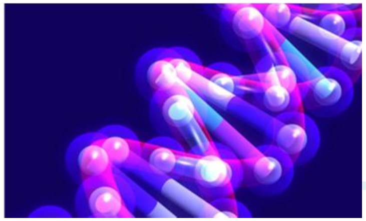
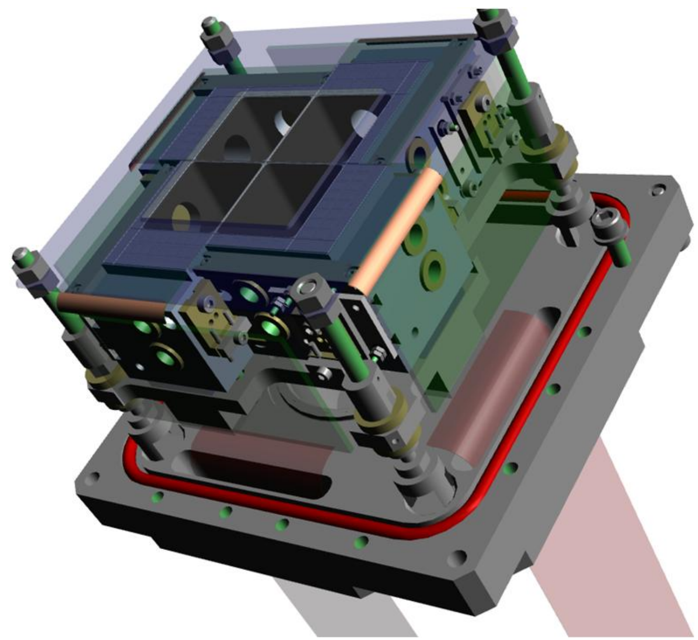


EDET Hybrid Measurement Results



OVERVIEW

- FROM HYBRID5 to EDET-HYBRID
  - PHILOSOPHY
  - CHANGES
  - COMPLETED COMPONENTS
- MAPPING ISSUES
- STANDARD MEASUREMENTS
- CALIBRATION ISSUES

Motivation for new E1 Hybrid Board

Space Constraints

- EDET small matrix (*active area: 12x7mm²*) larger than BELLE small matrix (*7.68x3.84mm²*) permitting connections to all DCDE and Switcher channels
  à new wirebond adapter

Integrate new connections

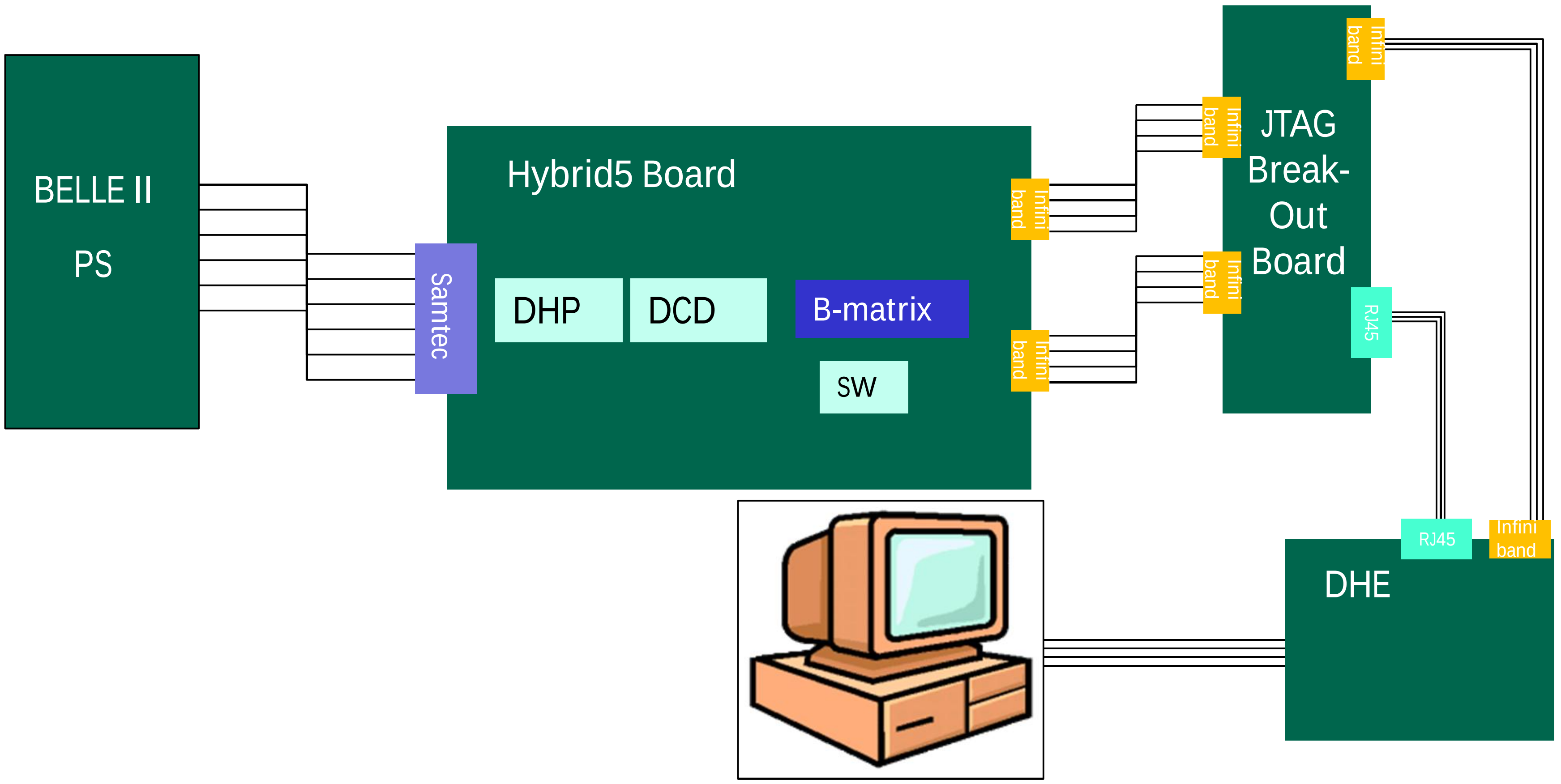
- compatibility to BELLE PS & PSP **à** Glenair connectors
- Switcher substrate line, Switcher V_{ref} line
- enabling sense lines to all ASIC voltages

Decision on data interface

- Change 2nd infiniband (JTAG lines) connector to RJ45 in order to get rid of JTAG breakout board

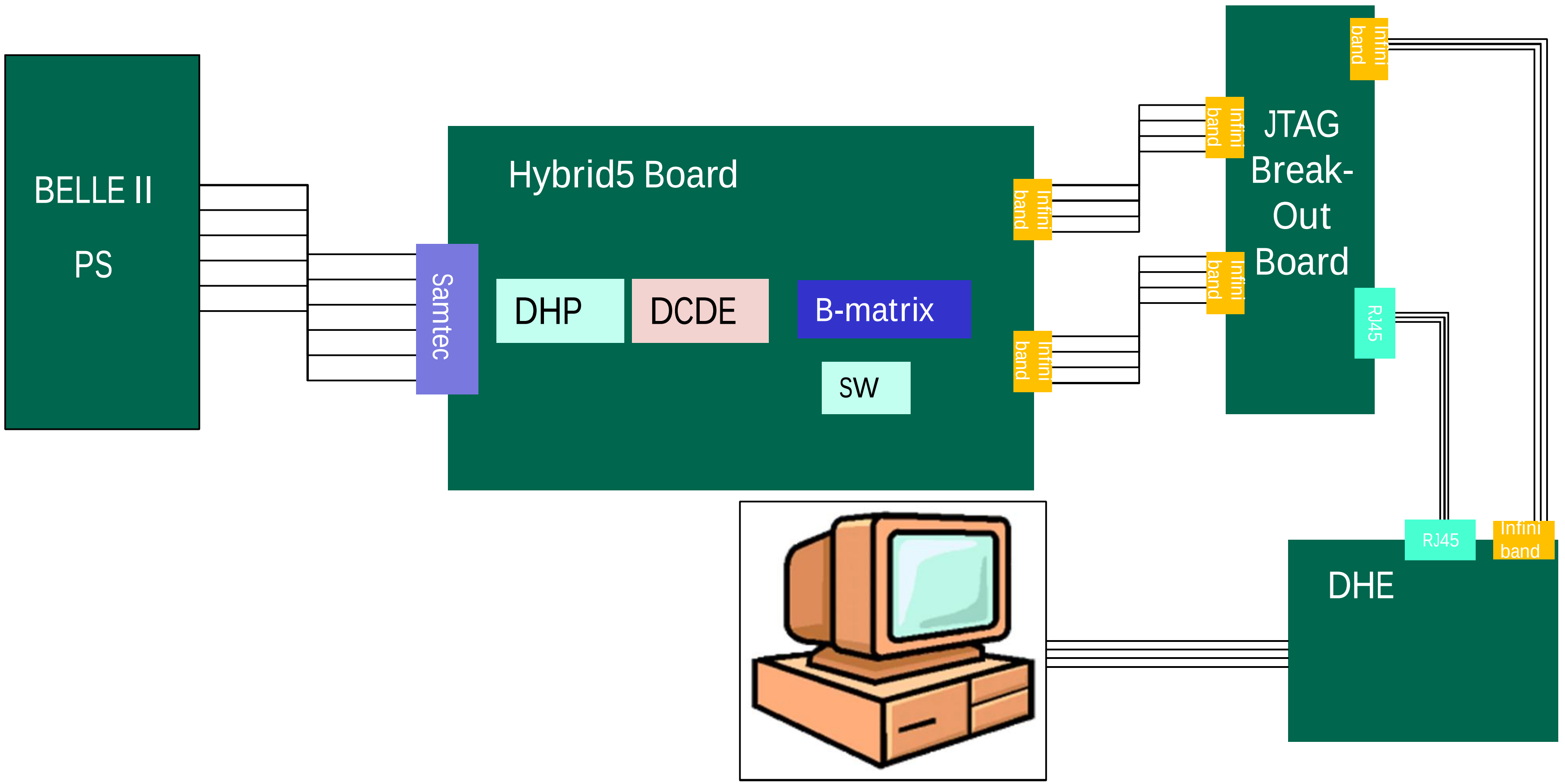
Philosophy

Starting with the functional BELLE II chain all components are stepwise replaced and tested



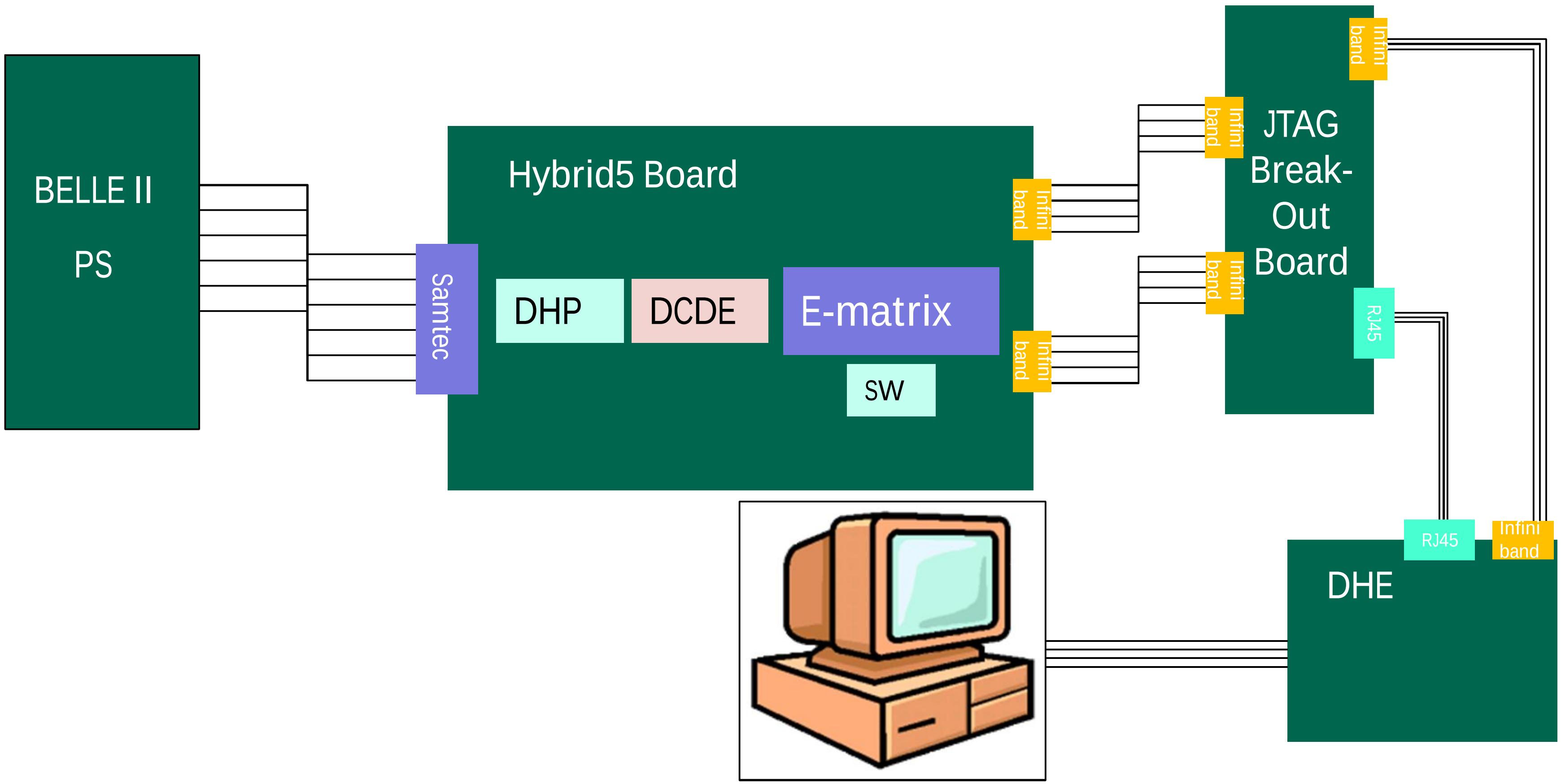
CHANGE (I) – DCDE

Starting with the functional BELLE II chain all components are stepwise replaced and tested



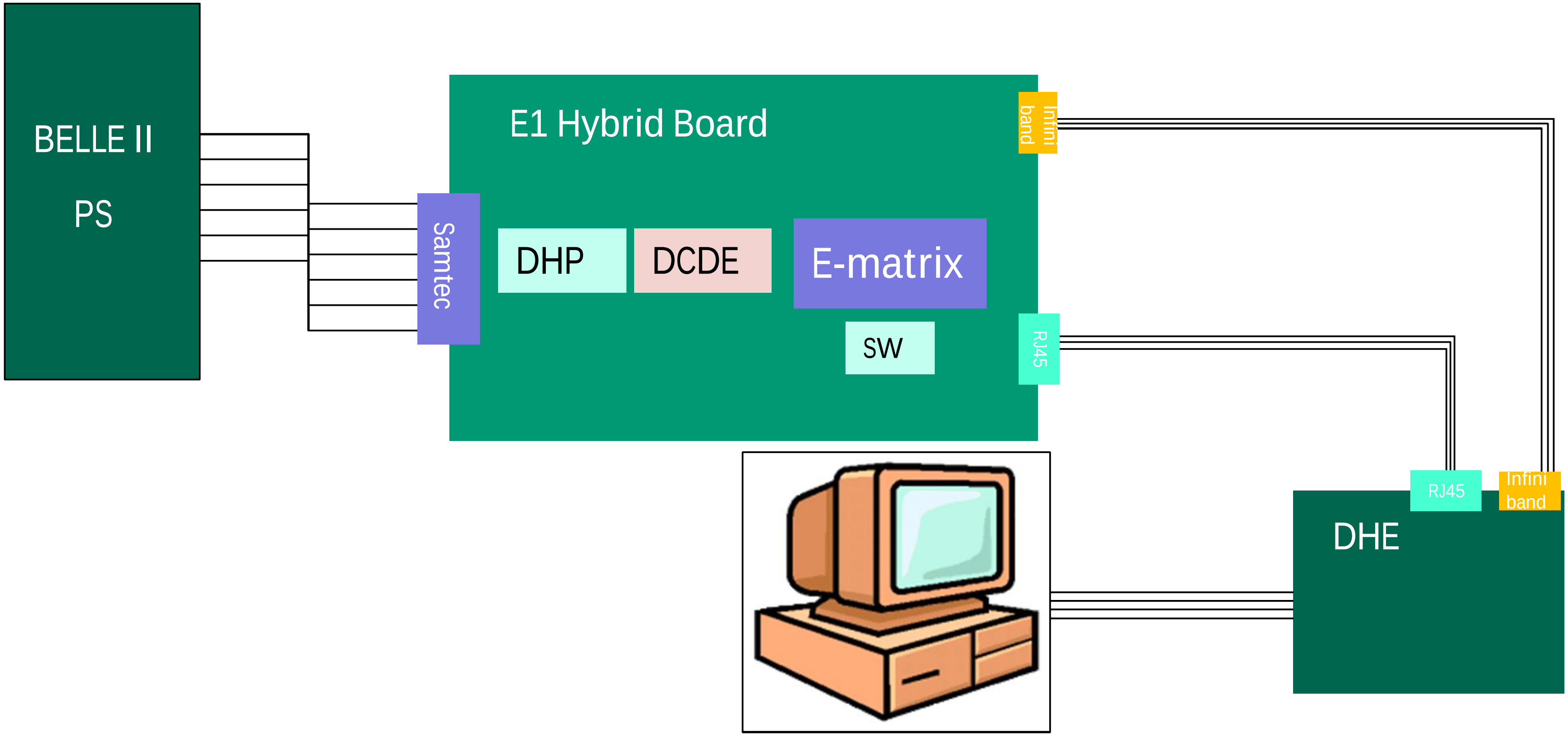
CHANGE (II) – EDET MATRIX

Starting with the functional BELLE II chain all components are stepwise replaced and tested



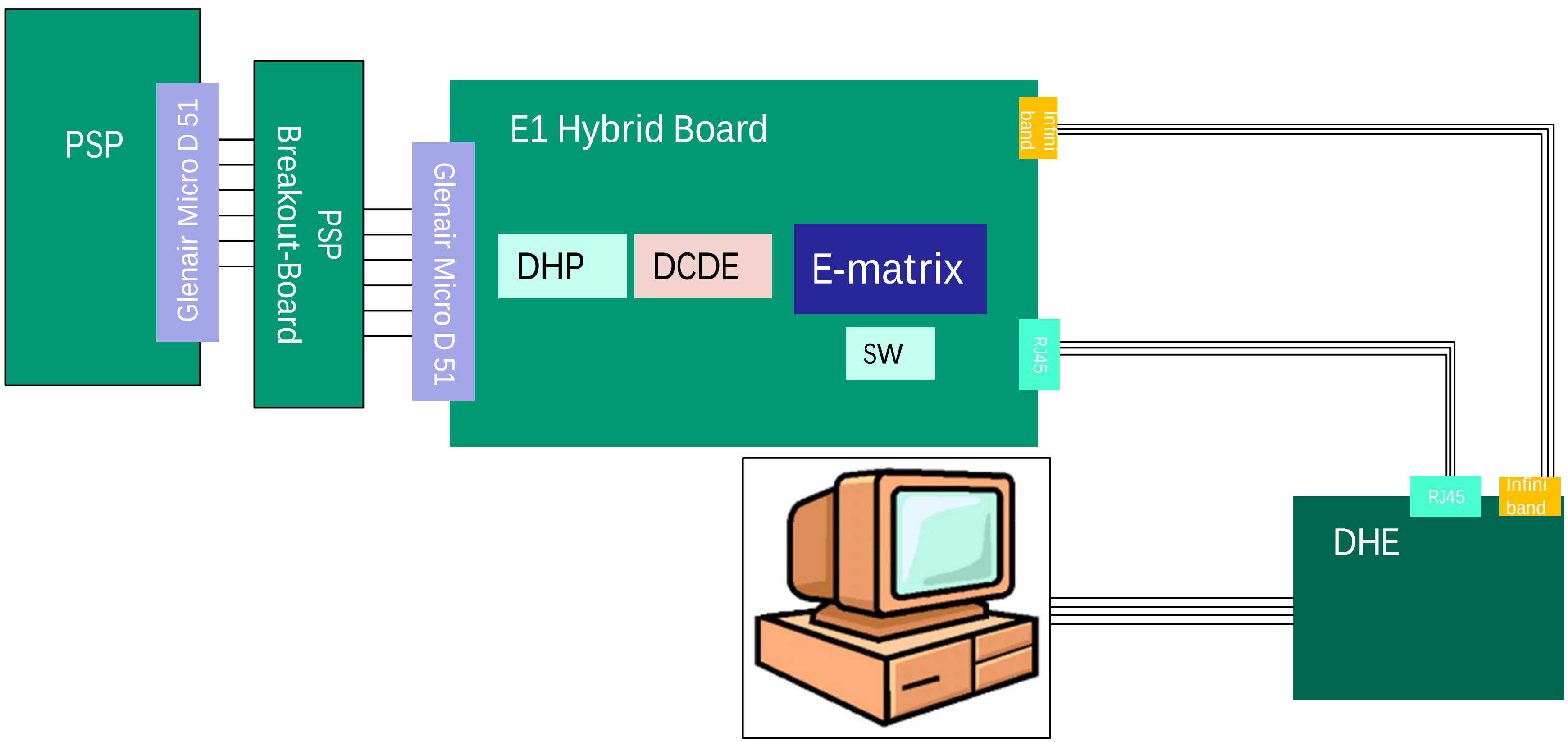
CHANGE (III) – EDET HYBRID BOARD

Starting with the functional BELLE II chain all components are stepwise replaced and tested

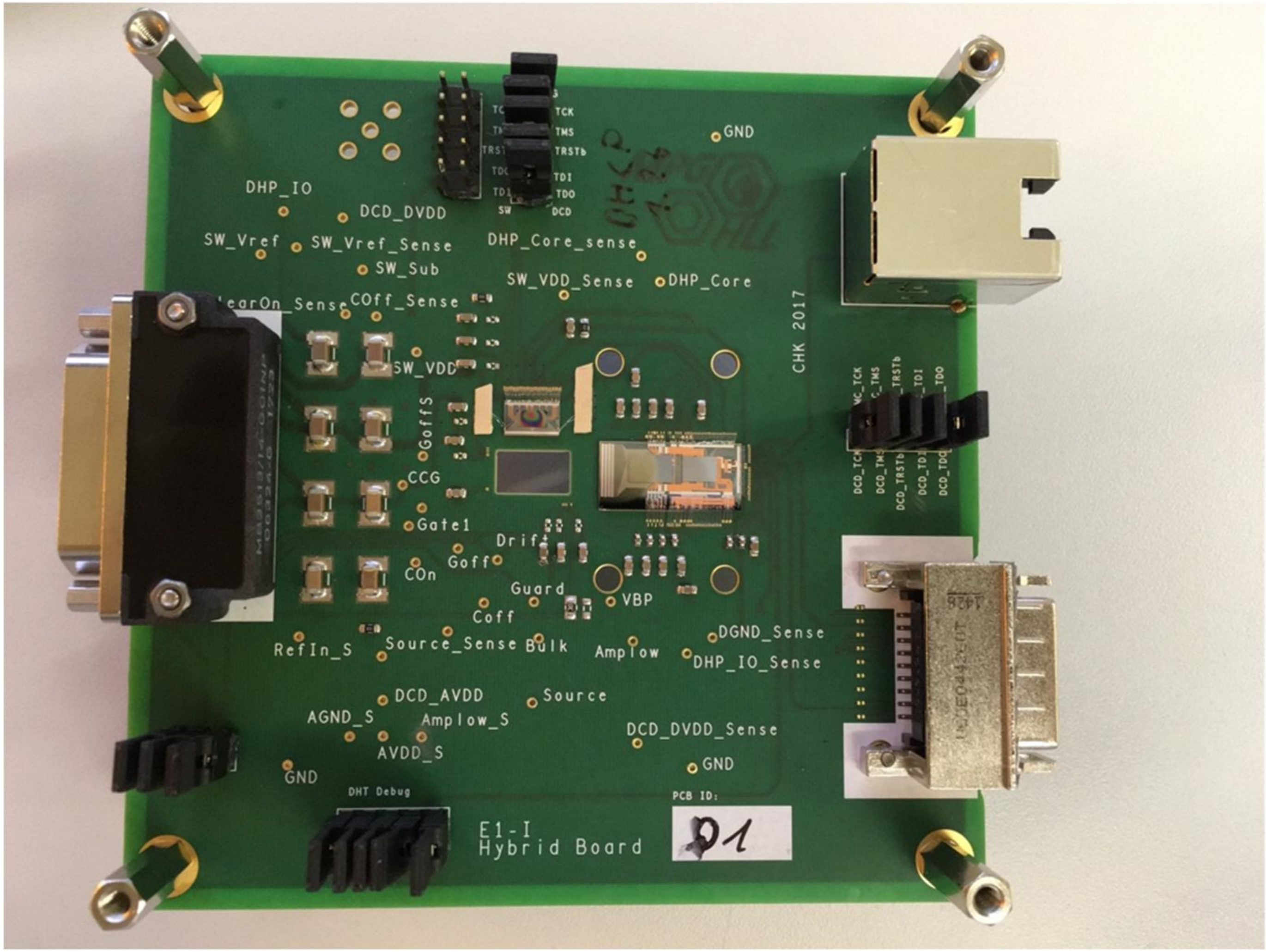


CHANGE (IV) – PSP

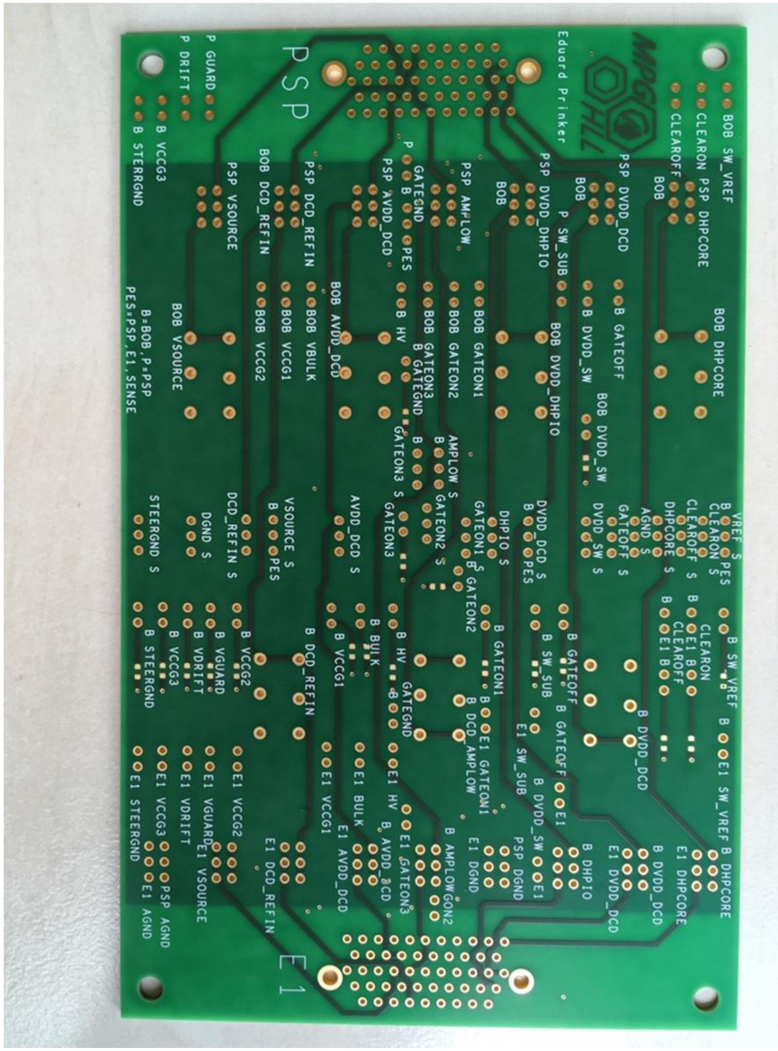
Starting with the functional BELLE II chain all components are stepwise replaced and tested

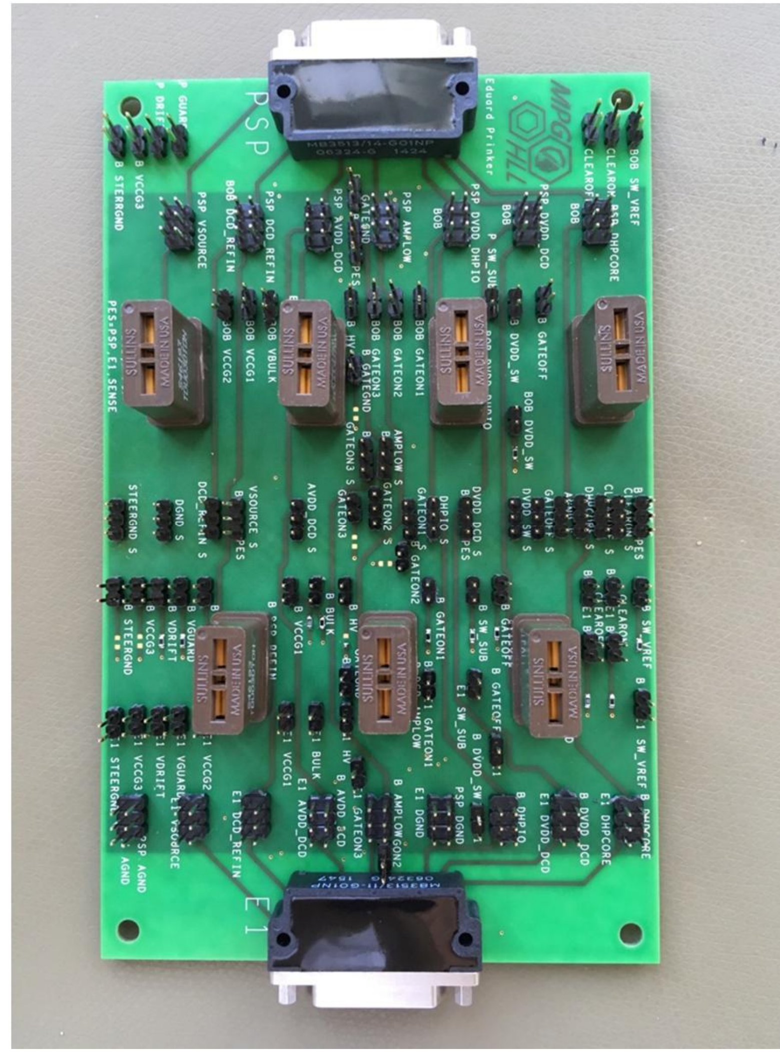


E1 – I – 01

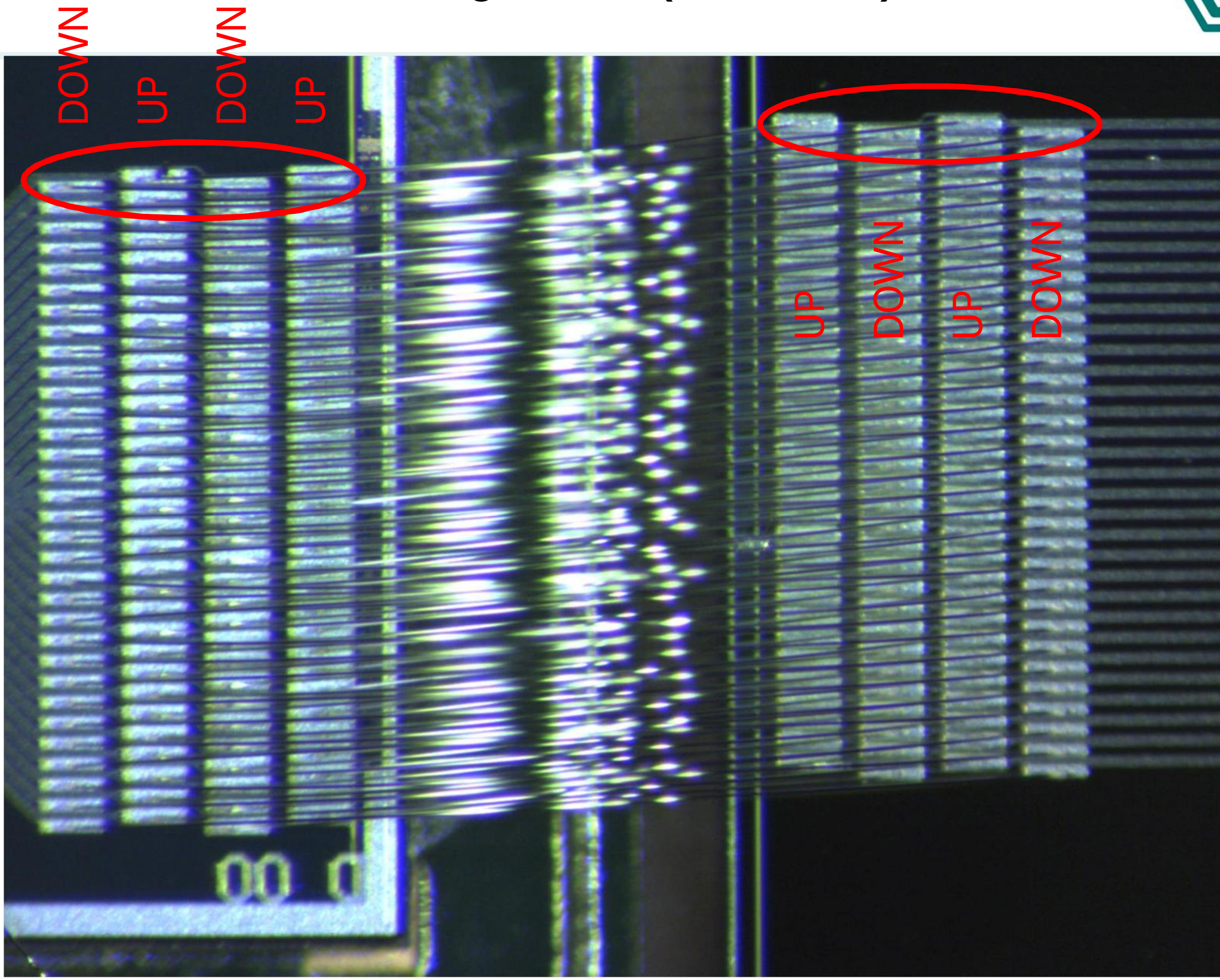

DHP_IO
DCD_DVDD
SW_Vref
SW_Vref_Sense
SW_Sub
DHP_Core_sense
SW_VDD_Sense
DHP_Core
GND
COff_Sense
SW_VDD
GoffS
CCG
Gate1
Drift
Goff
COn
Guard
VBP
Coff
RefIn_S
Source_Sense
Bulk
Amplow
DGND_Sense
DHP_IO_Sense
DCD_AVDD
Source
AGND_S
Amplow_S
AVDD_S
DCD_DVDD_Sense
GND
GND
DHT Debug
PCB ID:
E1-I
Hybrid Board
01
CHK 2017
TCK
TMS
TRSTb
TDI
TDO
DCD
DCD_TCK
DCD_TMS
DCD_TRSTb
DCD_TDI
DCD_TDO

PSP Breakout-Board – Final Board

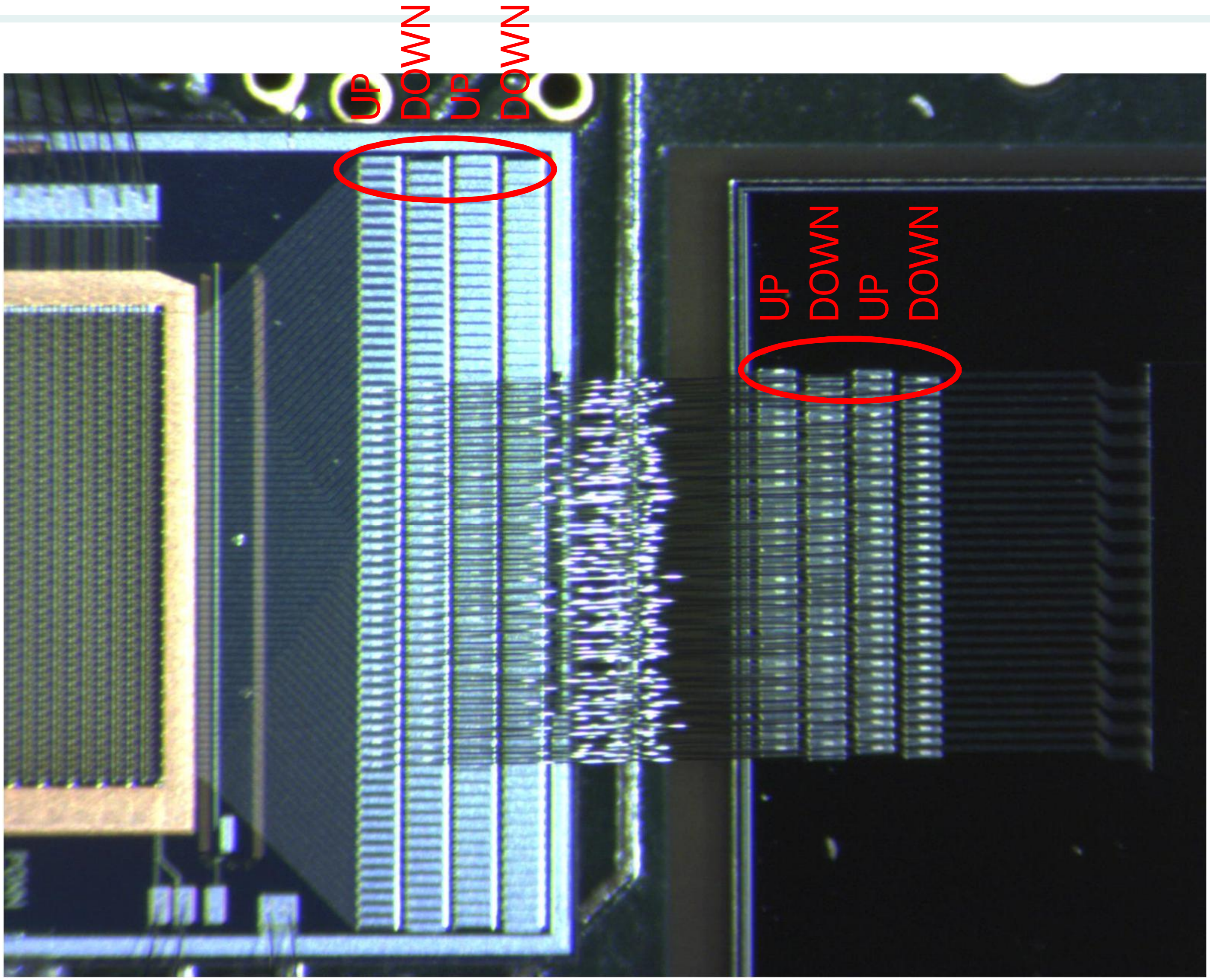




Wire-Bonding then (BELLE II) ...

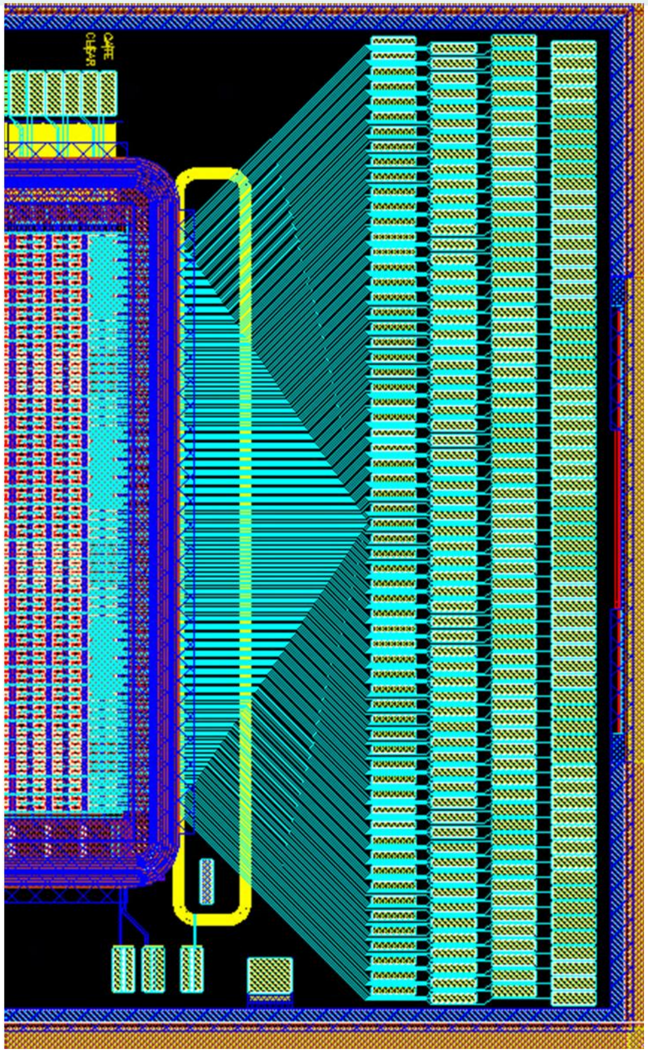


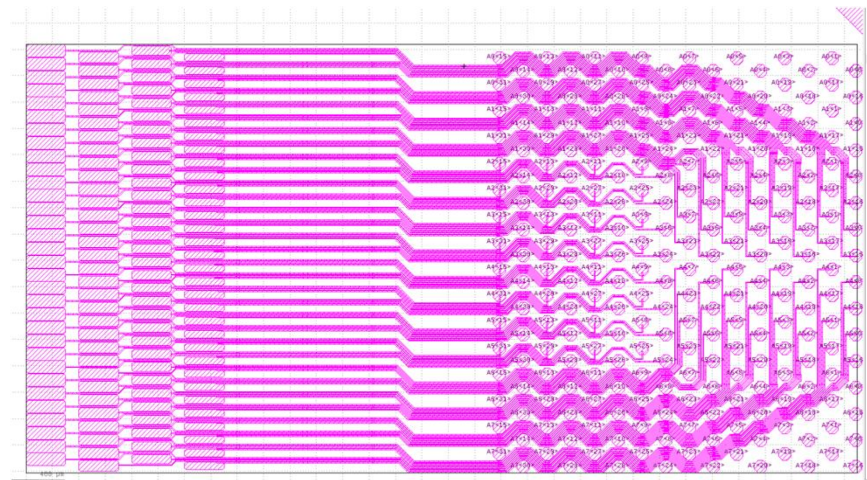
… and today (small EDET matrix) same WBA



MAPPING APPROACH (1)

- wire-bonding starts with closest pad rows, i.e. 1->1, 2->2, 3->3, 4->4





MAPPING APPROACH (2)

Matrix Arrangement

255	253	254	252
251	249	250	248
247	245	246	244
243	241	242	240
239	237	238	236
235	233	234	232
231	229	230	228
227	225	226	224
223	221	222	220
219	217	218	216
215	213	214	212
211	209	210	208
207	205	206	204
203	201	202	200
199	197	198	196
195	193	194	192
191	189	190	188
187	185	186	184
183	181	182	180
179	177	178	176
175	173	174	172
171	169	170	168
167	165	166	164
163	161	162	160
159	157	158	156
155	153	154	152
151	149	150	148
147	145	146	144
143	141	142	140
139	137	138	136
135	133	134	132
131	129	130	128
127	125	126	124
123	121	122	120
119	117	118	116
115	113	114	112
111	109	110	108
107	105	106	104
103	101	102	100
99	97	98	96
95	93	94	92
91	89	90	88
87	85	86	84
83	81	82	80
79	77	78	76
75	73	74	72
71	69	70	68
67	65	66	64
63	61	62	60
59	57	58	56
55	53	54	52
51	49	50	48
47	45	46	44
43	41	42	40
39	37	38	36
35	33	34	32
31	29	30	28
27	25	26	24
23	21	22	20
19	17	18	16
15	13	14	12
11	9	10	8
7	5	6	4
3	1	2	0

DCD WB

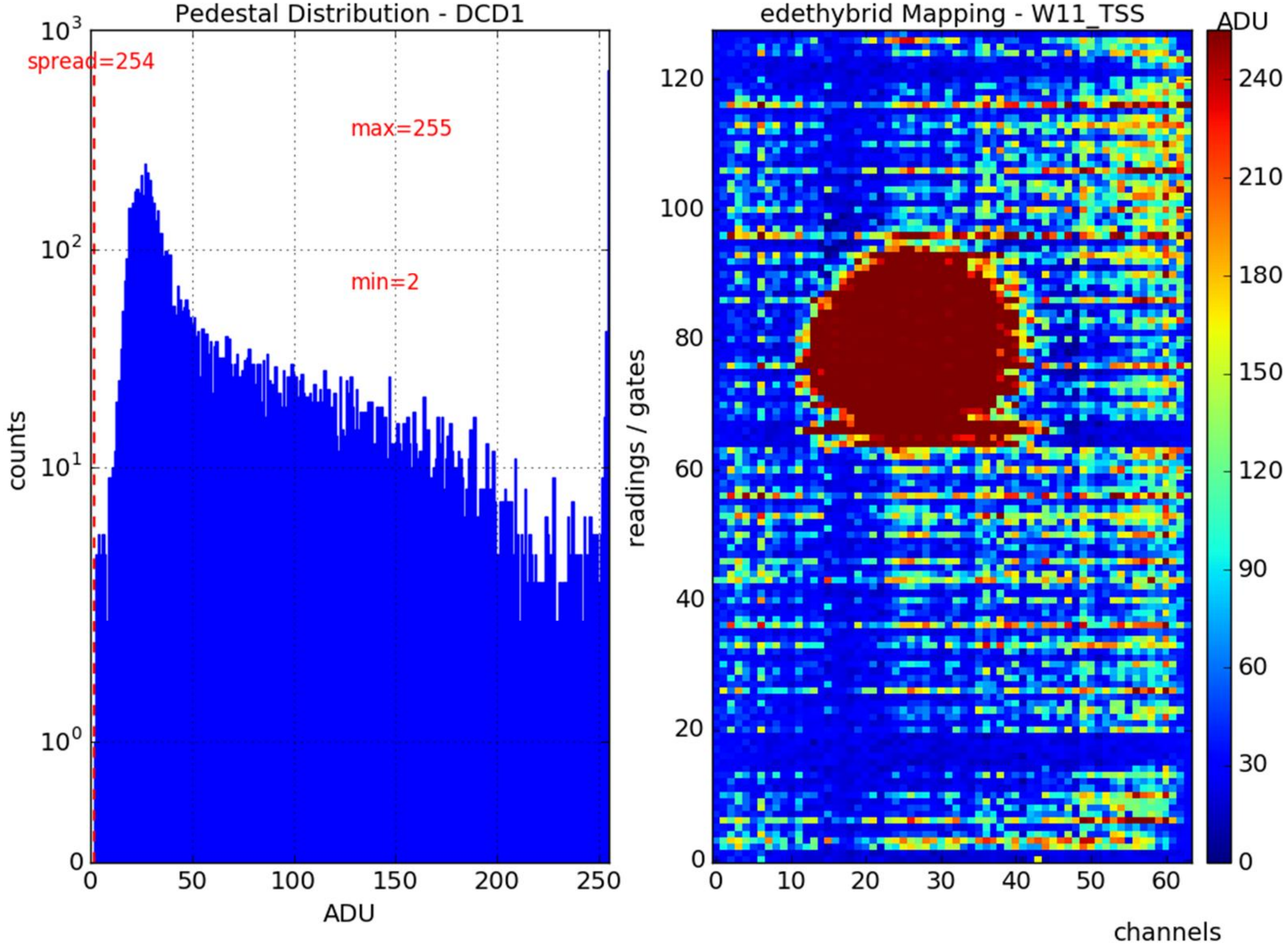
0		16	
64	32	80	48
1	96	17	112
65	33	81	49
2	97	18	113
66	34	82	50
3	98	19	114
67	35	83	51
4	99	20	115
68	36	84	52
5	100	21	116
69	37	85	53
6	101	22	117
70	38	86	54
15	102	13	118
7	11	8	9
14	10	31	12
25	29	23	27
28	24	30	26
43	47	41	45
42	39	44	40
51	46	59	63
56	57	58	55
79	60	77	62
71	75	72	73
78	74	95	76
89	93	87	91
92	88	94	90
107	111	105	109
106	103	108	104
125	110	123	127
120	121	122	119
143	124	141	126
135	139	136	137
142	138	159	140
153	157	151	155
156	152	158	154
171	175	169	173
170	167	172	168
189	174	187	191
184	185	186	183
207	188	205	190
199	203	200	201
206	202	223	204
217	221	215	219
220	216	222	218
235	239	233	237
234	231	236	232
253	238	251	255
248	249	250	247
134	252	150	254
198	166	214	182
133	230	149	246
197	165	213	181
132	229	148	245
196	164	212	180
131	228	147	244
195	163	211	179
130	227	146	243
194	162	210	178
129	226	145	242
193	161	209	177
128	225	144	241
192	160	208	176
	224		240

- enter correct pad connections from the layout in an excel sheet
- electrical row consists of 4 geometrical rows
- the pad arrangement for the EDET-Small-Matrix does not fully correspond to the geometrical numbering: 3,2,1,0 à 3,1,2,0
- sort by DCD channel index & reversely by matrix index and copy corresponding matrix to python program mapping.py

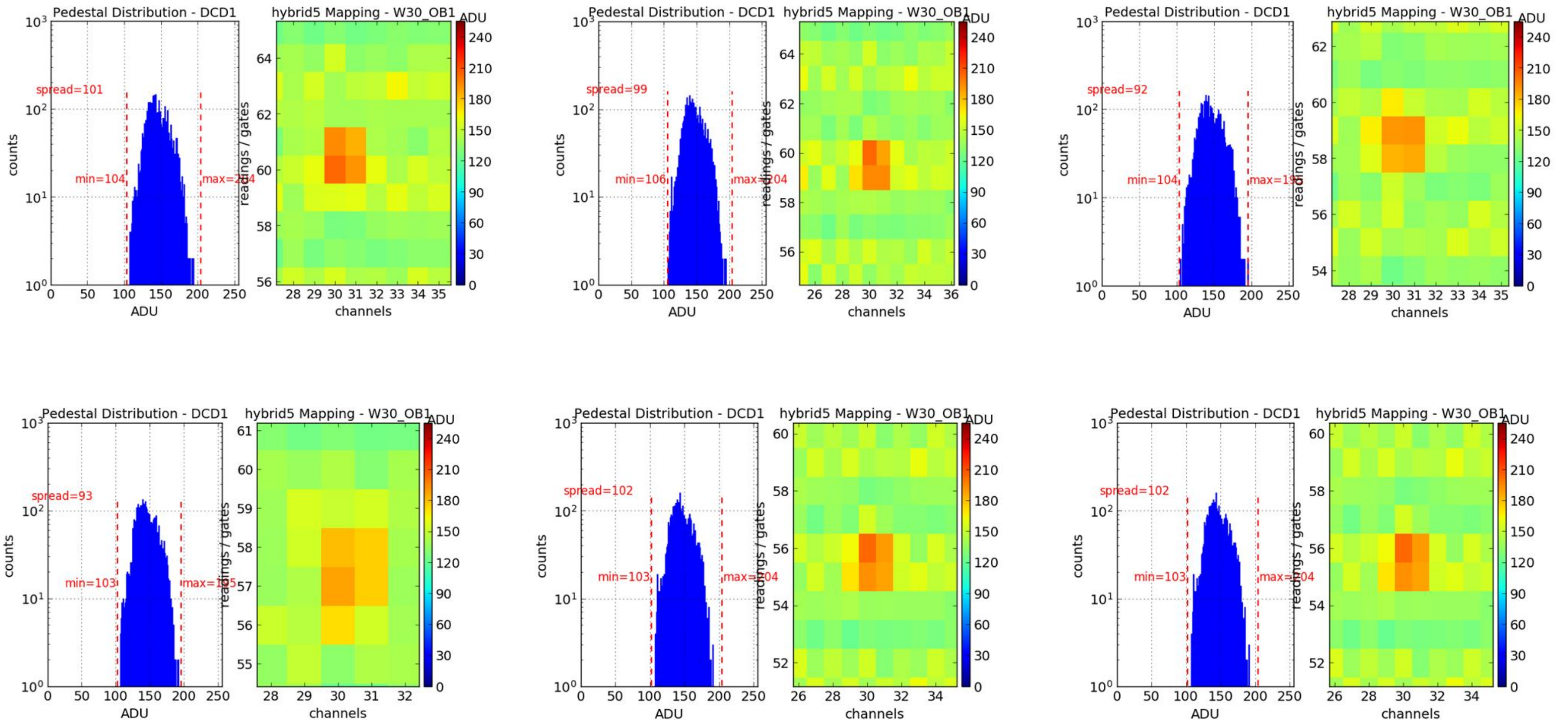
```
DHPHybrid5Mapping =np.asarray([
0,16,224,240,192,208,160,176,128,144,225,241,193,209,161,177,
129,145,226,242,194,210,162,178,130,146,227,243,195,211,163,179,
131,147,228,244,196,212,164,180,132,148,229,245,197,213,165,181,
133,149,230,246,198,214,166,182,134,150,252,254,248,250,249,247,
253,251,238,255,234,236,231,232,235,233,239,237,220,222,216,218,
217,215,221,219,206,223,202,204,199,200,203,201,207,205,188,190,
184,186,185,183,189,187,174,191,170,172,167,168,171,169,175,173,
156,158,152,154,153,151,157,155,142,159,138,140,135,136,139,137,
143,141,124,126,120,122,121,119,125,123,110,127,106,108,103,104,
107,105,111,109,92,94,88,90,89,87,93,91,78,95,74,76,
71,72,75,73,79,77,60,62,56,58,57,55,51,59,46,63,
42,44,39,40,43,41,47,45,28,30,24,26,25,23,29,27,
14,31,10,12,7,8,11,9,15,13,102,118,70,86,38,54,
6,22,101,117,69,85,37,53,5,21,100,116,68,84,36,52,
4,20,99,115,67,83,35,51,3,19,98,114,66,82,34,50,
2,18,97,113,65,81,33,49,1,17,96,112,64,80,32,48
], dtype=np.uint8)
```

MAPPING – FUNCTIONAL TEST

E1-I-02 Hybrid Board



Laser Spot x-direction



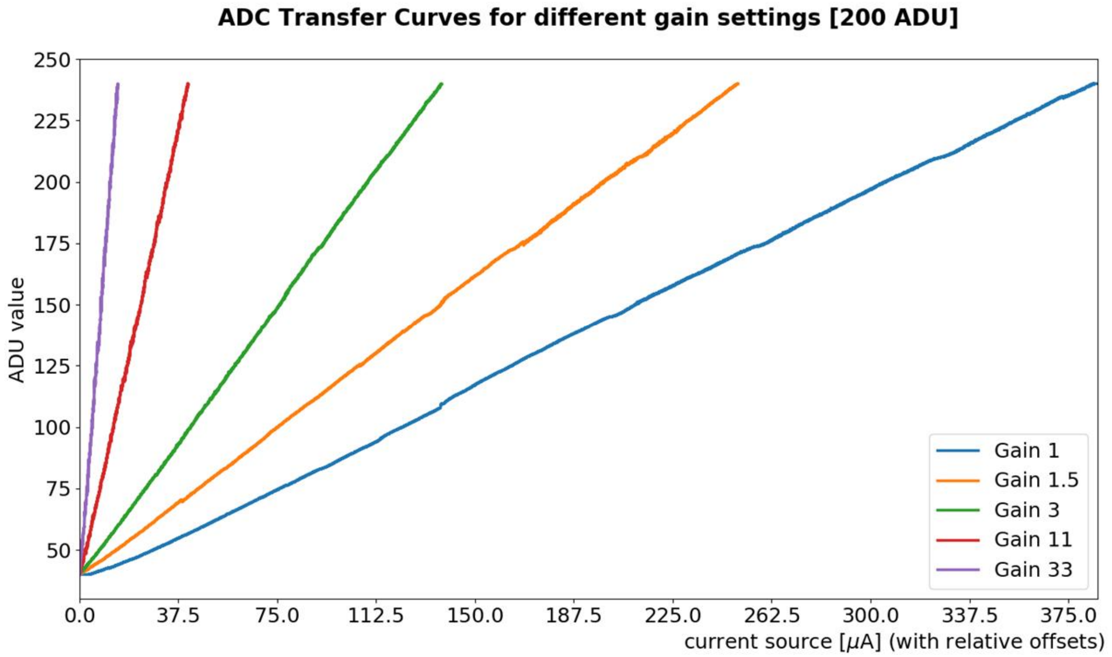
DCDE-Manual DAC-Registers

Bit No	Name	Purpose	Description
[250:253]	q(26:29)	En30 (TIA gain BELLE 26/15) (EDET: 60/15), En60 (TIA gain BELLE 13/15) (EDET: 3/15), En90 (TIA gain BELLE 19/15) (EDET: 1.5/15), En120 (BELLE not used) (EDET 15/30) (ADC range is 32 μA)	gain control (Fig. 1.4)
[254:257]	q(30:33)	EnCap(0:3); EnCap(1) Stability cap	Bandwidth control (Fig. 1.4)
[258:261]	q(34:37)	(34): Belle: NU; EDET: 0 - boost SubIn 1 - normal SubIn, (35): NU, (36): CMC cap (if ACMC is used set to one), (37): ConnAmpLow (if ACMC is used set to zero)	Fig. 1.4
[262]	q(38)	EnDoubleSamplingB	Zero enables double sampling mode (Fig. 1.3)
[263]	q(39)	EnDoubleSampling	One enables double sampling mode (Fig. 1.3)

Table 3.3: Global shift register

DCDE Gain Variation

En30	En60	En90	En120	Gain	Times lowest Gain
1	1	1	1	0.061	1.0
0	1	1	1	0.063	1.0
1	1	1	0	0.065	1.1
0	1	1	0	0.067	1.1
1	0	1	1	0.087	1.4
0	0	1	1	0.091	1.5
1	0	1	0	0.095	1.6
0	0	1	0	0.100	1.7
1	1	0	1	0.154	2.5
0	1	0	1	0.167	2.8
1	1	0	0	0.182	3.0
0	1	0	0	0.200	3.3
1	0	0	1	0.667	11.0
0	0	0	1	1.000	16.5
1	0	0	0	2	33



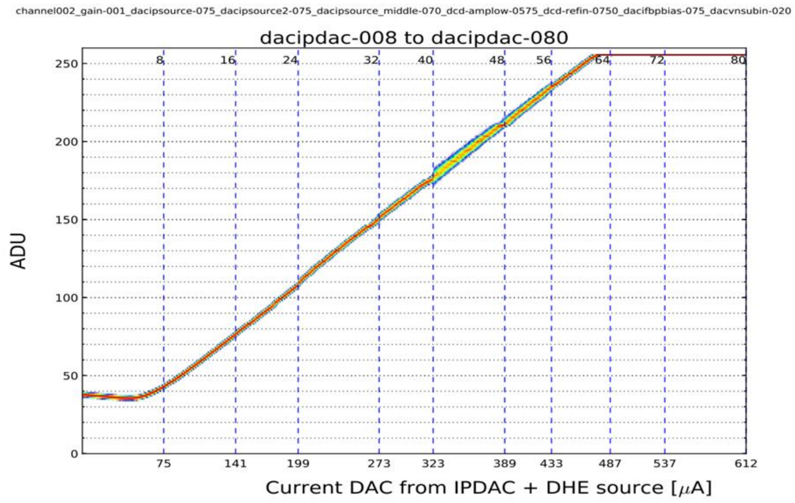
R_f: En30 = 30k
En60 = 3k
En90 = 1.5k
En120 = 15k
R_s = 15k

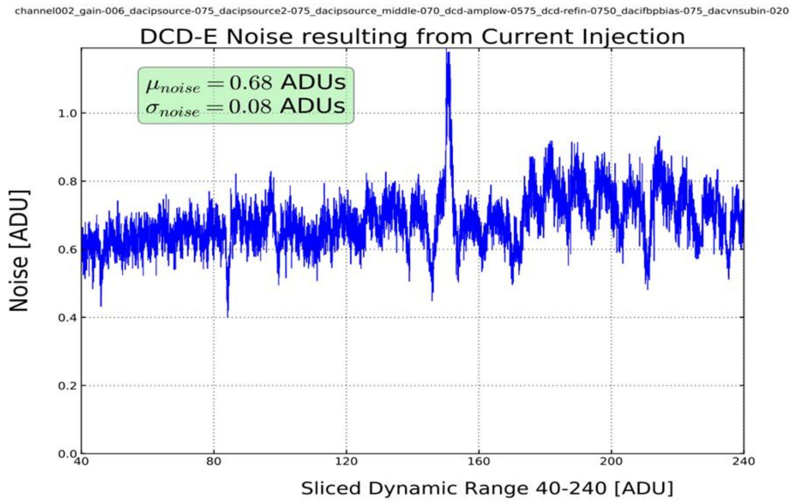
$$Gain = \frac{R_f}{R_s}$$

Gain	dynamic range for 200 ADU [μA]
1	380
1.5	250
3	137
11	41
33	15

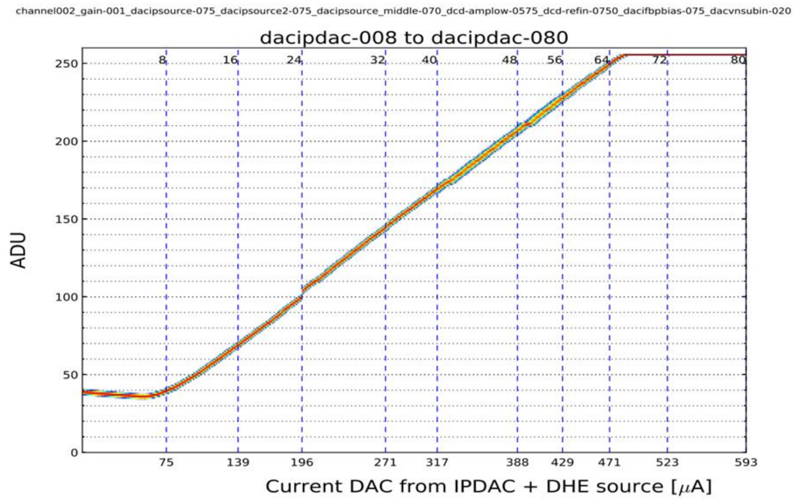
Resistor	EDET	BELLE
En30	30k	19k
En60	3k	15k
En90	1.5k	26k
En120	15k	not used

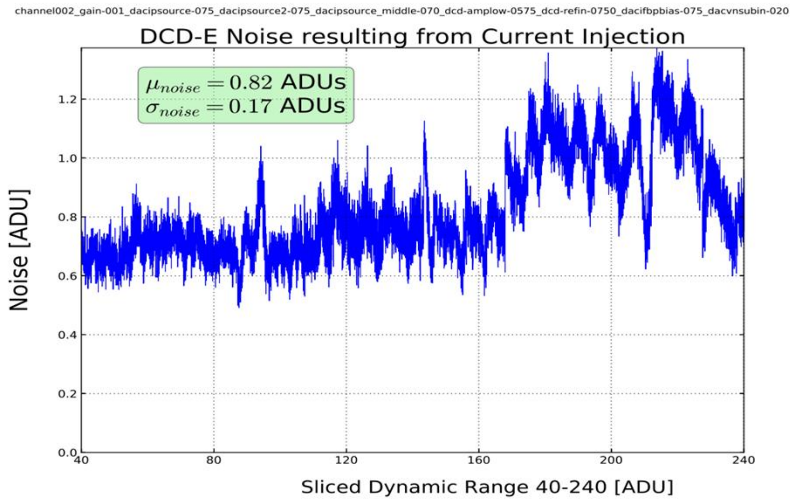
BELLE (top) vs EDET (bottom) PS – low gain



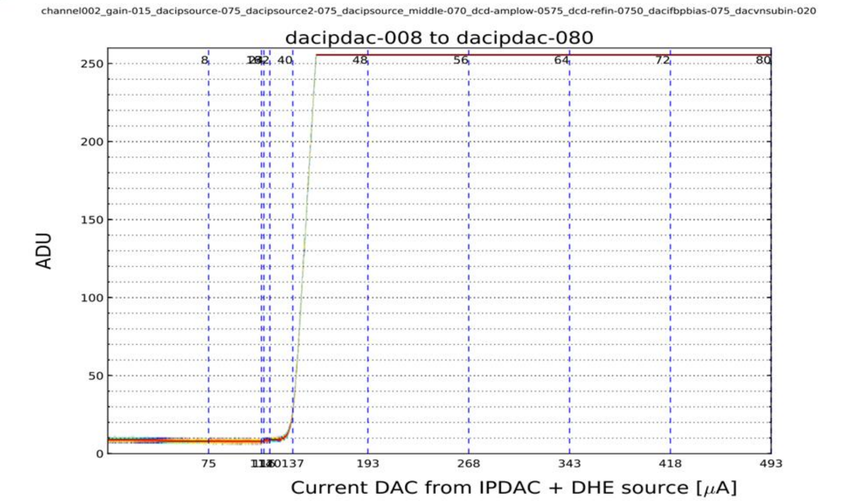


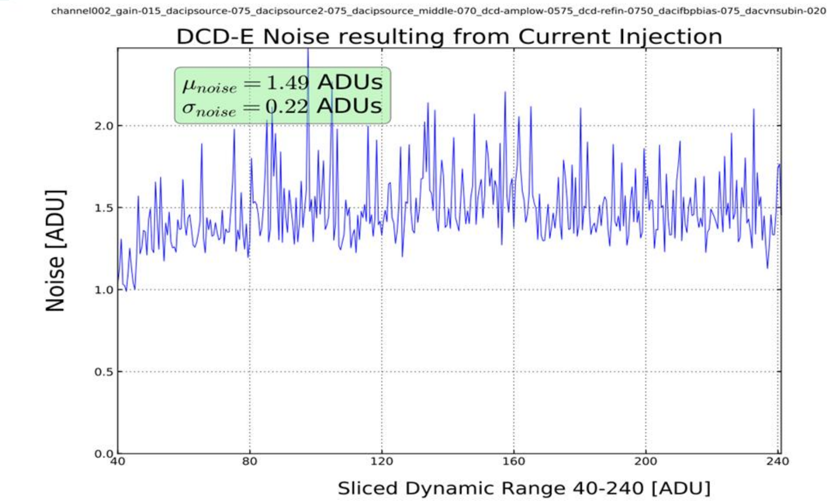
DHE current source limited to 75µA à solution: compound curves with IPDAC

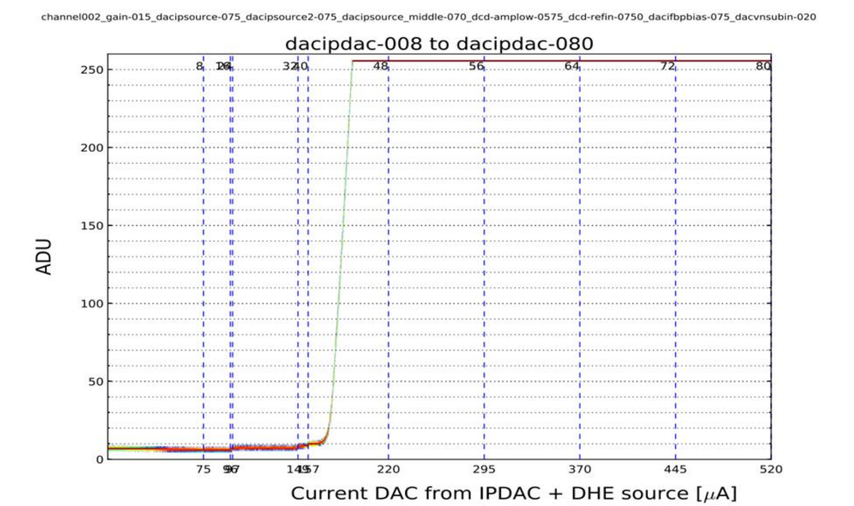


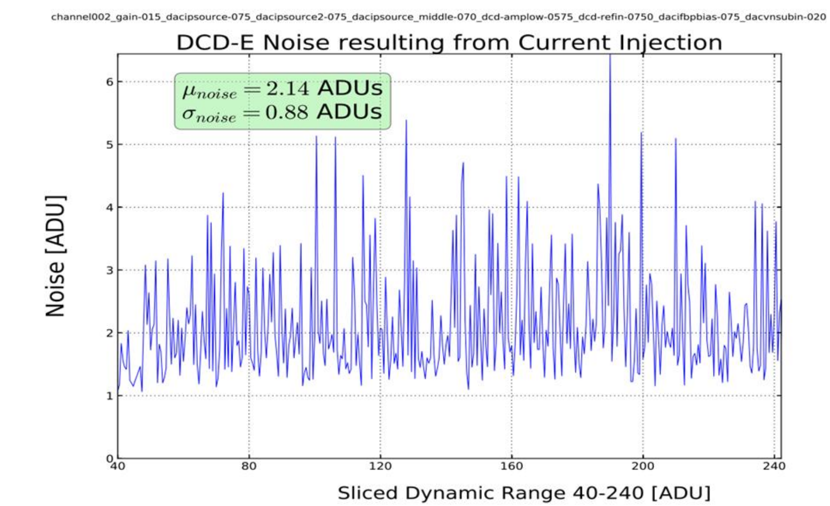


BELLE (top) vs EDET (bottom) PS – high gain

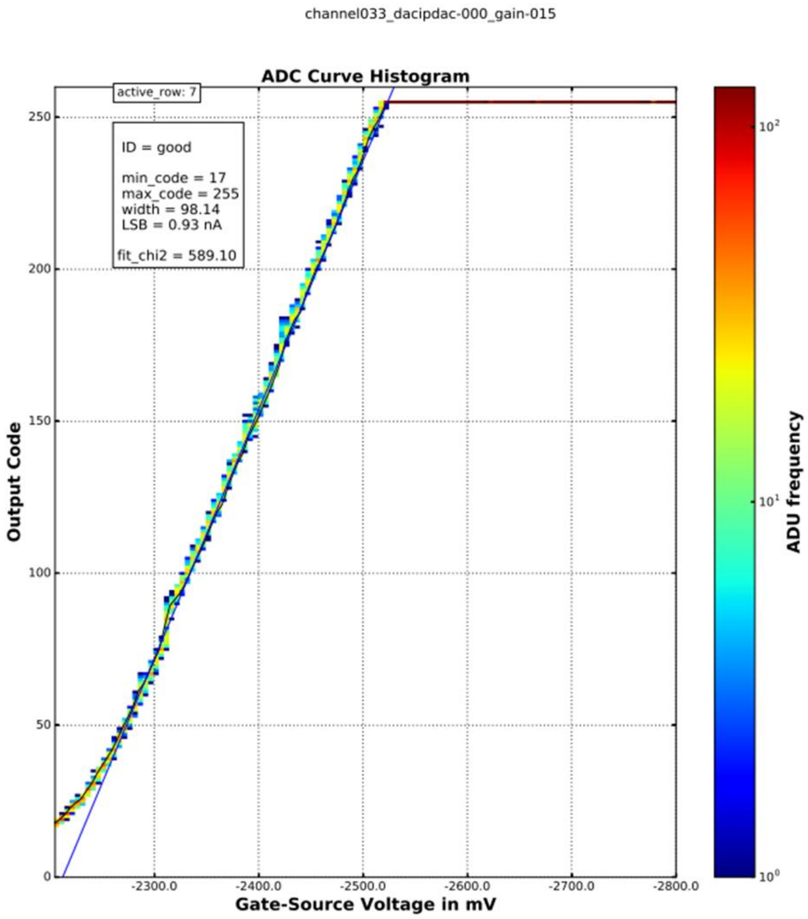


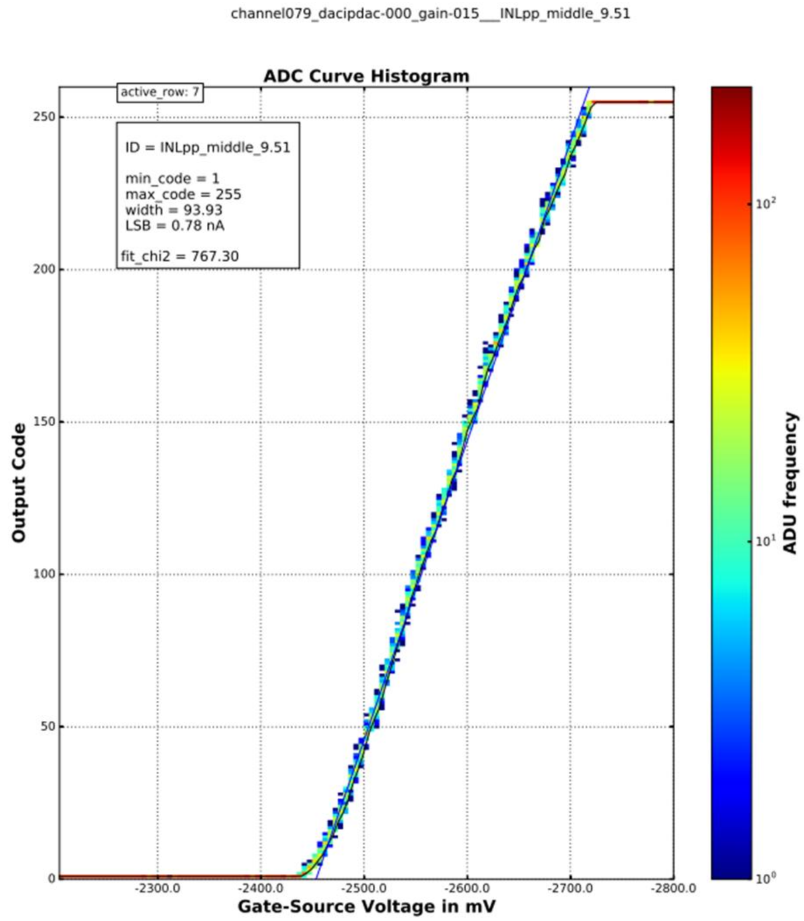




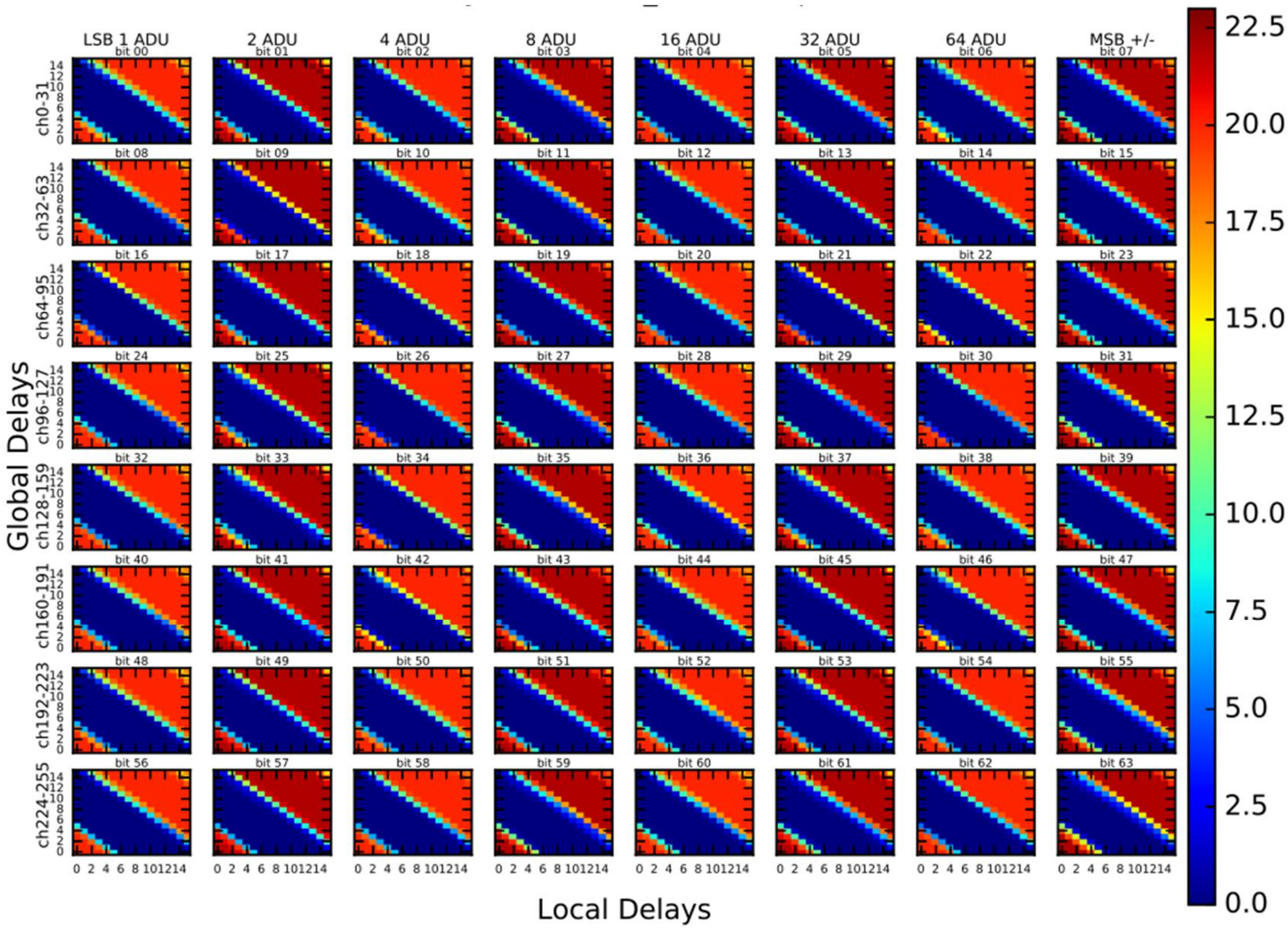


Matrix based Transfer Curves – high gain





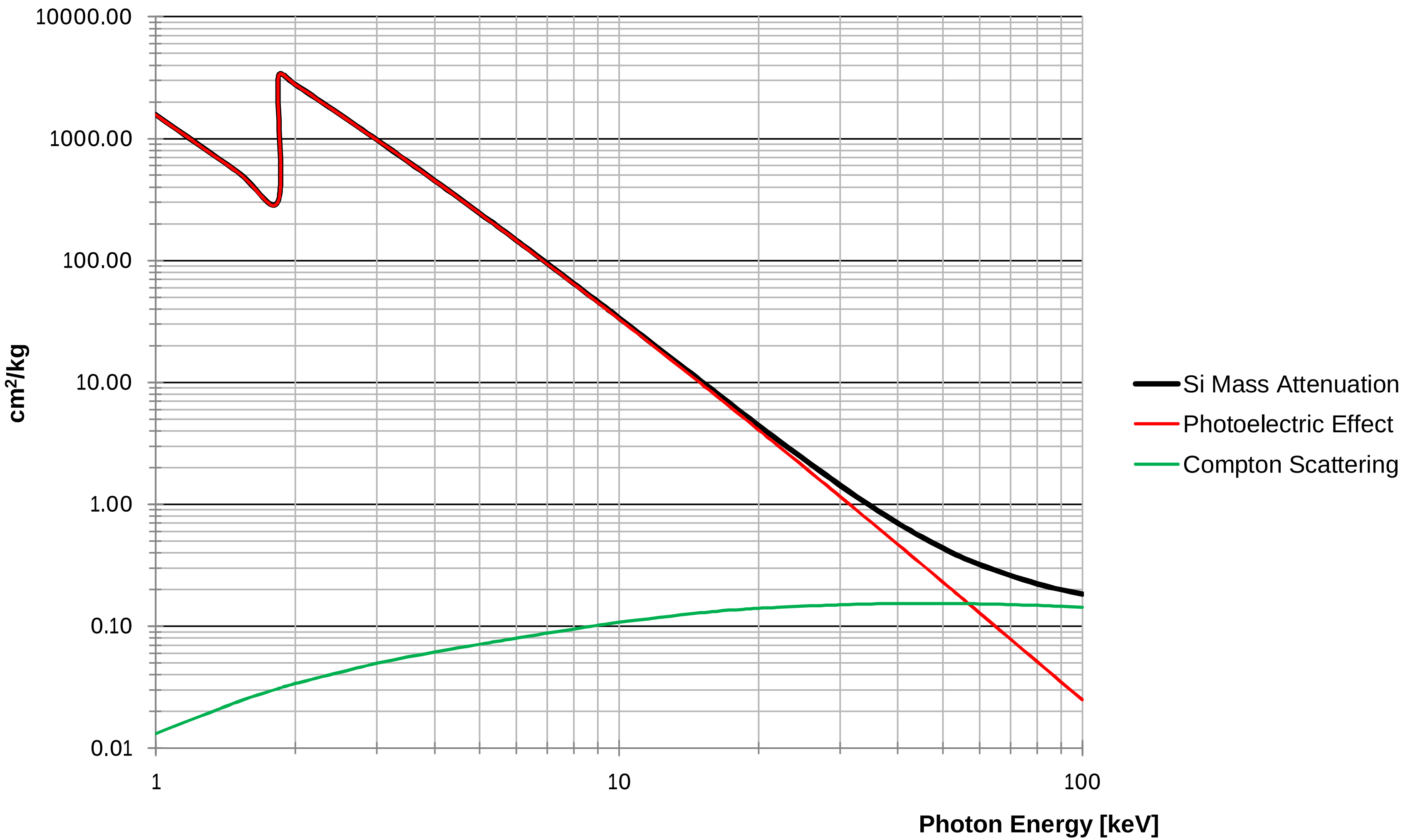
DELAY SCAN – E1-I-04



CALIBRATION BRAINSTORMING

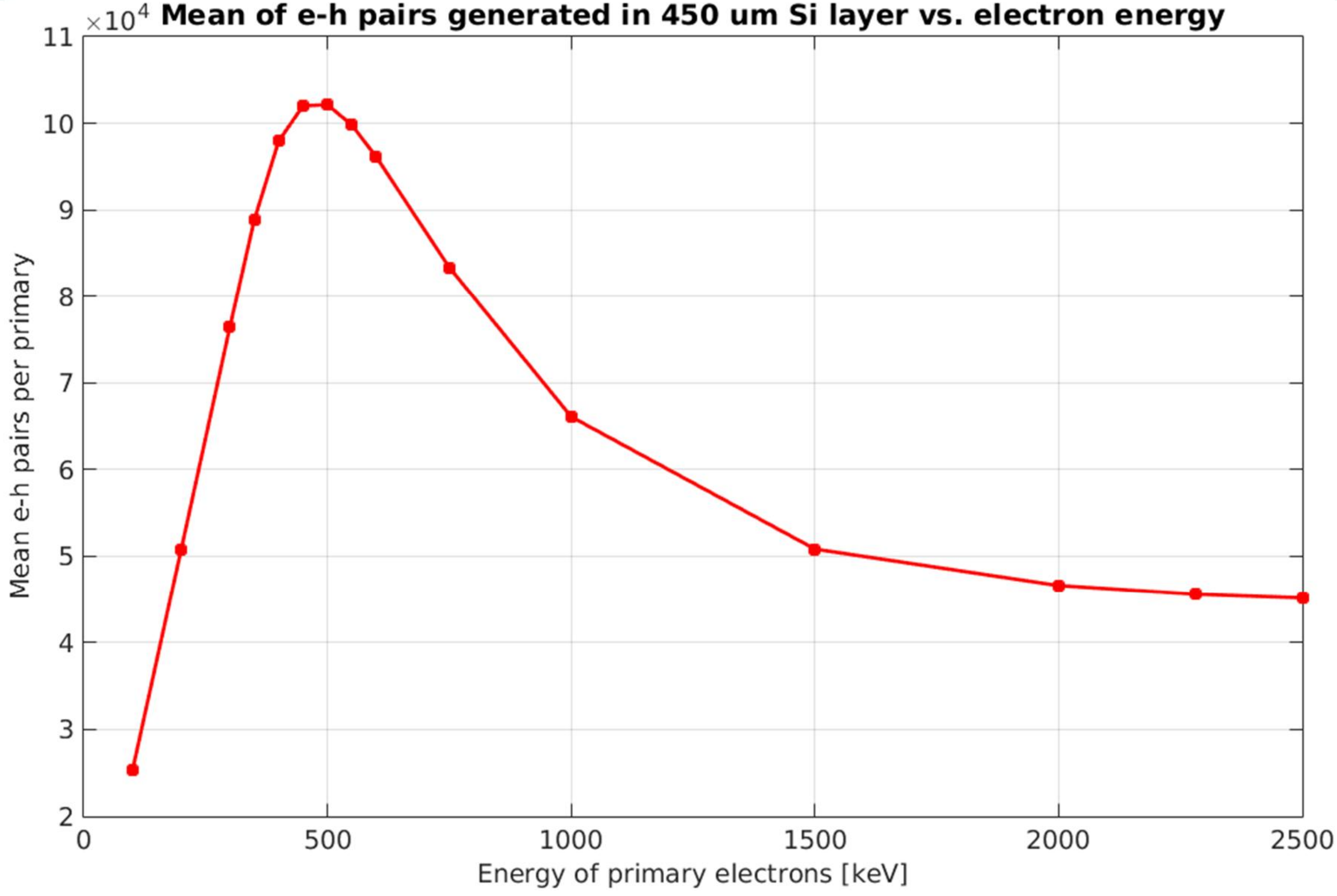
METHOD	DESCRIPTION	PROS	CONS
X-ray Source (low energy)	Cd^{109} 22keV	• acceptable interaction probability • equipment HLL available	• generates only about 6000 e^- • geometry allows for only 1-2 events per readout
X-ray Source (high energy)	beyond 140keV (corresponds to 10ADUs)	• no vacuum apparatus necessary	• very low photoabsorption probability of 0.01% • Compton effect dominates • availability of Source
b- emitter	Sr^{90} continuous spectrum	• generates over 100,000 e/h pairs (I. Dourki)	• around 300 keV electrons would leave the detector, so escape energy has to be measured (scintillator)
a emitter	Am^{241} 5.486MeV (encapsulated as 60keV g-source usable)	• forces internal gate capacity to maximum level (1,000,000 e^-)	• vacuum device and corresponding interconnection hardware necessary • detector radiation damages • radiation protection N
SEM/TEM		• gradual increase of both intensity (in 10eV steps up to 300keV) and quantity of e^-	• vacuum device and corresponding interconnection hardware necessary
Laser	660nm	• easy focusing • intensity controllable via applied voltage and time (pulsing) • equipment HLL available	• exact energy transfer unknown (approximation with optical power meter) • only cell-by-cell calibration
CLEAR Backinjection	capitalizes on variation of integration time	• relatively quick calibration of all pixels possible	• level of original backinjection not known (but can be measured indirectly – laser) • finding optimal operation point for all pixels (process variation)

Above 60keV Compton Scattering dominates



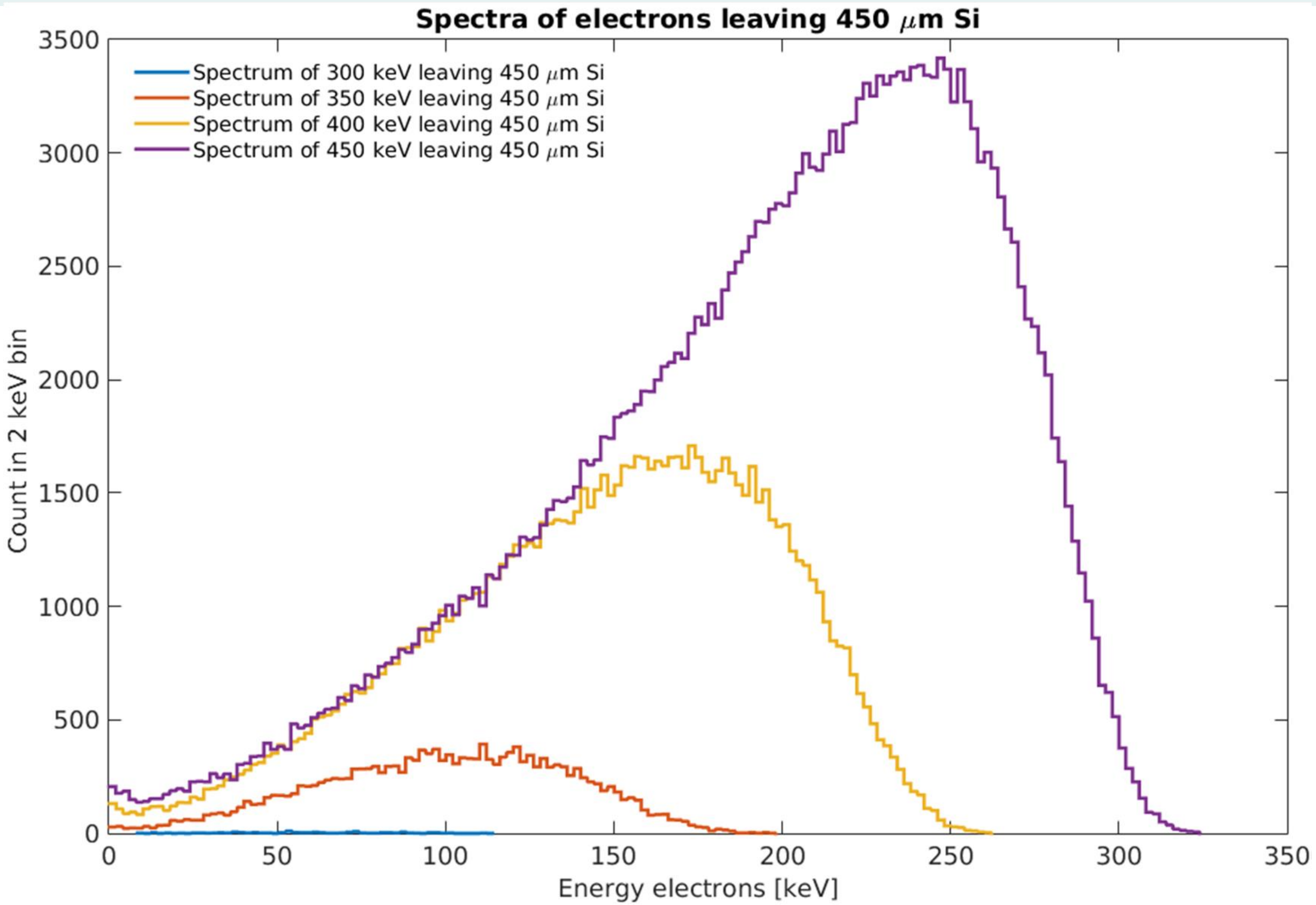
Source: NIST data

Different Energetic Primary Electrons



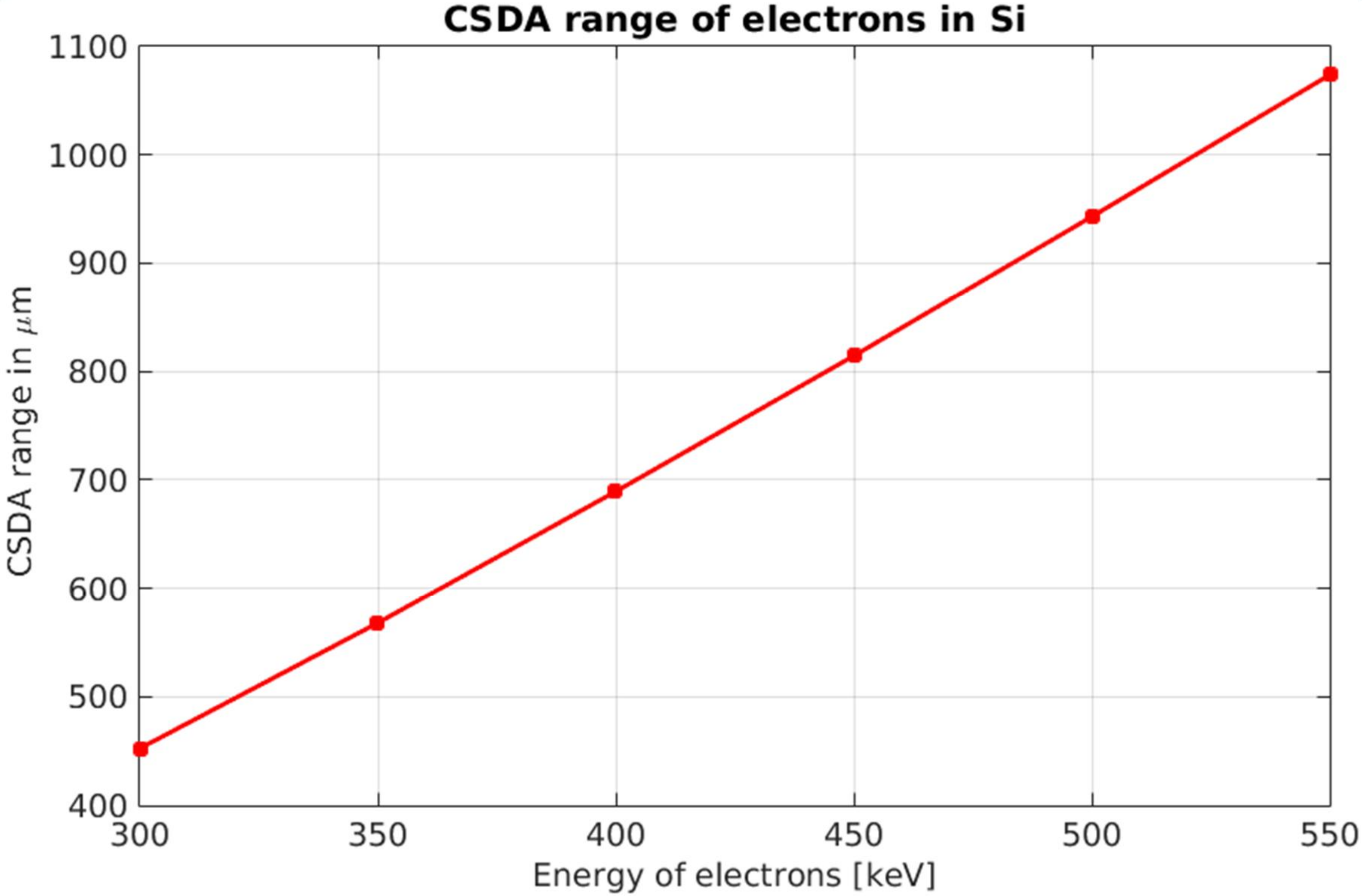
Ibrahym Dourki

Spectra of high energetic electrons leaving Si



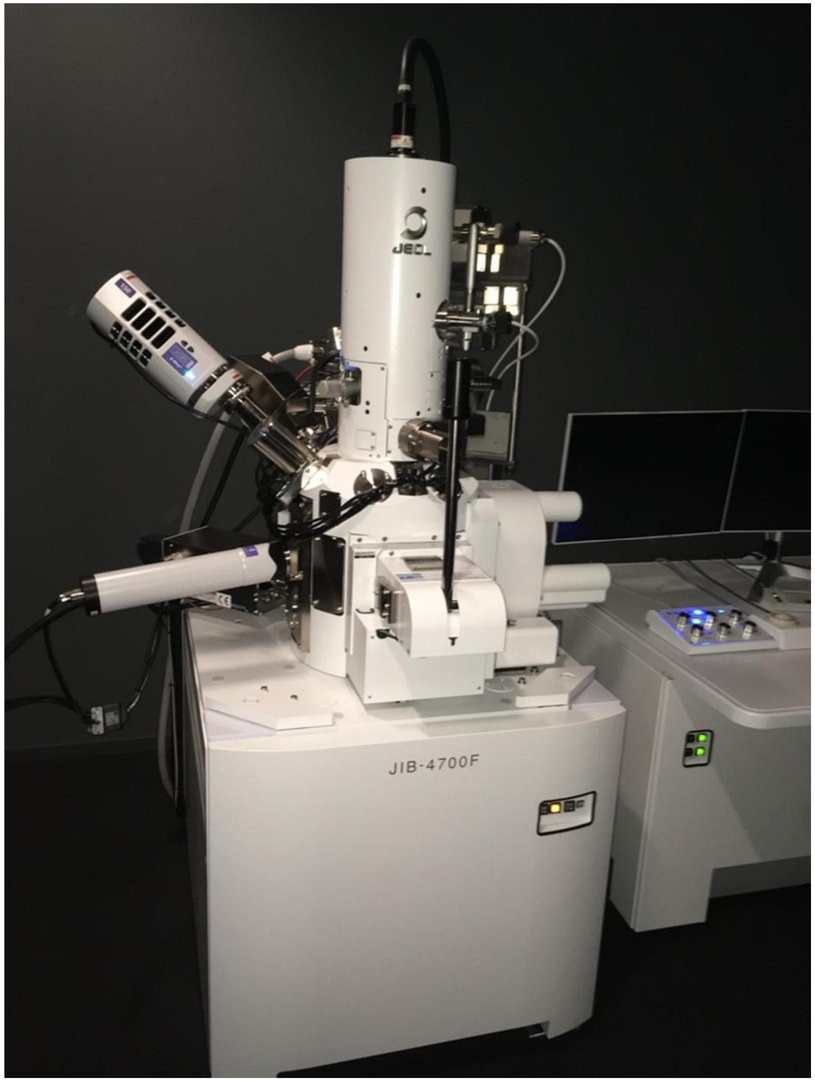
Ibrahym Dourki

average path length of electrons in Si



Ibrahym Dourki

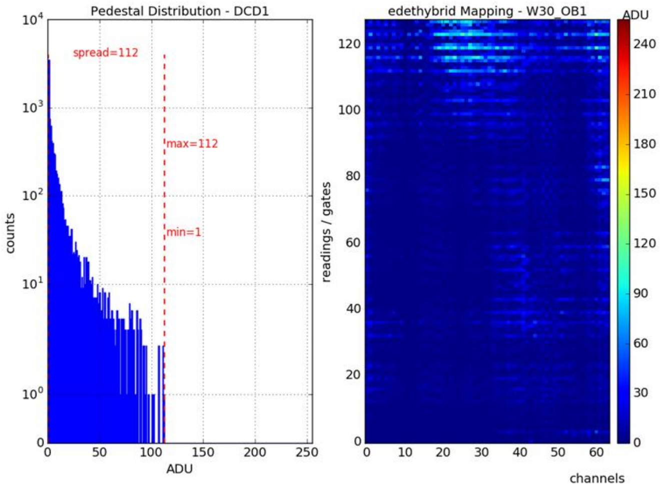
SEM/TEM – JEOL

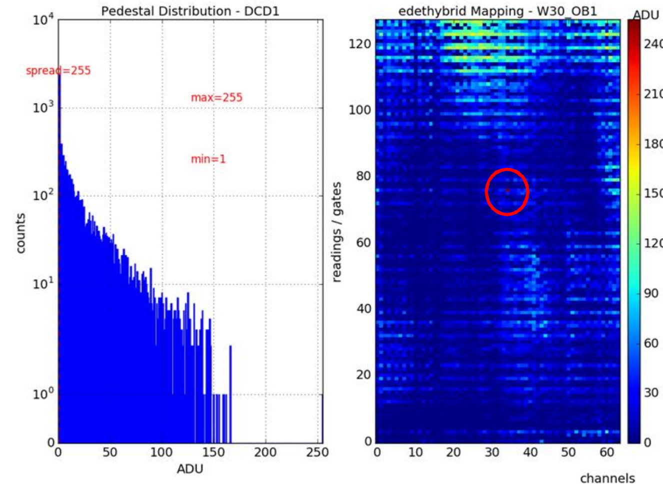


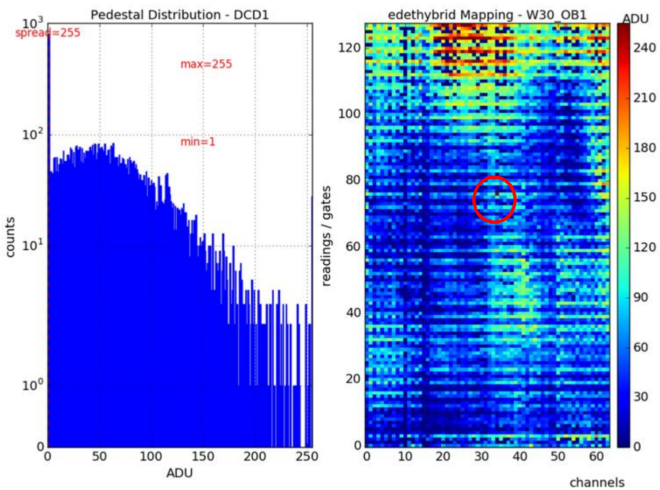
SOLUTION

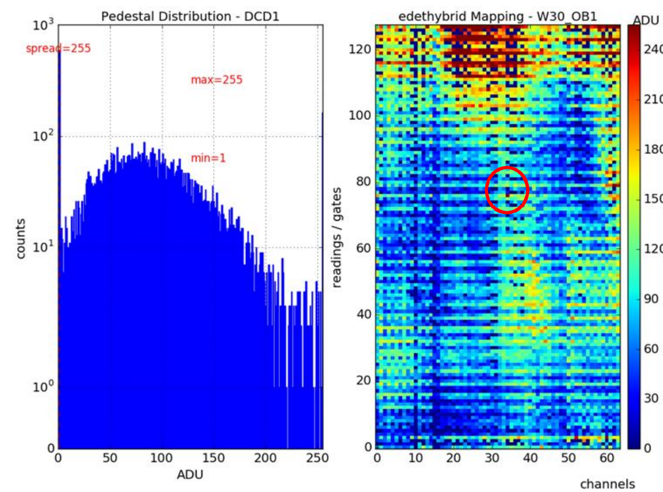
- Calibrate laser pulse with Cd^{109} source in high gain mode (from BELLE experience about 20 ADU, which corresponds to 1-2 ADU in lowest gain mode)
- Step-increase of pulse count within one readout period in order to measure a discrete gain curve

Find optimal HV-Voltage 0V,-10V, -20V, -30V









Expected Cd109-Peak – Calculations

$$g_q \sim \frac{1}{W^{1/2} L^{3/2}} \sqrt{I_{drain}}$$

$$g_q^{smat} \sim \frac{1}{4.4^{1.5} \times 28.6^{0.5}} = 0.020 \qquad g_q^{spix} \sim \frac{1}{5.4^{1.5} \times 21.6^{0.5}} = 0{,}0171 \qquad g_q^{belle} \sim \frac{1}{3.6^{1.5} \times 13.4^{0.5}} = 0.044$$

parameter	value	unit
L(small matrix gate)	4.4*	µm
L(small pixel gate)	5.4*	µm
W(small matrix gate)	28.6*	µm
W(small pixel gate)	21.6*	µm
DCD-E dynamic range (high gain)	20	µA
à 1 ADU	78.4	nA
Cd109 – 22 keV	»6000	e^-
small pixel measured g_q	200	pA/e^-
6000 x 200pA à 1.2µA	15.3	ADU
$I_{drain}^{smat}, I_{drain}^{spix}$	74, 100(140)	mA
à rescaled by $\sqrt{I_{drain}}$ and g_q	**15.3 (13.0)**	ADU

* For wet etching normally a value of 1.4µm has to be deducted (in case of L) or added (in case of W) respectively from the design value; here it was plasma-etched à only 0.6µm

Calculated hits with Cd-Source

Source	Cd^{109}
Reference Date	15.04.2015
Measurement Date	06.04.2018
elapsed time t (d)	1087.00
halflife $T_{1/2}$ (d)	462.00
decay constant λ	0.001500
Activity Ref.Date	7.40E+08
Emission Rate (s^{-1} $ster^{-1}$)	4.85E+07
Activity Meas.Date	1.45E+08
Sensor-Thickness (µm)	50
Si density (g/cm³)	2.329
Be density (g/cm³)	1.848
Al density (g/cm3)	10.49

$I/I_0 = exp[-(\mu/\rho)x]$

$Sensor\ Thickness \times \rho$
$= mass\ thickness\ x$

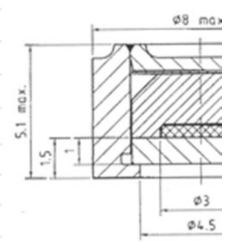
Frame Time (µs)	4.096
Detector side	back
#Frames	100000

exp. Entries (with XL)		9,601
exp. Entries (without XL)		9,578
entries per event		0.10
detailed		
	XL	0
	$XK_{\alpha 2}$	2,877
	$XK_{\alpha 1}$	5,356
	$XK_{\beta 3,1,5}$	1,154
	$XK_{\beta 2,4}$	190
	γ	23

Photon Emissions	energy keV	Photons (per 100 disint.)
XL	3.191	10.37
$XK_{\alpha 2}$	21.9906	29.21
$XK_{\alpha 1}$	22.16317	55.1
$XK_{\beta 3,1,5}$	25.00	15.25
$XK_{\beta 2,4}$	25.48	2.65
γ	88.0336	3.66
		116.235

Photon Emissions: LNE-LNHB, PTB / M.M. Bé, E. Schönfeld 2/
Photoabsorption: http://web-docs.gsi.de/~stoe_exp/web
http://nucleardat

source geometry	in mm
capsule thickness	1.5
collimator length	5.89
distance PCB	5
PCB thickness	1.6
glue	0.1
matrix cavity	0.4
total distance	**14.49**
opening collimator	4.3
area sphere	2638.44
area beam	212.71
area matrix	12.10
ratio sphere/matrix	218.12



small EDET Matrix with 12
always place the source c

Calculator: http://web-docs.gsi.de/~stoe_exp/web

Find optimal Voltages: high offset dispersion

GateOn= -1,660mV

ClearOn=18,000mV

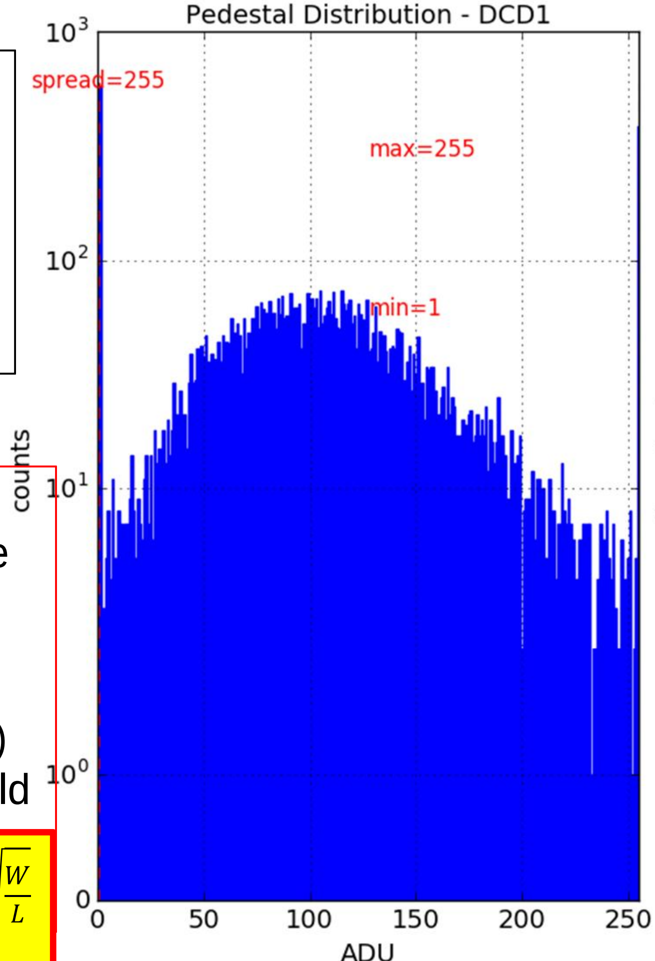
ClearOff=3,000mV

HV= -25,000

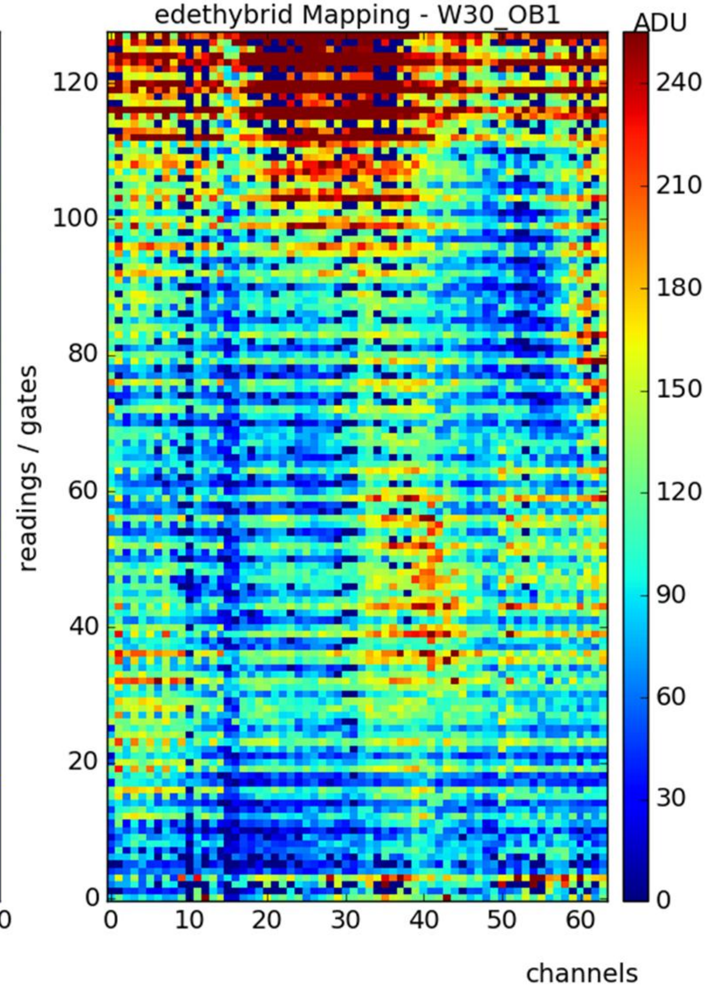
higher (vs BELLE) offset dispersion due to

- higher g_m (32%)
- higher gain (15%)
- different threshold level
- ...

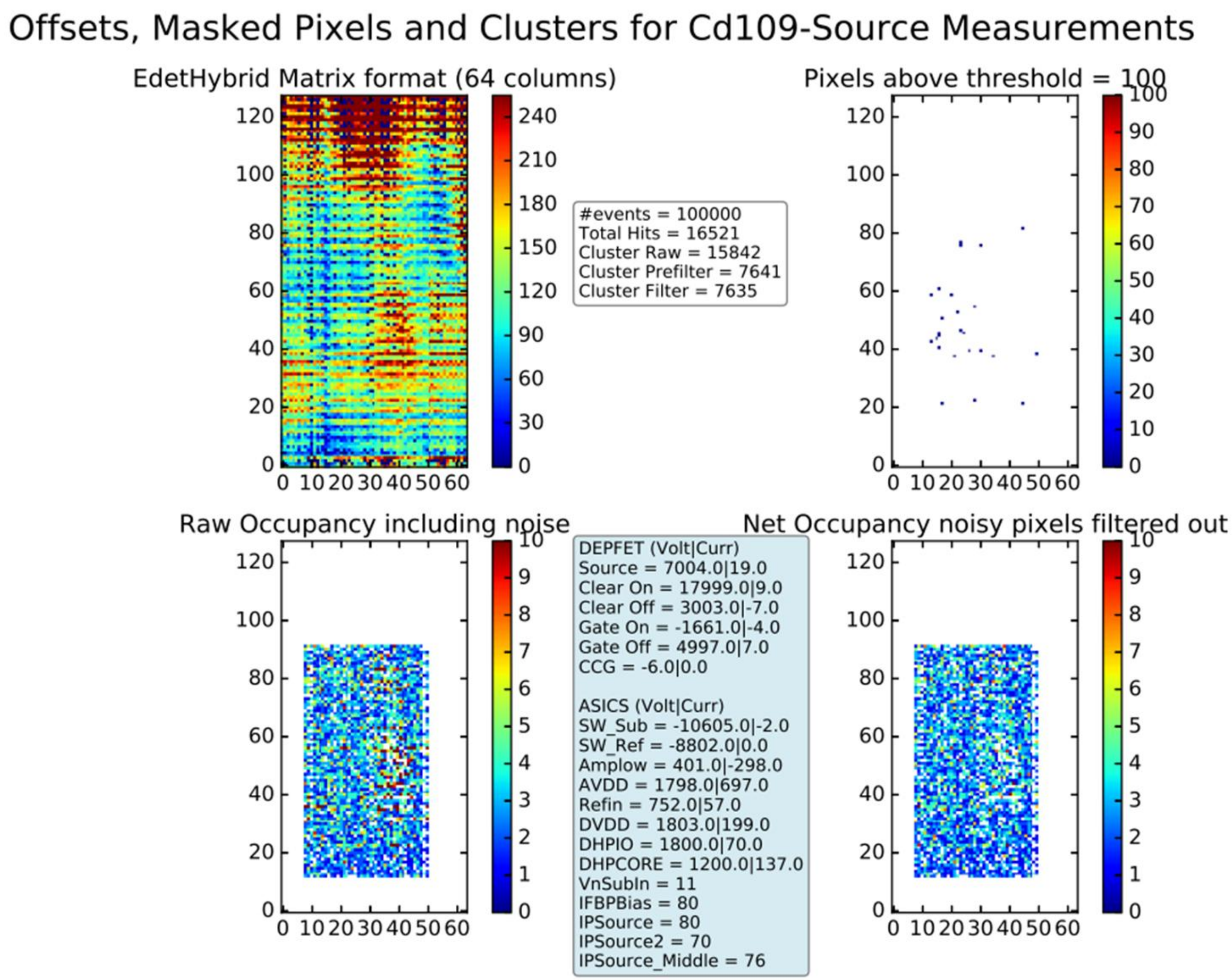
$$g_m \sim \sqrt{\frac{W}{L}}$$



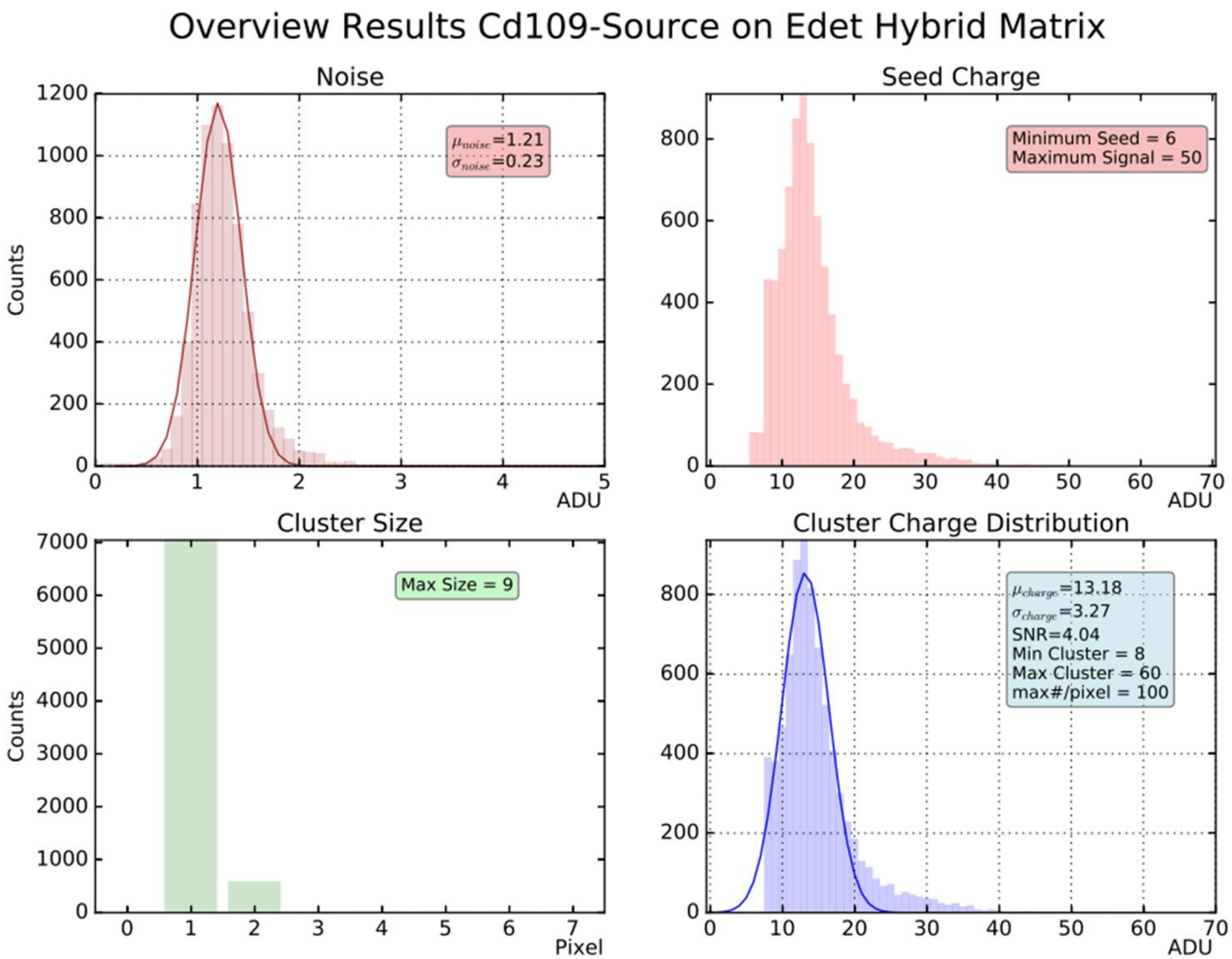
E1-I-04 Hybrid Board



Cd-Source Measurement (1)



Cd-Source Measurement (2)



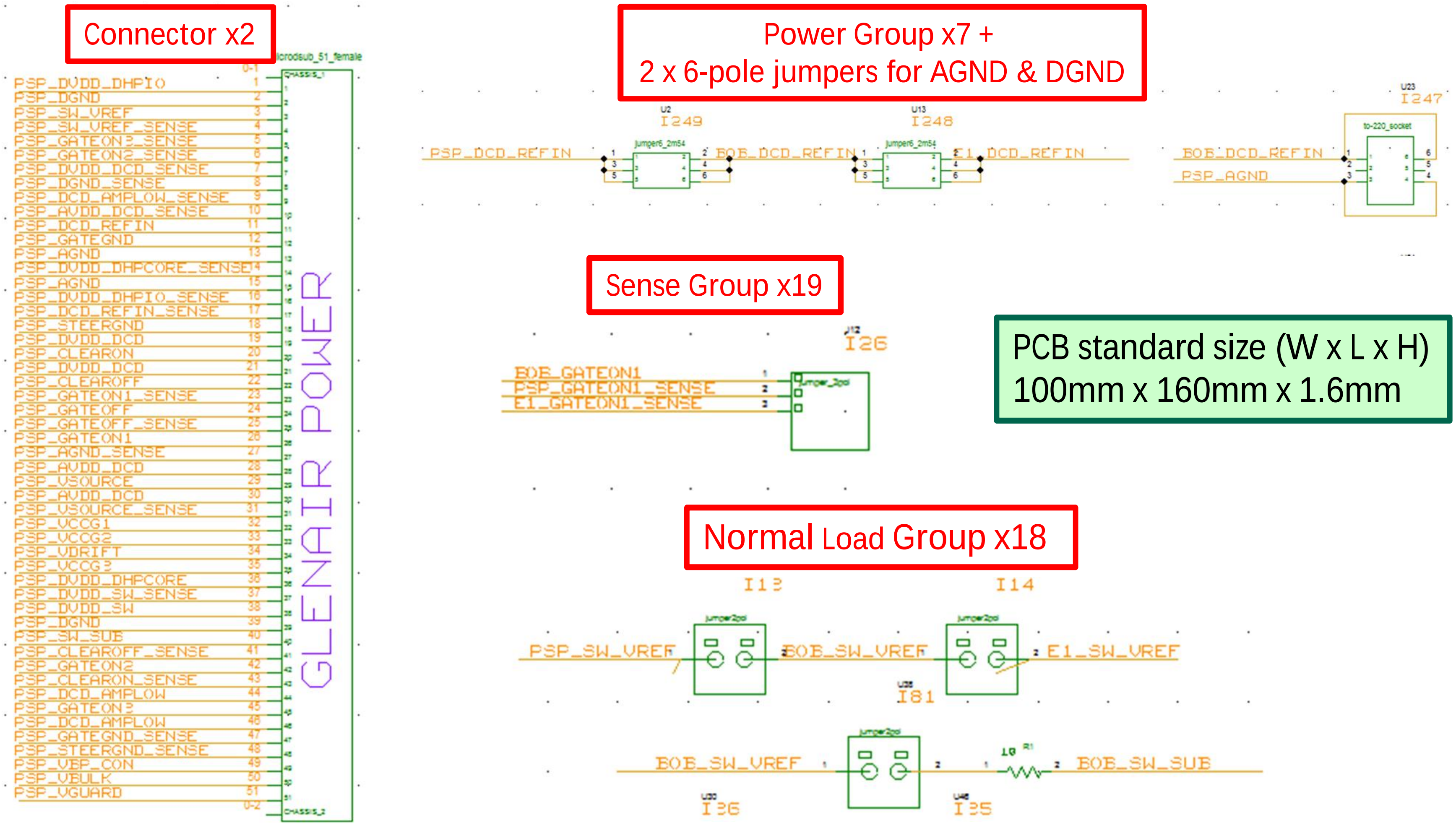
CONCLUSION: channel-length of 5µA should be chosen

NEXT STEPS

- Optimize Settings for Source Measurements
- Calibration of low gain/signal compression with Laser Pulse
- Integration of PSP

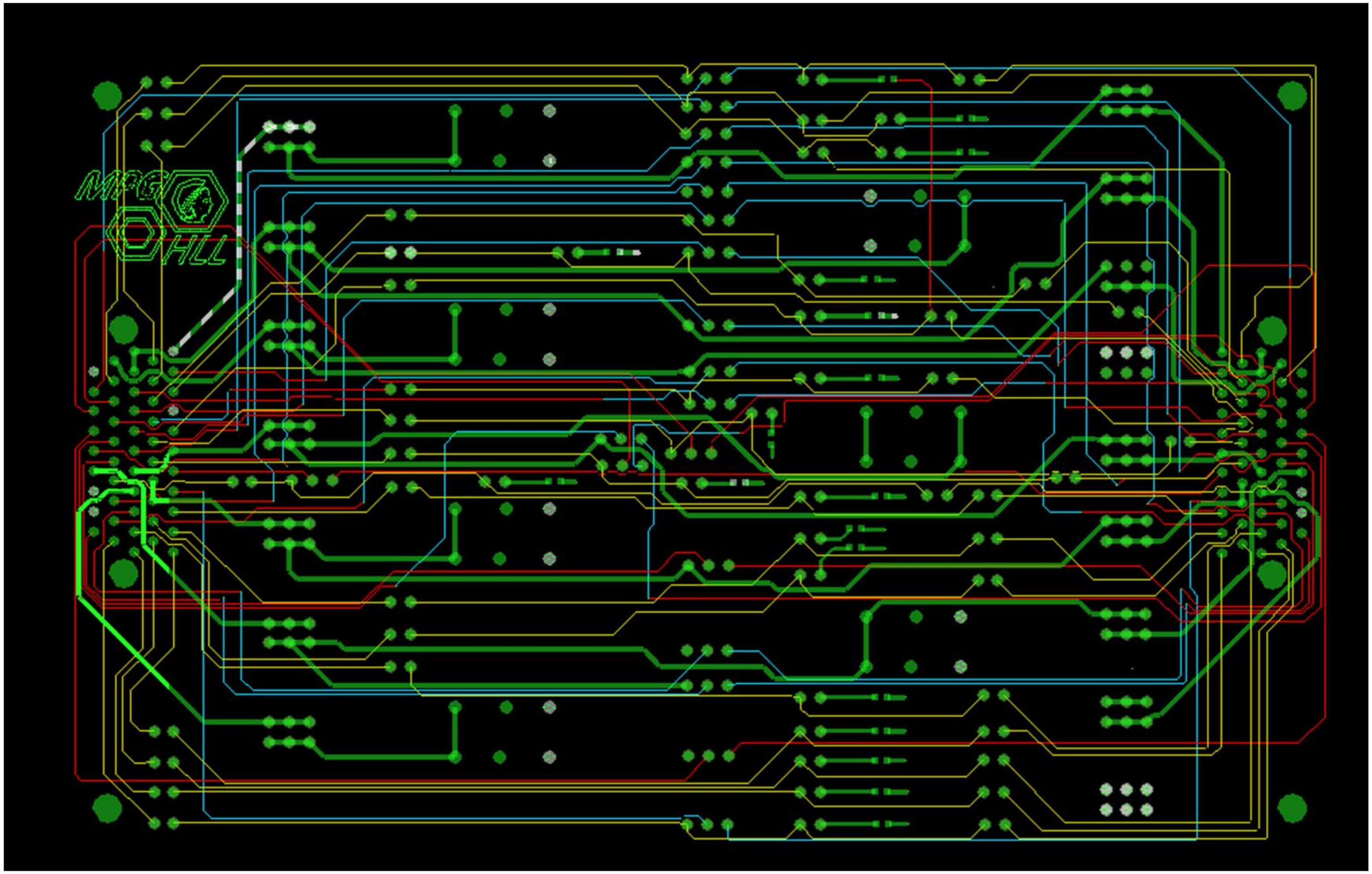
THANK YOU FOR YOUR ATTENTION

PSP Breakout-Board – electronic schematics



- circuit diagram/layout documents the electrical wiring of different components
- define footprints and functionalities in component library

PSP Breakout-Board - Design



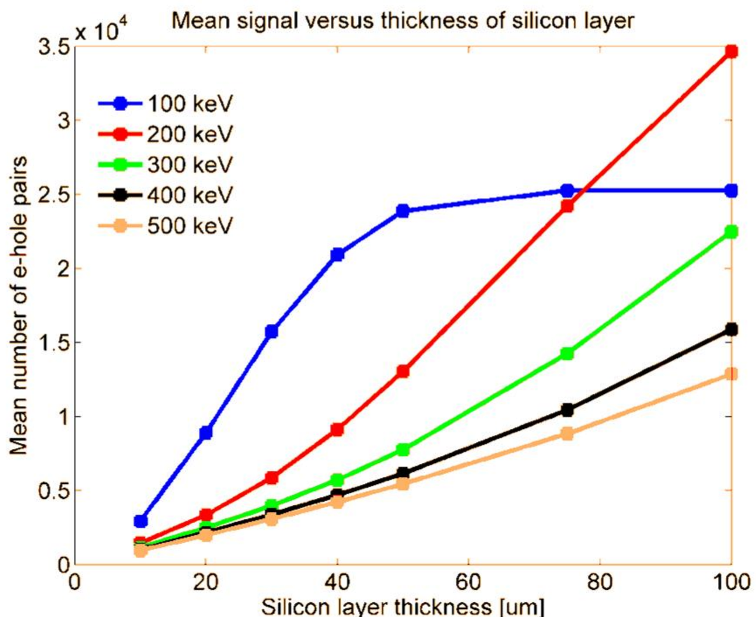
DCDE Noise

Gain	range 200 ADU [µA]	Current/ADU [µA]	DCDE noise [ADU]	DCDE noise [µA]
1	380	1.9	0.92*	1.75
1.5	250	1.25	0.69	0.86
3	137	0.69	0.69	0.48
11	41	0.2	0.96	0.19
33	15	0.08	1.50	0.12

*Maybe too high because of discrete IPDAC transition

1 primary electron generates
$\approx$ 8000 e^- (300 keV)
$\approx$ 24,000 e^-(100 keV)
in 50µm thick silicon detector

EDET detector response for
$1^{st} primary\ electron$ = 300 pA
$100^{th} electron$ = 60 pA
à Incremental Signal for
$1^{st} primary\ electron$ = 2.4 µA
$100^{th} electron$ = 0.48 µA



DCDE noise mainly induced
by quantization error (0.5 ADU)
Not relevant because of statistical deviations
for spatiotemporal signal generation

$$\Delta\ primary\ e^- = \sqrt{primary\ e^-}$$

100	100	100	100
100	110	100	100
100	110	90	100
100	90	100	100

Ibrahym Dourki (CFEL)

SAMPLING POINT SCAN – E1-I-04