gas mixture.
2. Establish the **limiting parameters** for an efficient cluster counting:
   - cluster density (by changing the gas mixture)
   - space charge (by changing gas gain, sense wire diameter, track angle)
   - gas gain saturation
3. In optimal configuration, **measure the relativistic rise as a function of βγ**, both in **dE/dx** and in **dN_{cl}/dx**, by scanning the muon momentum from the lowest to the highest value (from a few GeV/c to about 250 GeV/c at CERN/H8).
4. Use the experimental results to fine tune the predictions on performance of **cluster counting** for **flavor physics** and for **jet flavor tagging** both in **DELPHES** and in **full simulation**

Motivations for a beam test

conceptual setup:







test configuration:

- 6 drift tubes 1 cm × 1 cm × 30 cm
  - 2 with 15 μm sense wire, 2 with 20 μm, 2 with 25 μm
- 3 drift tubes 2 cm × 2 cm × 30 cm
  - 1 with 20 μm sense wire, 1 with 25 μm, 1 with 30 μm
- 2 drift tubes 3 cm × 3 cm × 30 cm
  - 1 with 20 μm sense wire, 1 with 30 μm
- 11 preamplifier cards (1 GHz, 20 db) + termin.
  - more configurations to choose from
- 11 independent HV power supply channels
- 11 digitizer (2 GSa/s, 12 bit) (WDB + O-scope)
  - max drift time ≈ 2μs for 3 cm drift at 45°
- gas mixing, control and distribution (only He and iC_4H_{10})
- 2-3 trigger scintillators (HV, discr., coinc., TU)

Motivations for a beam test

- number of clusters versus **cell size** and **gas mixture at a fixed muon momentum**:
  - **from 12 cm^{-1}** (gas: 90/10) to **25 cm^{-1}** (gas: 70/30) for **m.i.p.** (×3 for the 3 cm tube)
  - **measure counting efficiency versus cluster density**
  - **estimate the cluster size distribution both in He and in isobutene**
- number of clusters versus **space charge effects**:
  - different **gas gain** (from 1x10^5 to 5x10^5) for He/iC$_4$H$_{10}$ = 90/10
  - sense wire diameters **15, 20, 25, 30 µm** for the same **gas gain** (5x10^5)
  - angle between track and wire: 0°, 30°, 45°, 60° for the same **gas gain** (5x10^5)

can be done at a fixed muon momentum

- choose optimal operating conditions (counting efficiency):
  - gas mixture
  - gas gain
  - sense wire diameter
  - track angle
- scan muon momentum from a few GeV/c to 250 GeV/c ($\beta\gamma$ = 40 ÷ 1800) and **measure relativistic rise**: essential to **predict particle separation independently of the assumptions in Heed and Geant4 simulations**.

scan the muon momentum

Beam test availability in parasitic mode at CERN/H8

week	location	main users	beam
week 42 - Oct. 18-25	PPE168	LHCb and CMS MDT	muons at 180 GeV/c
week 43 – Oct 26-31	PPE158-168	LHCb and TOTEM	muons and hadrons
weeks 44-45 Nov. 1-12	PPE158	ATLAS TileCal	muons: scan in momentum