Report on recent CERN hardware activities for FCAL
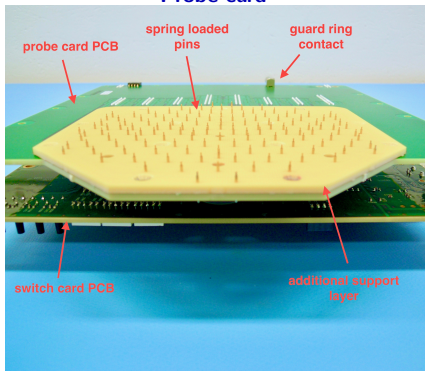
Eva Sicking (CERN)
with material from CERN, JINR Dubna, and Tel Aviv University

34th FCAL Collaboration Workshop
March 27, 2019

Probe/Switch card motivation

- CMS endcap calorimeter upgrade (HGCAL): $600\,\mathrm{m}^2$ of silicon sensors, made of 8-inch wafers with several hundred DC-coupled, $0.5\text{–}1\,\mathrm{cm}^2$ pads
- System needed for electrical sensor characterisation in prototyping phase and for quality control in mass production (IV, CV, V_{BD}, V_{FD}, C_{FD})

Probe card
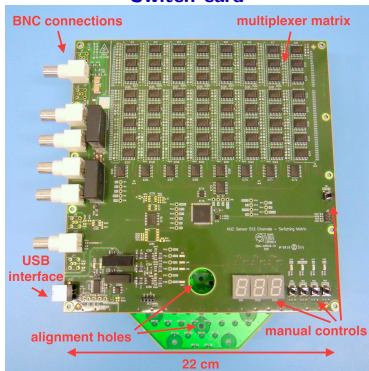

- Need to bias all pads during testing
  - Probe-card based system
- System to switch between pads
  - Commercial switching units expensive + need for many high-quality shielding cables
  - → Switching matrix designed by Szymon Kulis, connectable to probe cards
- Probe cards adaptable to sensor geometry → not limited to HGCAL
- → Probe card produced for LumiCal prototype sensor layout

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Switch card

BNC connections
multiplexer matrix
USB interface
alignment holes
manual controls
22 cm

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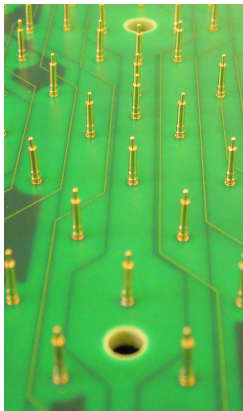# Probe/Switch card circuit

- Mother-daughter card system of switch card and probe card
  - Probe card: passive device, connects sensor using spring loaded pins
  - Switch card: Large array of multiplexers that controls measurement
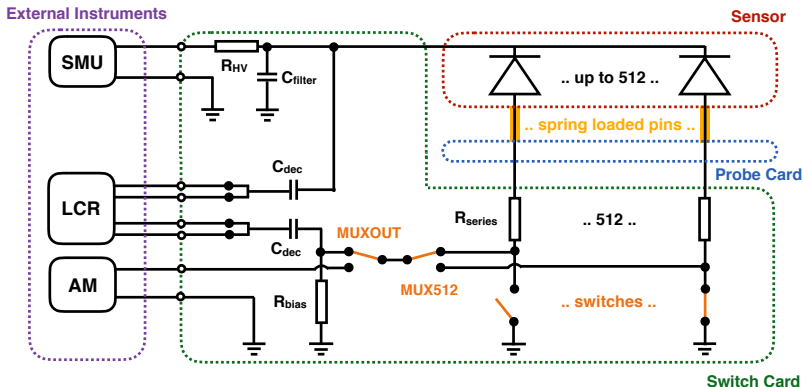
- More details in publication on system submitted on Monday to NIM A
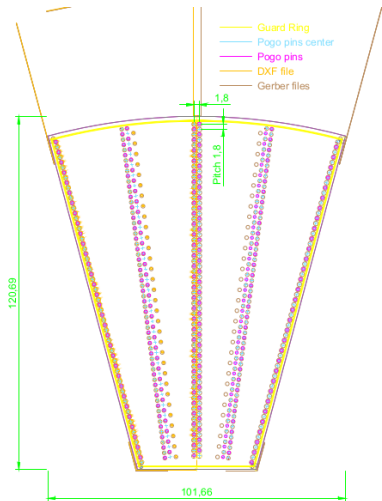 https://cds.cern.ch/record/2668752

Pins: position accuracy
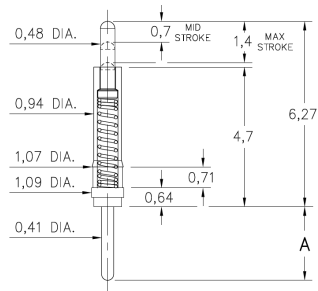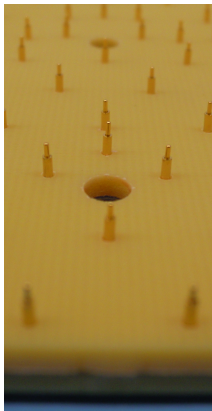
Unit=mm, A=3.81

- ▶ Spring loaded, gold plated pins with 1.4 mm travel, 240 um radius at tip
- ▶ Through-hole pins soldered into PCB by hand
- ▶ Yellow stiffener acts as jig keeping pins straight during assembly
- ▶ Precision in principle good enough for LumiCal contact pads of $1\,mm^2$

LumiCal contact-pad positions

- ▶ Small disagreement between various design files of Lumical sensor layout (DXF files, Gerber, EUDET PDF)
- ▶ Had to make a choice on which source to use (EUDET PDF)
- ▶ For contact pads with $1\,\text{mm}^2$ size small differences become important
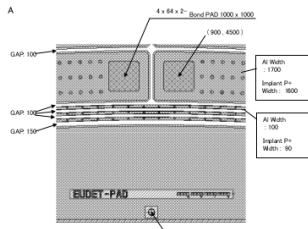
Designs

Probe card / Adapter for PM5 probe station

EDA-03713-V1-0
LumiCal 256 Cells Sensor Probe Card
Top View.

EDA-03713-V1-0
LumiCal 256 Cells Sensor Probe Card
Bot View.

http://edms.cern.ch/nav/EDA-03713-V1-0

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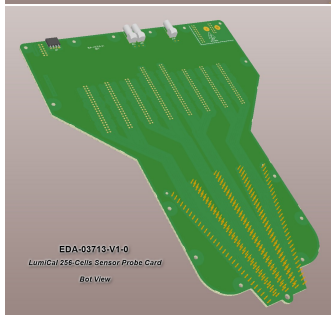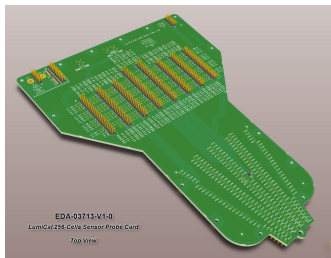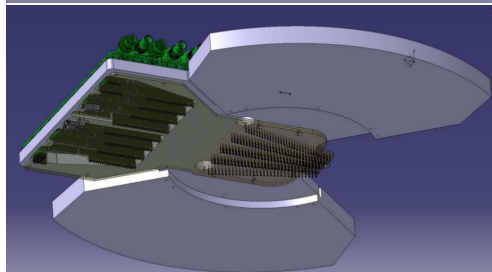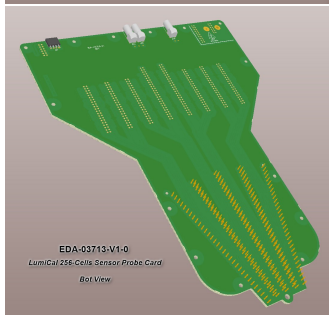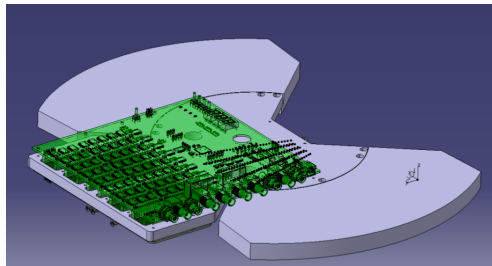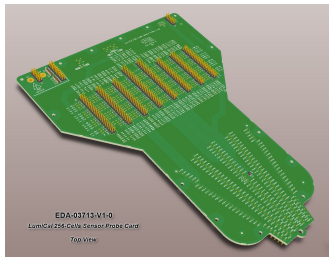
Produced parts
Probe card / Adapter for PM5 probe station
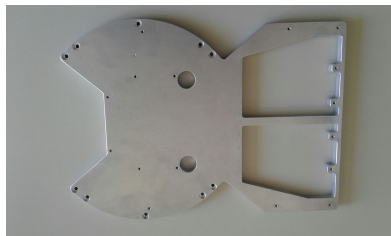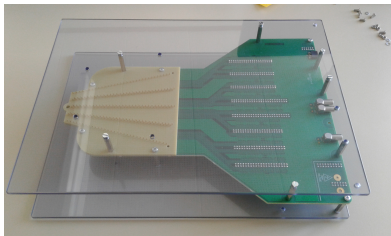
- ▶ Probe card design finished in October 2017
- ▶ Two LumiCal probe cards were produced in November 2017
- ▶ Transport protection made of PVC plates

- ▶ Probe card to be integrated into Karl Suess PM5 probe station at Tel Aviv University
- ▶ Design and production of mechanical adapter based on aluminium plates finished in March 2018
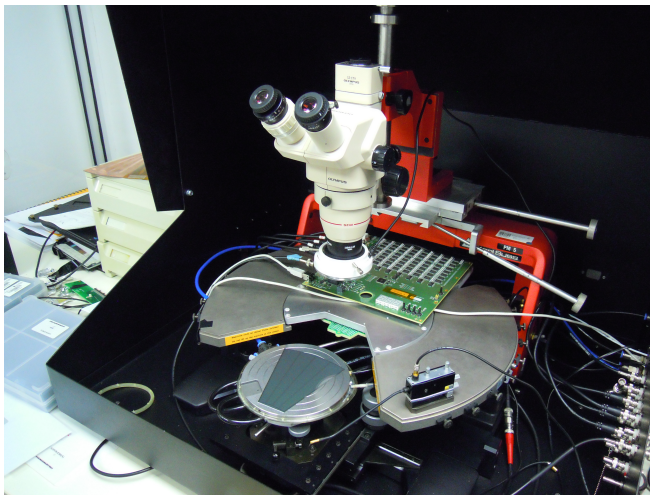
- ▶ Probe and switch card installation at Tel Aviv University
- ▶ Relative alignment of sensor and probe card using microscope looking through alignment holes in adapter and PCBs

Data Acquisition and Analysis
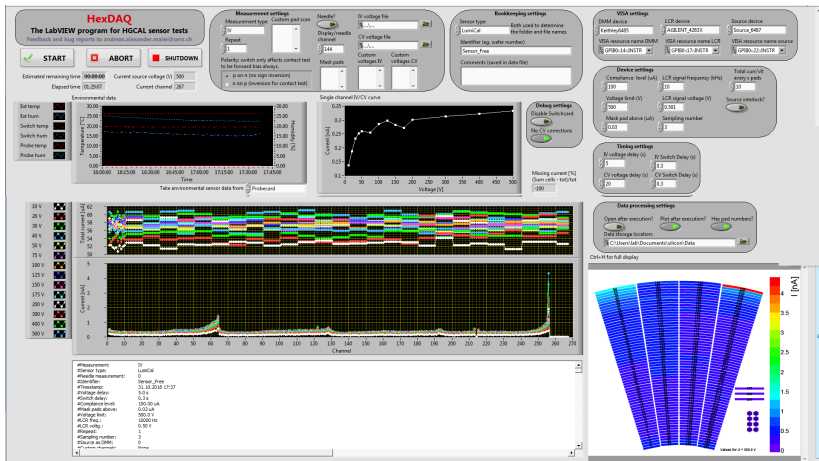
- ▶ Data acquisition in LabVIEW could be transferred from HGCAL tests
- ▶ Needed to add TAU laboratory instruments into LabVIEW code
  - ▶ Keithley 6487 (source meter), Keithley 6485 (picoammeter), Agilent E4263B (LCR meter)

Results: Leakage current
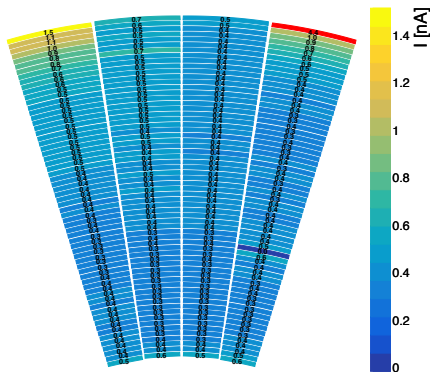
Leakage current at 500 V

Leakage current versus voltage

- ▶ First IV results with LumiCal sensor
- ▶ One cell is not connected, leakage current distributed to direct neighbours
- ▶ Current below 5 nA @ 500 V without guard ring biasing
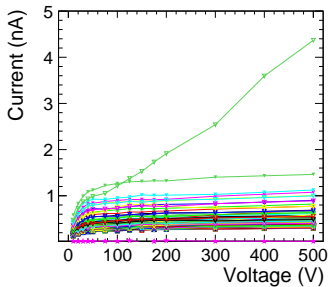
- ▶ Results in switch and probe card publication
  `cds.cern.ch/record/2668752`
- ▶ Measurement with 14 voltage steps for 256 cells, 1 guard ring and 8 test capacitors: 1.5 hours
- ▶ **Next steps**: Understand discrepancy between sum of cell currents and total current

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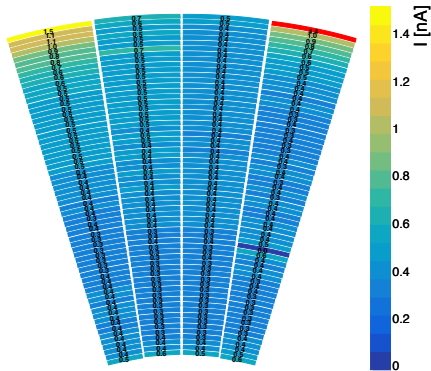
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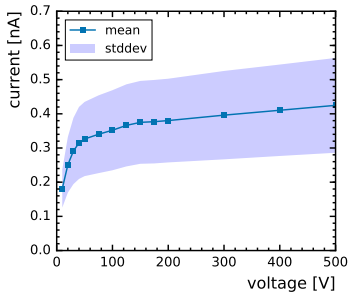
- ▶ Results in switch and probe card publication
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Capacitance

Capacitance at 120 V

Values for U = 120.0 V

- ▶ Capacitance increases with cell size ($C = \varepsilon_0 \varepsilon_R A/d$)
- ▶ Test capacitors on probe card for cross check (10 pF to 220 pF of 5% production accuracy)

- ▶ Measurement with 16 voltage steps for 256 cells, 1 guard ring and 8 test capacitors: 2.5 hours
- ▶ **Next steps**: understand open correction (parasitic capacitances from probe and switch card)
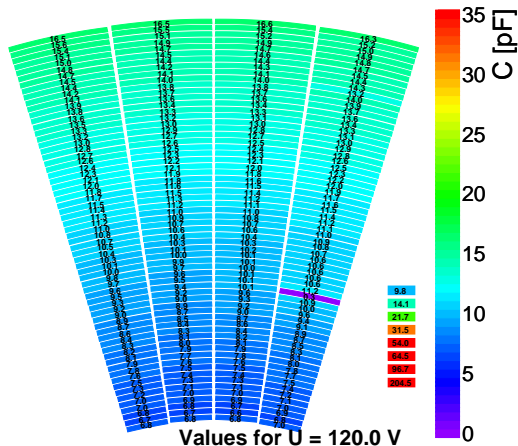
- ▶ First CV results with LumiCal sensor
- ▶ One cell is not connected, low capacitance

Tungsten plates

Tungsten plates from JINR Dubna
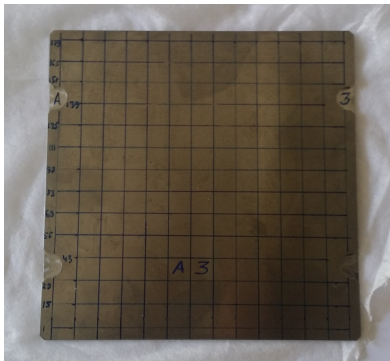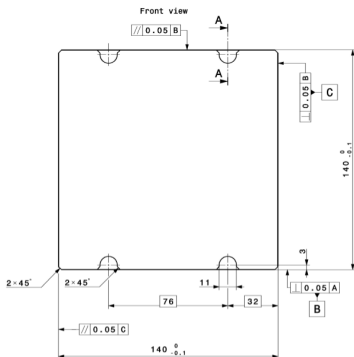
- ▶ 25 tungsten plates produced at JINR with thickness set value of 3.5 mm
- ▶ Thickness measured at JINR
- ▶ Plates were then sent to CERN

JINR metrology results

Absorber thickness
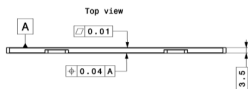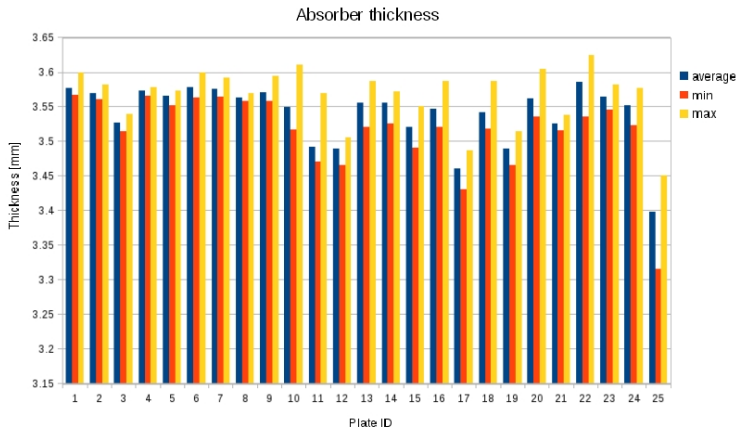
- ▶ Measurements results of all produced tungsten plates presented by Alexey Zhemchugov at 38th FCAL workshop (▶ link)
- ▶ Measure thickness from both sides for 14 x 14 points
- ▶ Measurement results close to 3.5 mm for all plates
- ▶ Measurements repeated at CERN for plates 3, 14, 24

CERN metrology method
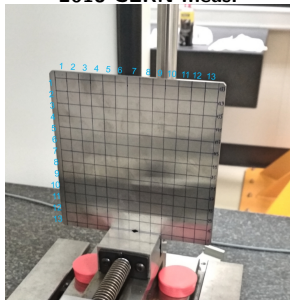
2018 CERN meas.

2012 CERN meas.
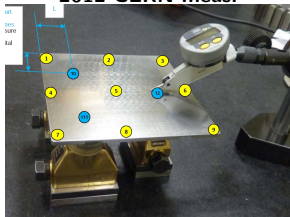
- ▶ CERN metrology group performed in 2018 measurements with three JINR example plates (A3, B14, B24)
  - ▶ Fix plate inside bench vice
  - ▶ Measure 13×13 points on both sides with LEITZ PMMC
- ▶ Measurements equivalent to the ones performed in 2012 of Plansee tungsten plates
  - ▶ Place plate on 3 points and level the plate, measure 3×3 points on front side
  - ▶ Place plate on table, measure 3×3 points on backside

- ▶ Measurement concept used by CERN and JINR differ
- ▶ More information needed on JINR measurement method
- ▶ Direct comparison of results not easy

Example results A3 (front)
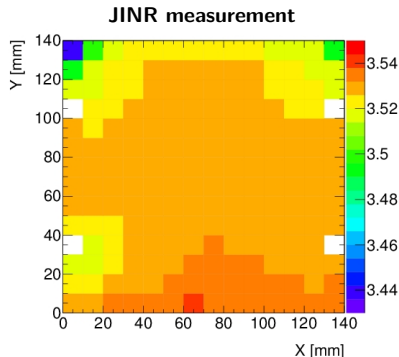
JINR measurement

CERN measurement

	1	2	3	4	5	6	7	8	9	10	11	12	13
1	-0,012	-0,006	-0,002	0,003	0,006	0,010	0,011	0,010	0,008	0,005	-0,001	-0,010	-0,019
2	-0,009	-0,004	0,000	0,003	0,008	0,010	0,011	0,012	0,012	0,010	0,002	-0,009	-0,018
3	-0,004	-0,001	0,003	0,006	0,010	0,012	0,016	0,017	0,017	0,014	0,005	-0,006	-0,014
4	0,000	0,002	0,006	0,010	0,013	0,017	0,019	0,020	0,019	0,015	0,008	-0,004	-0,011
5	-0,001	0,003	0,007	0,015	0,019	0,022	0,021	0,022	0,020	0,016	0,010	-0,001	-0,011
6	0,000	0,003	0,012	0,019	0,024	0,025	0,024	0,022	0,019	0,015	0,008	-0,003	-0,011
7	0,000	0,003	0,011	0,020	0,018	0,025	0,024	0,020	0,015	0,009	0,003	-0,007	-0,013
8	-0,002	0,001	0,007	0,015	0,021	0,020	0,019	0,014	0,009	0,004	-0,004	-0,012	-0,017
9	-0,005	-0,002	0,001	0,007	0,012	0,013	0,010	0,006	0,001	-0,005	-0,013	-0,017	-0,023
10	-0,005	-0,004	-0,002	-0,001	0,001	0,002	-0,001	-0,004	-0,007	-0,012	-0,017	-0,023	-0,031
11	-0,008	-0,005	-0,005	-0,003	-0,003	-0,004	-0,007	-0,009	-0,012	-0,014	-0,020	-0,026	-0,036
12	-0,009	-0,007	-0,007	-0,007	-0,007	-0,008	-0,009	-0,011	-0,013	-0,016	-0,020	-0,026	-0,032
13	-0,010	-0,008	-0,007	-0,007	-0,006	-0,008	-0,009	-0,012	-0,013	-0,016	-0,020	-0,025	-0,029

Example results A3 (backside)

JINR measurement
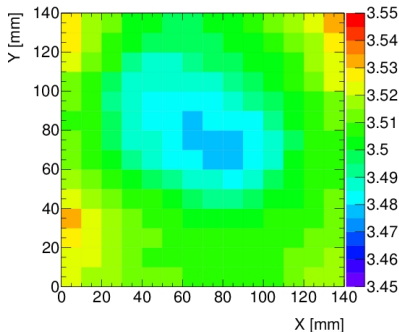
CERN measurement

	1	2	3	4	5	6	7	8	9	10	11	12	13
1	3,503	3,500	3,499	3,496	3,495	3,492	3,491	3,491	3,491	3,492	3,494	3,499	3,487
2	3,504	3,501	3,499	3,498	3,494	3,494	3,491	3,489	3,488	3,487	3,492	3,499	3,502
3	3,503	3,501	3,496	3,495	3,491	3,489	3,486	3,484	3,482	3,482	3,489	3,497	3,501
4	3,501	3,498	3,494	3,491	3,487	3,484	3,481	3,480	3,478	3,480	3,486	3,496	3,502
5	3,503	3,498	3,494	3,485	3,481	3,479	3,478	3,475	3,476	3,480	3,484	3,494	3,503
6	3,503	3,499	3,489	3,482	3,476	3,474	3,475	3,476	3,477	3,479	3,484	3,494	3,502
7	3,503	3,499	3,489	3,479	3,481	3,475	3,475	3,476	3,479	3,484	3,489	3,498	3,503
8	3,503	3,499	3,493	3,485	3,478	3,478	3,478	3,482	3,485	3,488	3,494	3,500	3,504
9	3,506	3,502	3,498	3,492	3,486	3,483	3,486	3,488	3,492	3,495	3,500	3,500	3,505
10	3,504	3,502	3,500	3,500	3,496	3,495	3,496	3,497	3,497	3,499	3,501	3,502	3,506
11	3,507	3,504	3,503	3,501	3,501	3,501	3,502	3,502	3,502	3,501	3,502	3,504	3,507
12	3,508	3,505	3,506	3,505	3,503	3,505	3,503	3,503	3,503	3,503	3,504	3,506	3,507
13	3,510	3,507	3,506	3,504	3,503	3,505	3,504	3,505	3,504	3,505	3,506	3,507	3,507

Example results B14 (front)

JINR measurement
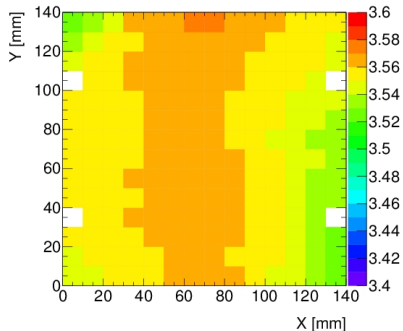
CERN measurement

	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0,004	0,006	0,007	0,008	0,010	0,013	0,018	0,021	0,020	0,016	0,002	-0,018	-0,031
2	0,001	0,000	0,000	0,001	0,005	0,009	0,015	0,018	0,018	0,012	0,002	-0,016	-0,026
3	-0,007	-0,007	-0,007	-0,006	-0,001	0,004	0,010	0,015	0,016	0,011	0,000	-0,014	-0,021
4	-0,012	-0,011	-0,012	-0,010	-0,005	-0,001	0,006	0,010	0,012	0,008	-0,003	-0,016	-0,022
5	-0,013	-0,014	-0,014	-0,010	-0,007	-0,003	0,002	0,006	0,007	0,003	-0,006	-0,018	-0,023
6	-0,011	-0,014	-0,012	-0,009	-0,007	-0,003	-0,001	0,001	0,001	-0,003	-0,010	-0,019	-0,024
7	-0,010	0,010	-0,010	-0,008	-0,004	-0,002	-0,001	-0,002	-0,004	-0,009	-0,013	-0,020	-0,025
8	-0,006	-0,006	-0,007	-0,005	-0,002	-0,002	-0,002	-0,003	-0,007	-0,011	-0,015	-0,021	-0,026
9	-0,001	-0,001	-0,001	-0,001	0,001	0,001	-0,001	-0,004	-0,007	-0,011	-0,017	-0,021	-0,025
10	0,005	0,005	-0,005	0,005	0,005	0,003	0,001	-0,002	-0,006	-0,011	-0,015	-0,019	-0,021
11	0,010	0,011	0,010	0,009	0,009	0,006	0,002	0,000	-0,004	-0,008	-0,011	-0,016	-0,017
12	0,015	0,016	0,016	0,013	0,013	0,010	0,006	0,004	-0,001	-0,005	-0,007	-0,011	-0,014
13	0,019	0,021	0,020	0,017	0,017	0,015	0,010	0,008	0,004	0,000	-0,003	-0,008	-0,011

Example results B14 (backside)
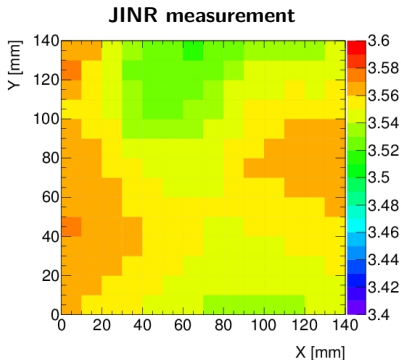
JINR measurement

CERN measurement

	1	2	3	4	5	6	7	8	9	10	11	12	13
1	3,522	3,524	3,532	3,538	3,539	3,537	3,536	3,533	3,531	3,526	3,522	3,519	3,515
2	3,522	3,527	3,535	3,538	3,542	3,542	3,539	3,537	3,533	3,530	3,526	3,522	3,518
3	3,523	3,529	3,536	3,510	3,544	3,542	3,542	3,541	3,538	3,535	3,532	3,527	3,524
4	3,525	3,531	3,538	3,541	3,544	3,542	3,543	3,543	3,542	3,539	3,538	3,534	3,530
5	3,526	3,529	3,535	3,539	3,542	3,544	3,542	3,542	3,542	3,542	3,540	3,537	3,535
6	3,523	3,526	3,531	3,537	3,540	3,541	3,542	3,544	3,544	3,545	3,543	3,541	3,537
7	3,516	3,519	3,524	3,529	3,534	3,538	3,541	3,544	3,545	3,546	3,547	3,544	3,542
8	3,511	3,513	3,517	3,523	3,529	3,535	3,540	3,543	3,546	3,547	3,547	3,545	3,542
9	3,509	3,510	3,513	3,519	3,525	3,533	3,540	3,544	3,546	3,547	3,549	3,547	3,543
10	3,507	3,512	3,514	3,519	3,526	3,533	3,541	3,546	3,548	3,551	3,548	3,548	3,543
11	3,516	3,518	3,522	3,526	3,531	3,536	3,541	3,546	3,549	3,551	3,548	3,545	3,543
12	3,521	3,526	3,530	3,535	3,539	3,541	3,544	3,547	3,549	3,550	3,550	3,546	3,544
13	3,520	3,526	3,533	3,539	3,541	3,542	3,545	3,548	3,550	3,549	3,549	3,546	3,543
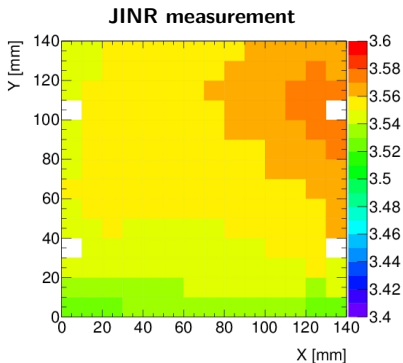
JINR measurement

CERN measurement

	1	2	3	4	5	6	7	8	9	10	11	12	13
1	-0,006	-0,005	-0,005	-0,006	-0,005	-0,005	-0,004	-0,005	-0,002	-0,002	0,000	0,001	0,001
2	0,001	0,000	0,001	0,001	0,001	0,000	-0,001	0,000	0,000	0,000	0,001	0,002	0,002
3	0,005	0,005	0,006	0,005	0,004	0,005	0,004	0,002	0,002	0,002	0,001	0,002	0,002
4	0,007	0,007	0,009	0,010	0,009	0,007	0,004	0,005	0,003	0,002	0,002	0,002	0,002
5	0,006	0,009	0,012	0,013	0,012	0,009	0,007	0,005	0,003	0,002	0,001	0,001	0,001
6	0,004	0,009	0,013	0,014	0,014	0,010	0,006	0,005	0,004	0,003	0,002	0,001	0,000
7	0,003	0,008	0,014	0,015	0,014	0,010	0,006	0,005	0,002	0,002	0,000	0,000	0,000
8	0,000	0,005	0,009	0,012	0,011	0,008	0,004	0,003	0,002	0,001	-0,001	-0,002	-0,003
9	-0,001	0,001	0,006	0,007	0,007	0,004	0,003	0,002	0,000	-0,001	-0,002	-0,003	-0,004
10	-0,004	-0,002	-0,001	0,002	0,002	0,001	0,000	-0,002	-0,002	-0,004	-0,006	-0,006	-0,006
11	-0,008	-0,008	-0,005	-0,004	-0,004	-0,004	-0,004	-0,004	-0,007	-0,007	-0,008	-0,008	-0,009
12	-0,015	-0,014	-0,012	-0,010	-0,009	-0,010	-0,010	-0,011	-0,011	-0,013	-0,014	-0,015	-0,015
13	-0,022	-0,019	-0,016	-0,014	-0,017	-0,014	-0,016	-0,016	-0,017	-0,018	-0,018	-0,019	-0,019
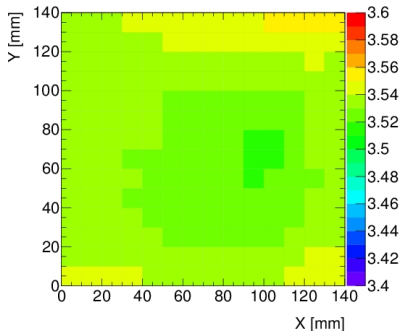
JINR measurement

CERN measurement

	1	2	3	4	5	6	7	8	9	10	11	12	13
1	3,522	3,525	3,527	3,527	3,525	3,525	3,525	3,527	3,525	3,527	3,525	3,522	3,518
2	3,524	3,526	3,523	3,522	3,521	3,522	3,523	3,523	3,524	3,524	3,526	3,527	3,525
3	3,527	3,523	3,520	3,519	3,519	3,517	3,519	3,522	3,523	3,525	3,526	3,527	3,524
4	3,524	3,520	3,517	3,515	3,514	3,516	3,519	3,519	3,521	3,524	3,526	3,527	3,525
5	3,523	3,517	3,513	3,510	3,511	3,513	3,516	3,518	3,522	3,524	3,525	3,528	3,526
6	3,524	3,516	3,511	3,510	3,509	3,512	3,516	3,517	3,520	3,522	3,524	3,527	3,526
7	3,523	3,516	3,509	3,507	3,508	3,511	3,515	3,517	3,521	3,522	3,526	3,528	3,526
8	3,524	3,518	3,513	3,509	3,509	3,512	3,516	3,518	3,520	3,523	3,525	3,528	3,527
9	3,524	3,520	3,514	3,513	3,512	3,514	3,516	3,517	3,520	3,523	3,525	3,528	3,526
10	3,525	3,521	3,519	3,516	3,515	3,515	3,517	3,520	3,521	3,524	3,526	3,528	3,527
11	3,527	3,524	3,520	3,520	3,519	3,519	3,519	3,519	3,523	3,524	3,526	3,528	3,527
12	3,524	3,527	3,524	3,523	3,522	3,522	3,522	3,524	3,524	3,527	3,528	3,529	3,525
13	3,523	3,525	3,526	3,524	3,527	3,523	3,525	3,526	3,526	3,528	3,527	3,526	3,523

Carbon-fibre envelopes

Carbon-fibre envelopes: Goal

thickness:
< 150 µm

120 ± 1 mm

132 ± 1 mm

glue – should be avoided
to run out here,
if at all possible

thickness:
< 750 µm

9 ± 1 mm

105° ± 0.1°

41.4 ± 0.5 mm

15 pieces
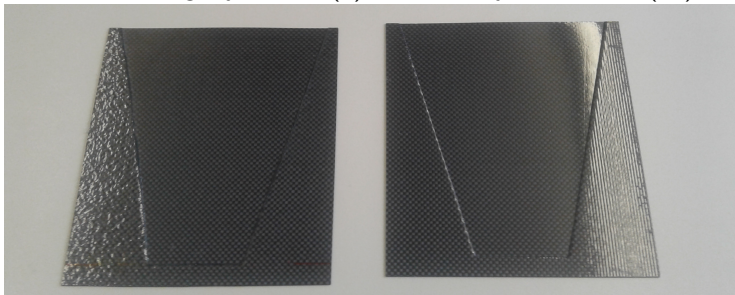
Carbon-fibre envelopes
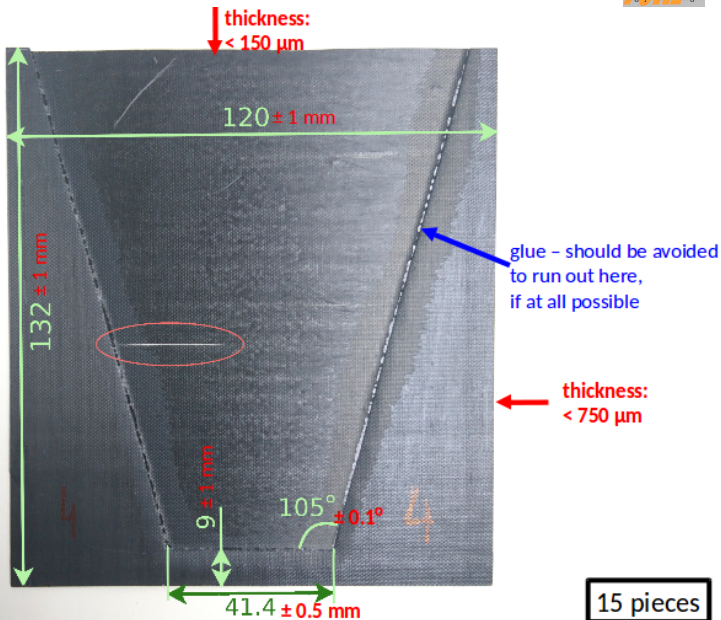
First trial slighlty thicker (2)   Very flat version (23)

- ▶ Francois Boyer (CERN) produced 25 carbon fibre envelopes (23 very flat ones)
- ▶ Instead of one-directional carbon fibre plys he used this time woven version (5+1 ply) $\rightarrow$ Avoid that single fibres get detached
- ▶ Using low amount of thixotropic glue prevented glue leaking out
- ▶ Thickness below 750 um ($\sim$600 um)
- ▶ Envelopes very symmetric due to especially prepared tooling for cutting
- ▶ Envelopes currently at TAU

Summary

- Sensor testings
  - Switch and probe-card system for electrical sensor characterisation
  - Probe cards produced for LumiCal sensor layout
  - Mechanical adapter for integration into probe station
  - Implementation of lab instruments into LabVIEW programme
  - Probe and switch card system used for first measurements at TAU

  - Testing duration depends on number of voltage steps
  - ~ 2 sensors per day possible with O(15) voltage steps for IV and CV

  - Next steps: Understand disagreement between total current and sum of cell currents, understand open correction in capacitance measurement
- Tungsten plates
  - 25 plates produced at JINR Dubna
  - CERN metrology tested 3 of the 25 plates
  - Measurement results at both JINR and CERN good
  - Different measurement methods at JINR and CERN make comparison difficult
  - Plates are currently at CERN
- Carbon fibre envelopes
  - 25 carbon fibre envelopes produced at CERN
  - Envelopes are currently at TAU