Evaluation of different AC-LGAD geometries

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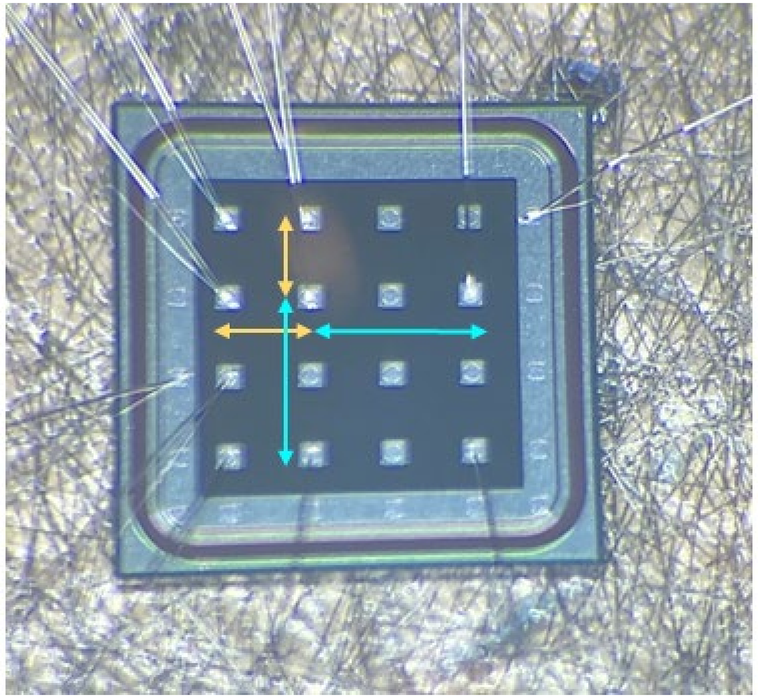
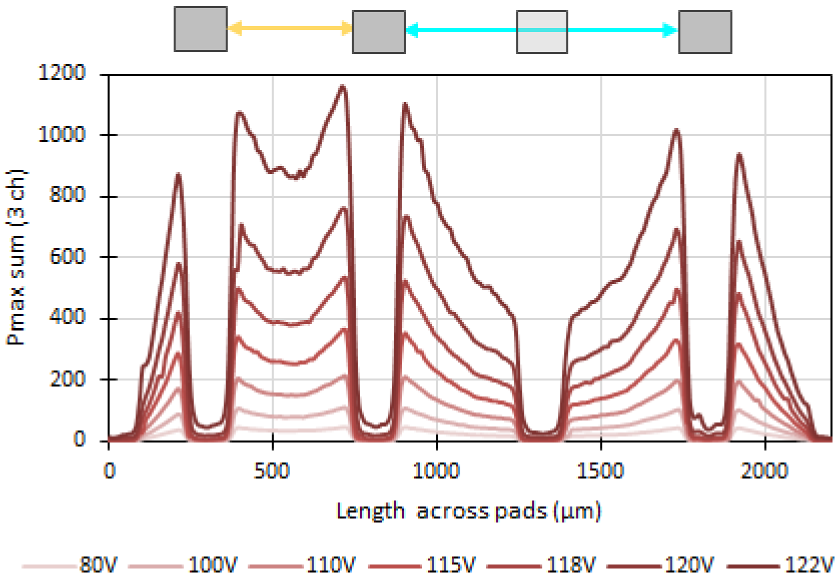
Standard square pad AC-LGAD

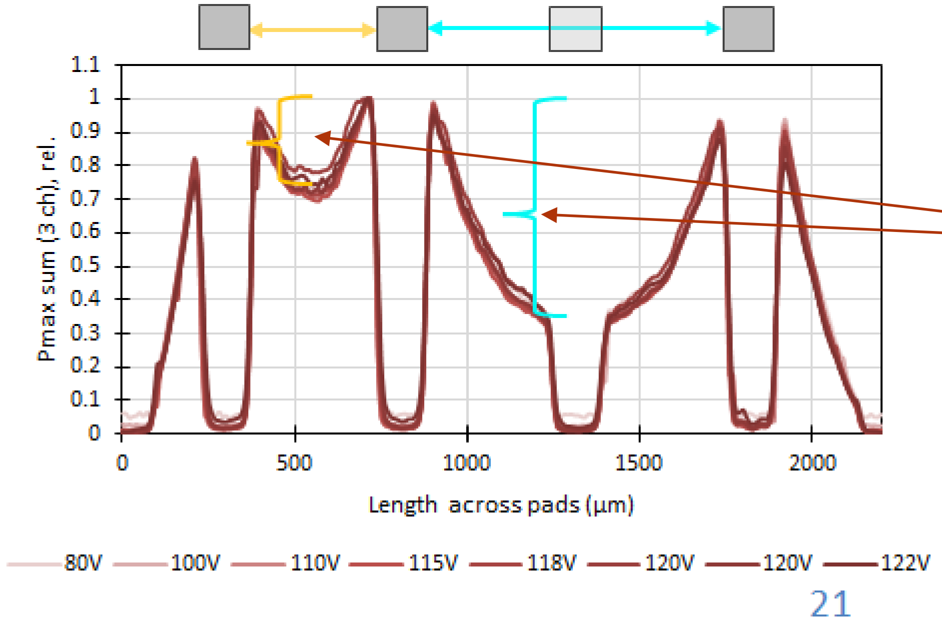
- Presented at TOF-PID meeting a few weeks ago
- Approach: leave some pads in a 4x4 pad array with 500 µm pitch unbonded and floating to mimic 1000 µm pitch, monitor pulse maximum as function of distance
- Using smallest currently available pad size in the HPK production: 150x150 µm. Here, a C600 sensor (more signal sharing) with bulk thickness 20 µm (faster rise time)



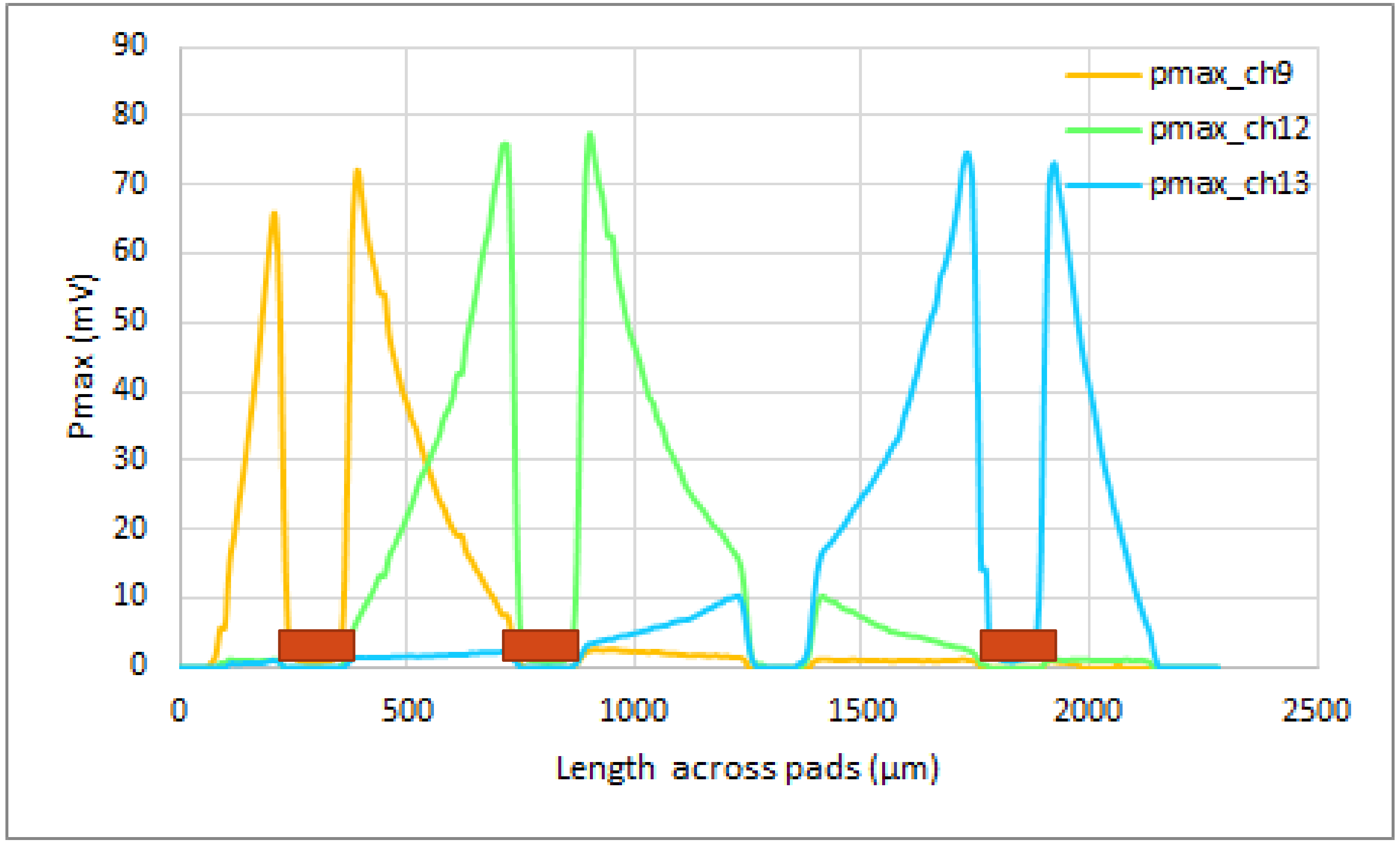
Standard square pad AC-LGAD

- Significant **loss of signal amplitude** between pads at 500 µm, more pronounced for the double distance: in this sensor, ca. 27% at the center point between adjacent pads, **ca. 65% for '1000 µm' pitch**
- The effect of the bias voltage on relative signal sharing is minimal (observed throughout this production)
- Whether smaller signal, worse SNR and jitter are acceptable depends on what gain the sensor is operated at = what absolute signal remains, and how critical the reduction of the metal size or channel count is finally determined to be



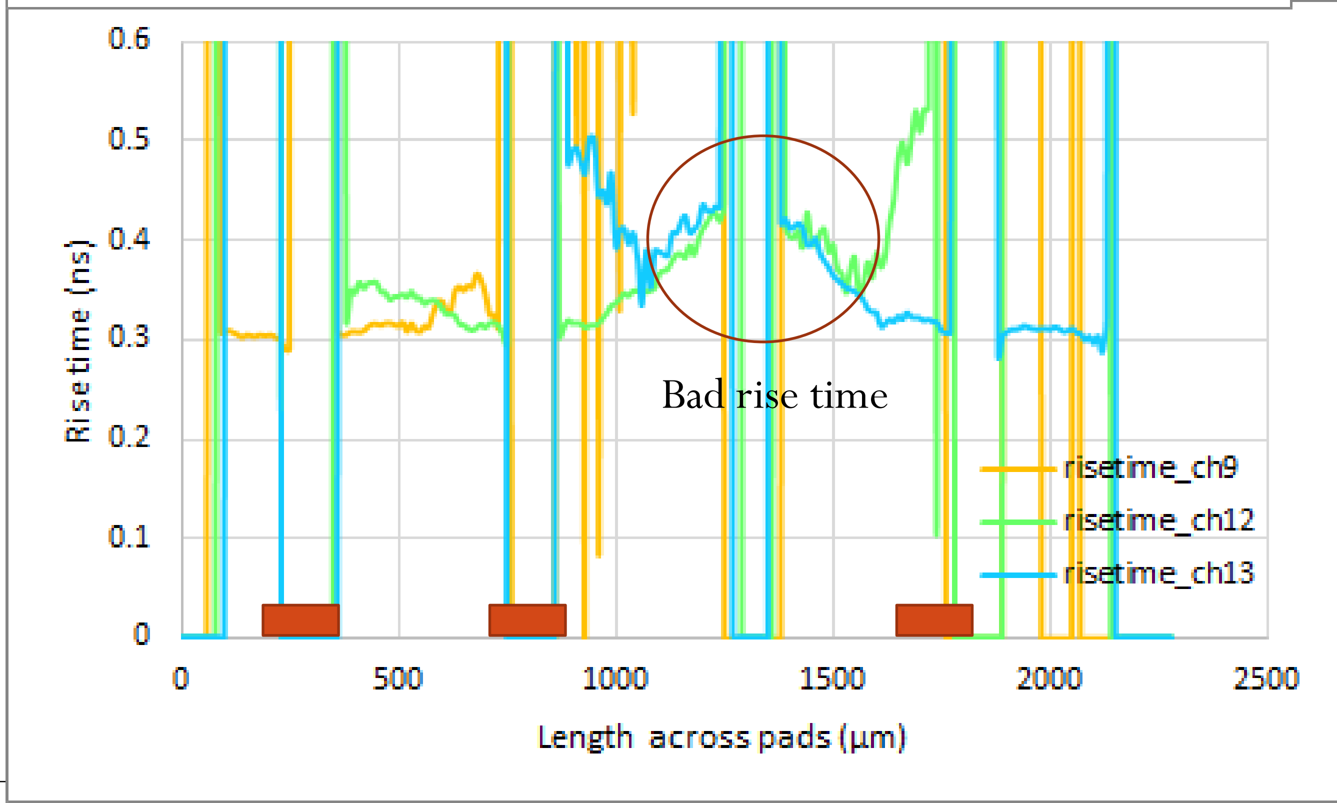


How to minimize the 'dip' in between pads?

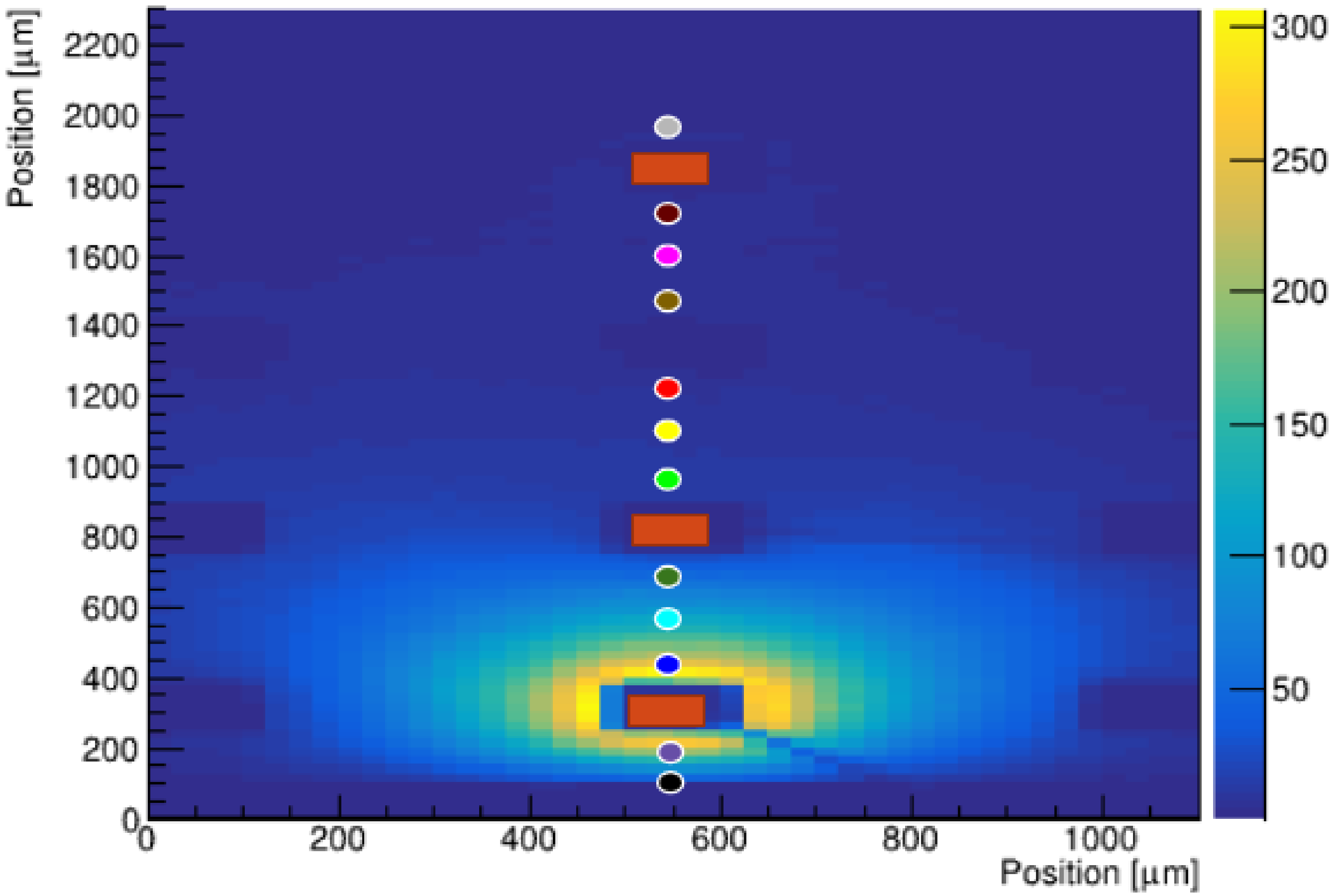


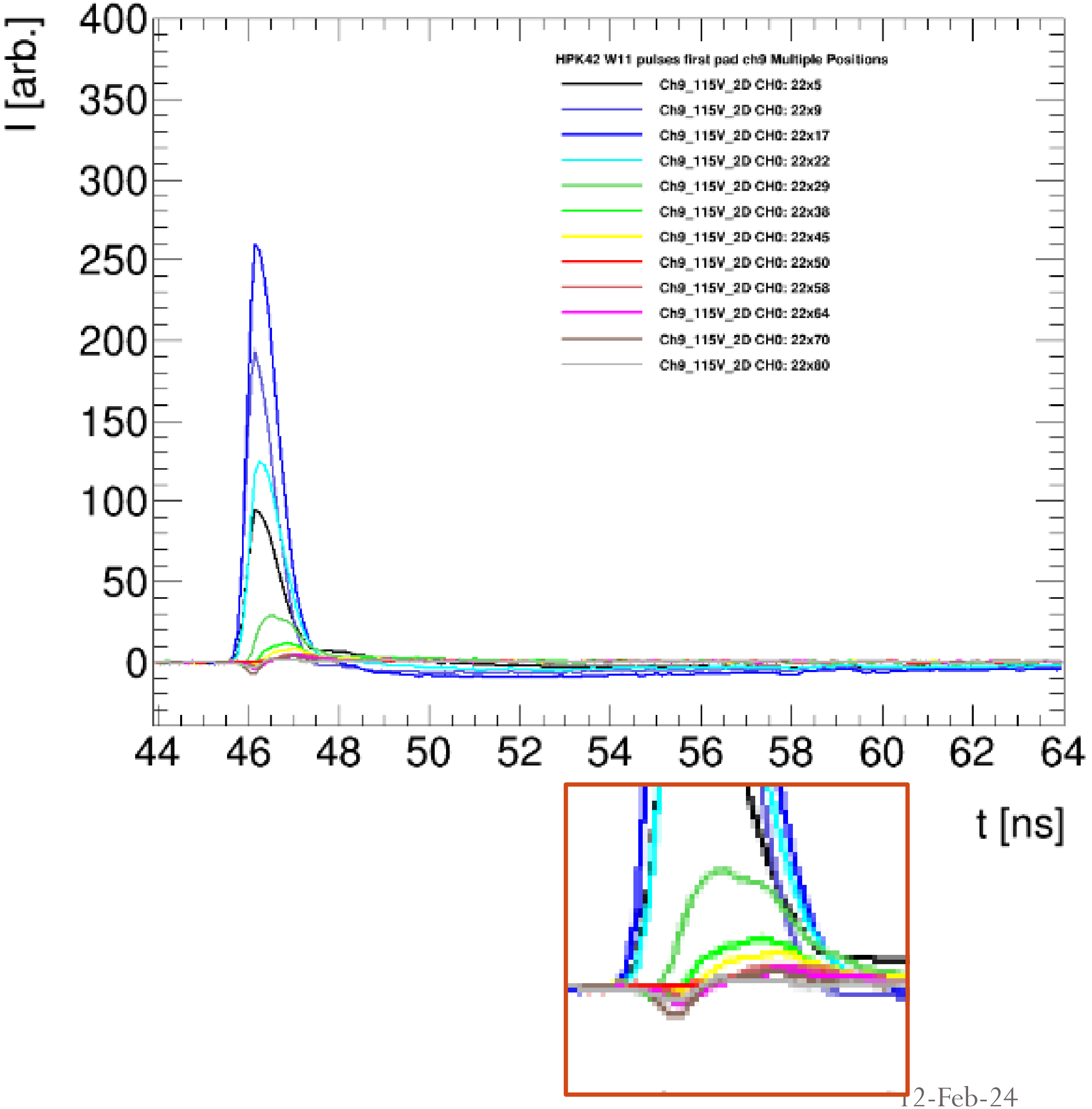
pmax_ch9
pmax_ch12
pmax_ch13
Pmax (mV)
Length across pads (µm)

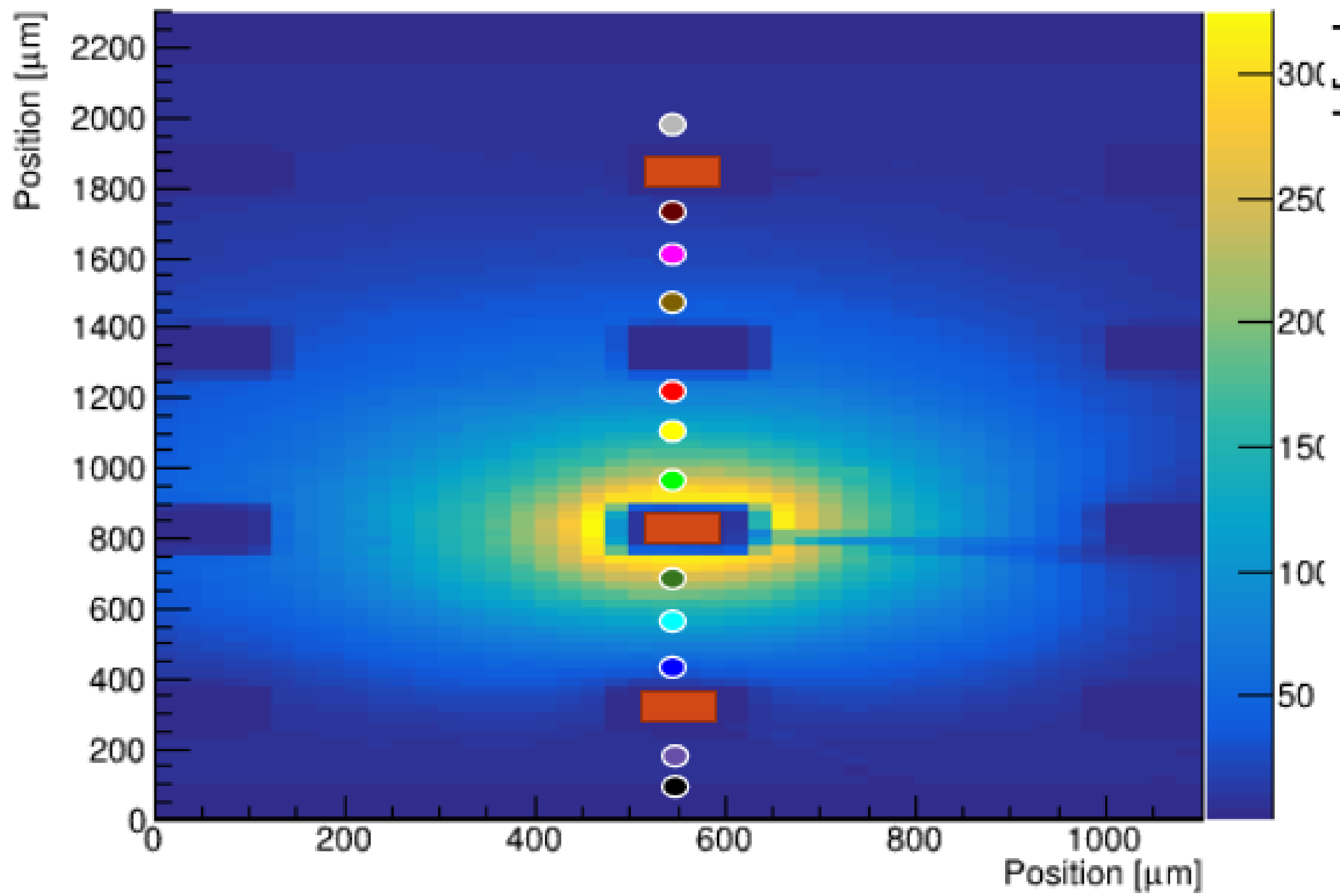
ToA_ch9
ToA_ch12
ToA_ch13
Time of arrival / CFD50 (ns)
Length across pads (µm)

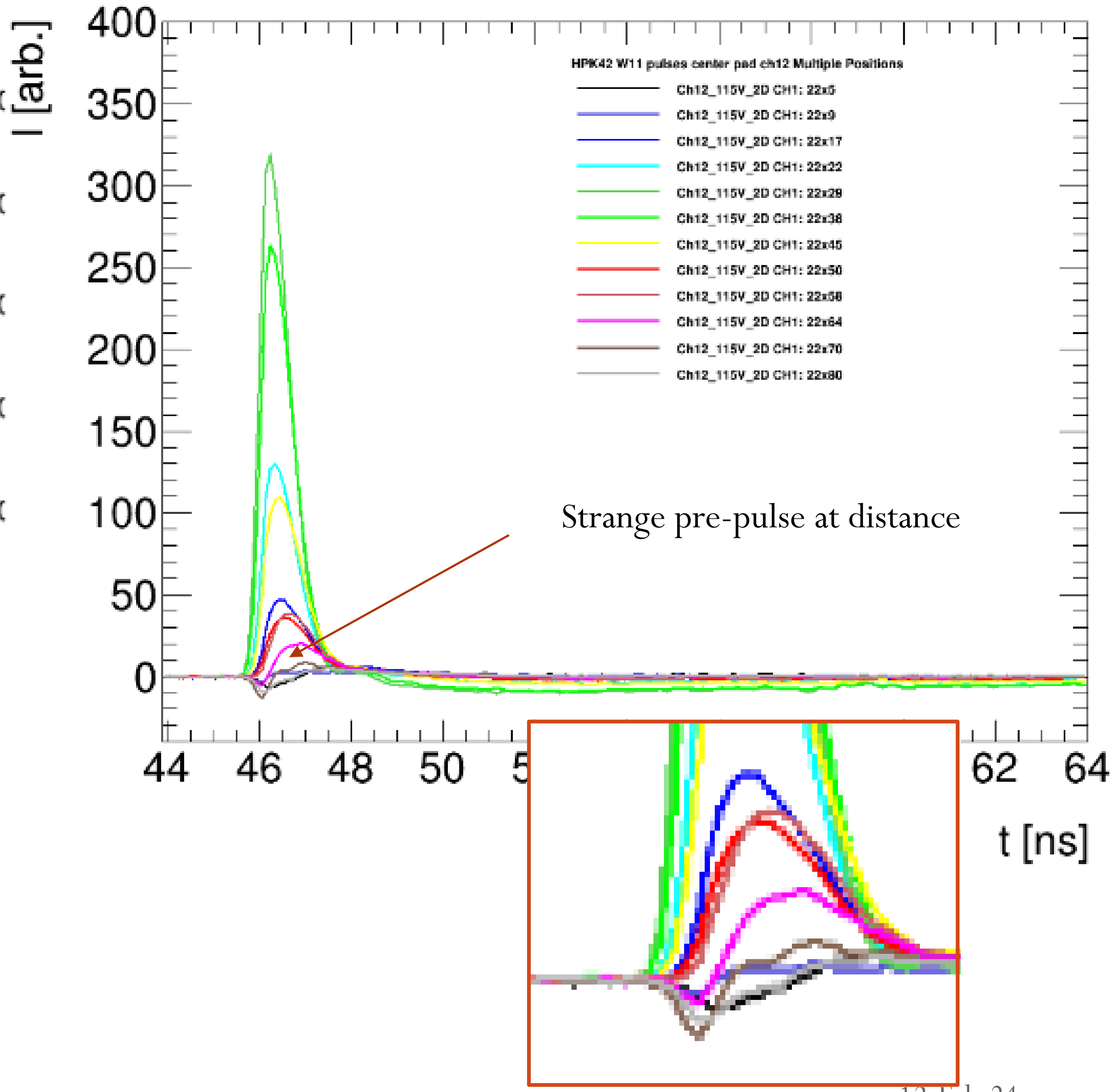


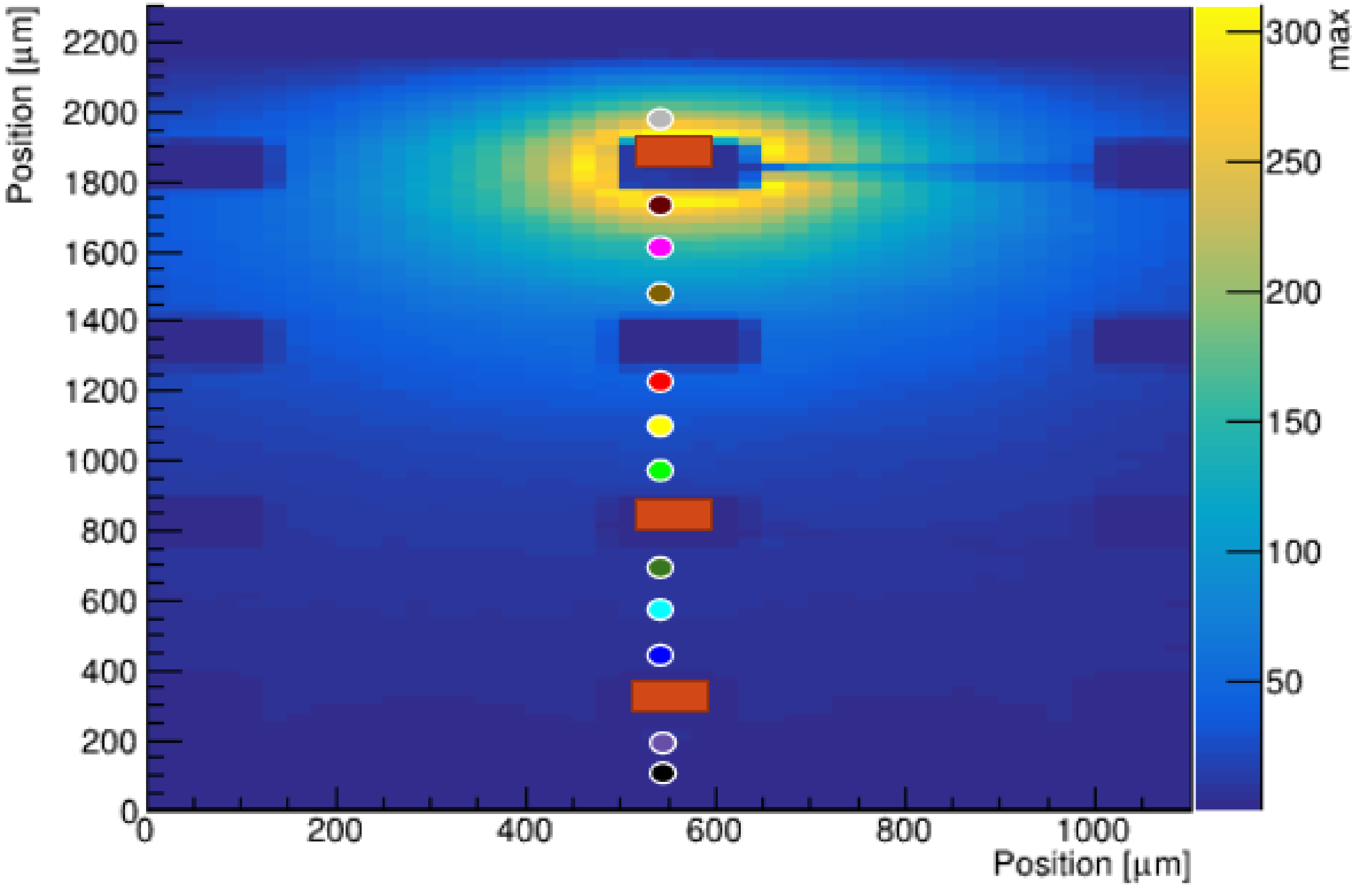
Bad rise time
risetime_ch9
risetime_ch12
risetime_ch13
Risetime (ns)
Length across pads (µm)


Position [µm]
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
200
400
600
800
1000
Position [µm]
300
250
200
150
100
50

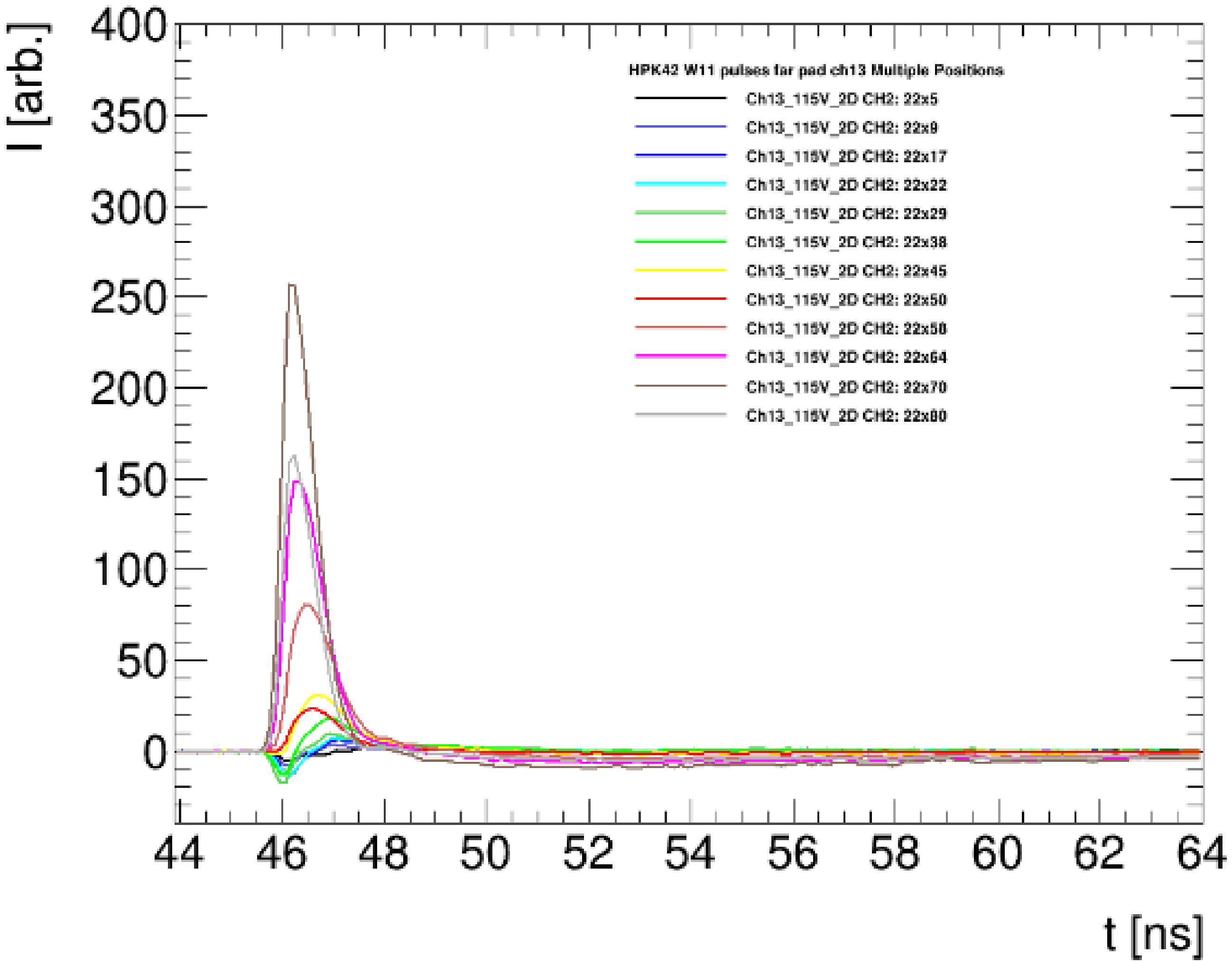

I [arb.]
400
350
300
250
200
150
100
50
0
44
46
48
50
52
54
56
58
60
62
64
t [ns]
HPK42 W11 pulses first pad ch9 Multiple Positions
Ch9_115V_2D CH0: 22x5
Ch9_115V_2D CH0: 22x9
Ch9_115V_2D CH0: 22x17
Ch9_115V_2D CH0: 22x22
Ch9_115V_2D CH0: 22x29
Ch9_115V_2D CH0: 22x38
Ch9_115V_2D CH0: 22x45
Ch9_115V_2D CH0: 22x50
Ch9_115V_2D CH0: 22x58
Ch9_115V_2D CH0: 22x64
Ch9_115V_2D CH0: 22x70
Ch9_115V_2D CH0: 22x80


Position [µm]
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
200
400
600
800
1000
Position [µm]


I [arb.]
400
350
300
250
200
150
100
50
0
HPK42 W11 pulses center pad ch12 Multiple Positions
Ch12_115V_2D CH1: 22x5
Ch12_115V_2D CH1: 22x9
Ch12_115V_2D CH1: 22x17
Ch12_115V_2D CH1: 22x22
Ch12_115V_2D CH1: 22x29
Ch12_115V_2D CH1: 22x38
Ch12_115V_2D CH1: 22x45
Ch12_115V_2D CH1: 22x50
Ch12_115V_2D CH1: 22x58
Ch12_115V_2D CH1: 22x64
Ch12_115V_2D CH1: 22x70
Ch12_115V_2D CH1: 22x80
Strange pre-pulse at distance
44
46
48
50
62
64
t [ns]



Position [µm]
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
200
400
600
800
1000
Position [µm]
300
250
200
150
100
50
max

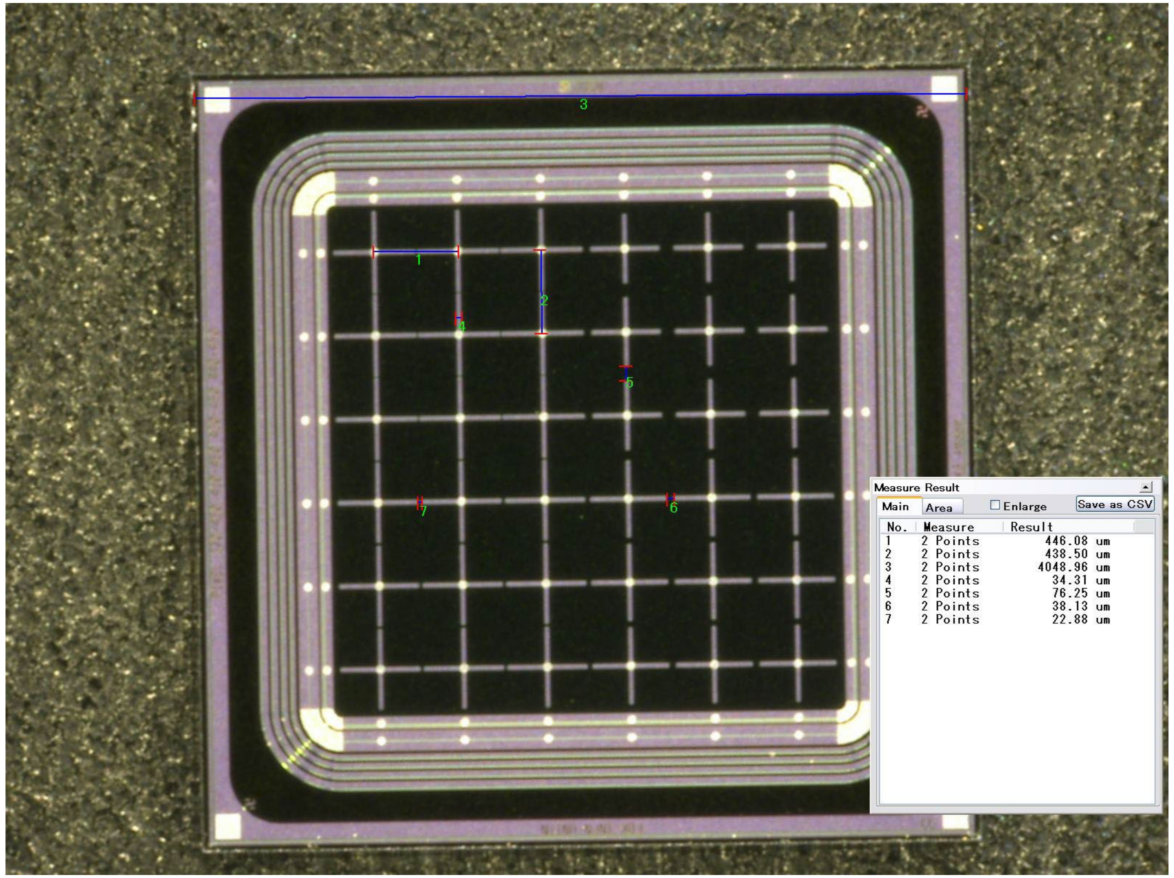


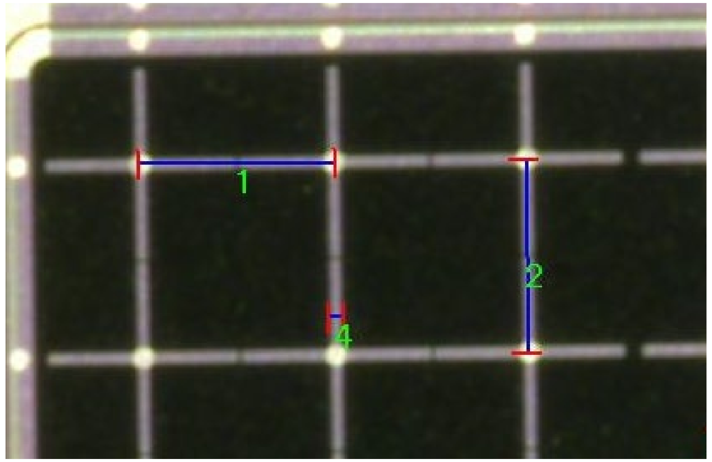
I [arb.]
400
350
300
250
200
150
100
50
0
44
46
48
50
52
54
56
58
60
62
64
t [ns]
HPK42 W11 pulses far pad ch13 Multiple Positions
Ch13_115V_2D CH2: 22x5
Ch13_115V_2D CH2: 22x9
Ch13_115V_2D CH2: 22x17
Ch13_115V_2D CH2: 22x22
Ch13_115V_2D CH2: 22x29
Ch13_115V_2D CH2: 22x38
Ch13_115V_2D CH2: 22x45
Ch13_115V_2D CH2: 22x50
Ch13_115V_2D CH2: 22x58
Ch13_115V_2D CH2: 22x64
Ch13_115V_2D CH2: 22x70
Ch13_115V_2D CH2: 22x80

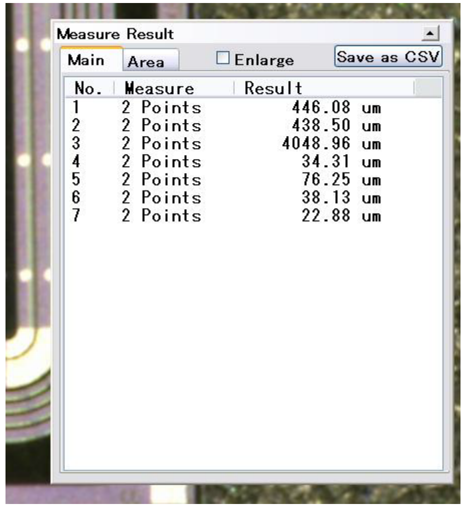
Crosses

New geometries - crosses

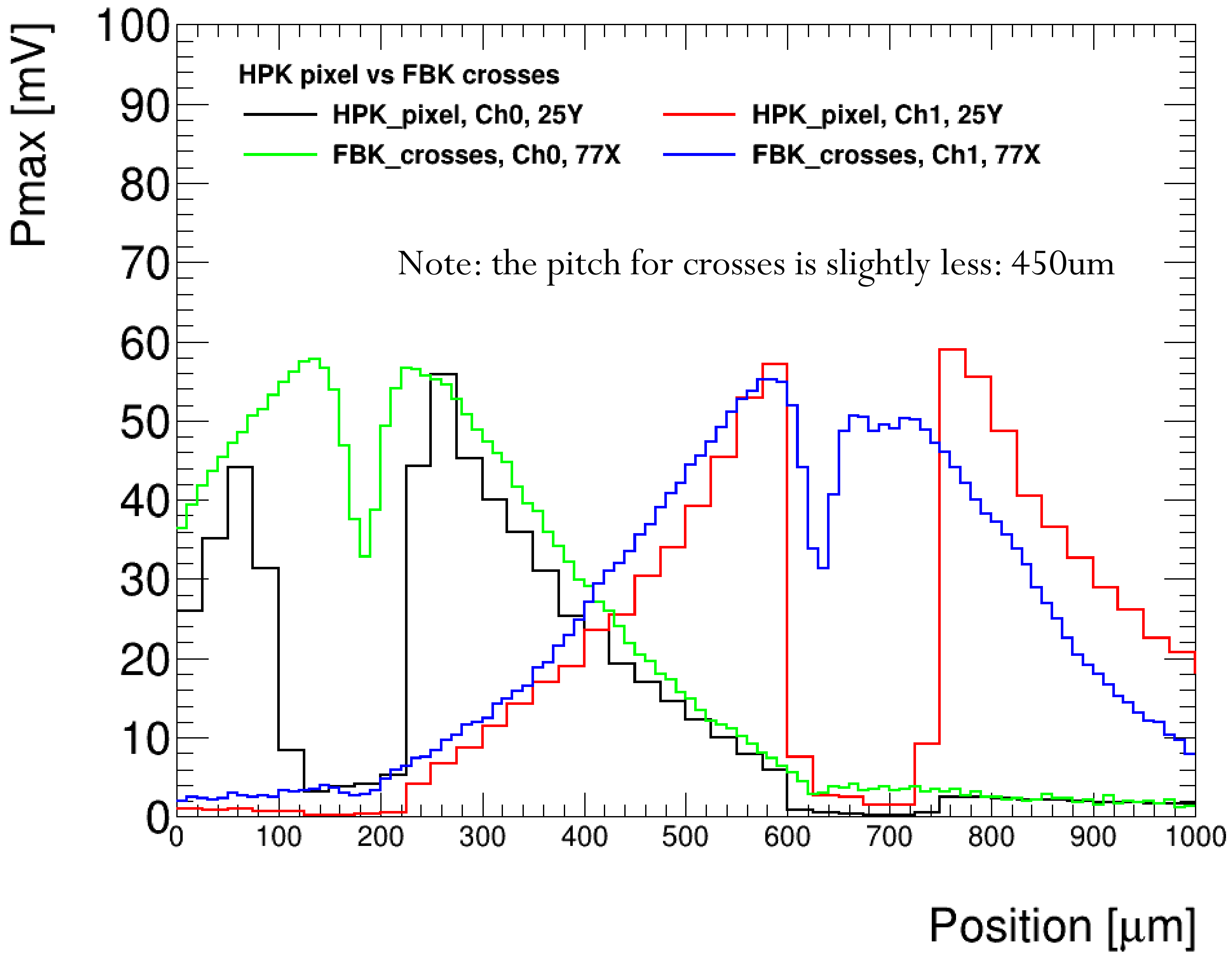
- FBK sensor from RSD2 production
  - Pitch 450um
  - Bond pad size ~50x50um
  - Metal arm width ~35um
- Using metal ‘arms’ to collect the charge in a cross-like pattern
- Reduce the signal reduction in between thanks to the more efficient charge collection
  - Tested with laser TCT and compared with standard square pad sensor
- Only relative for now, no absolute comparison





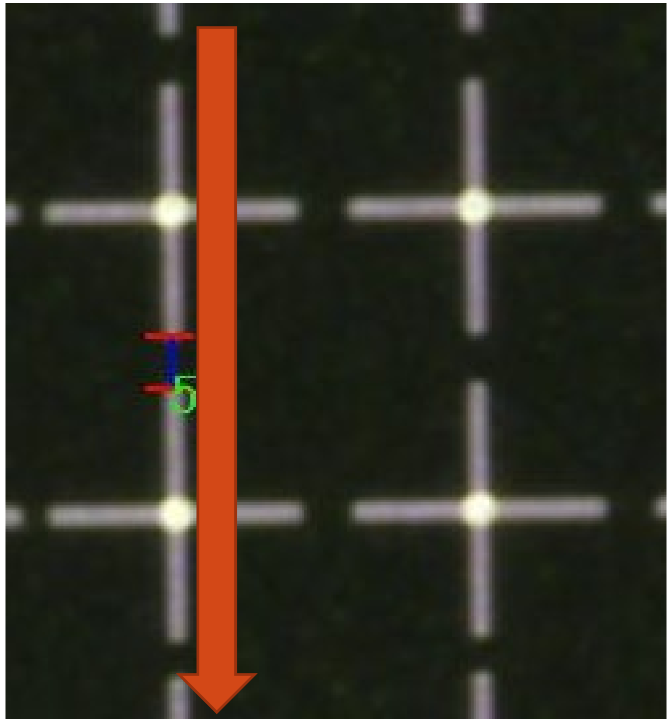


New geometries - crosses



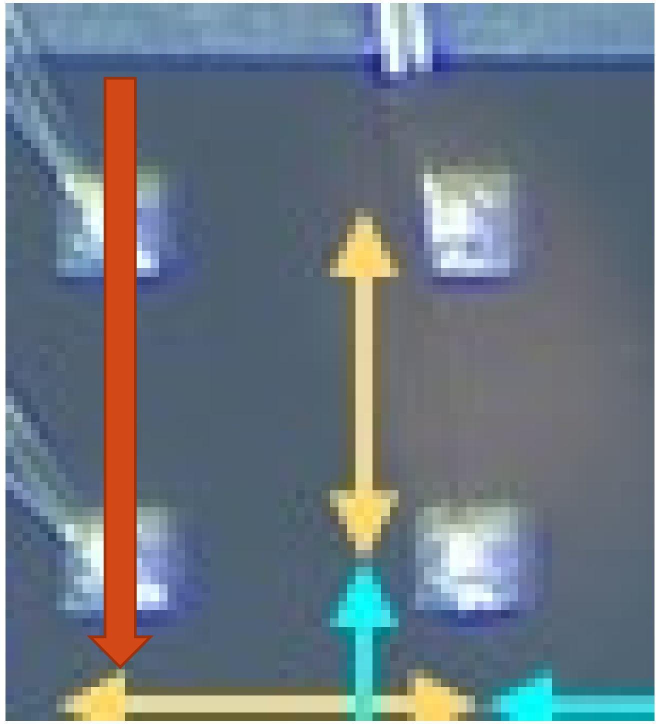
Note: the pitch for crosses is slightly less: 450um

FBK crosses

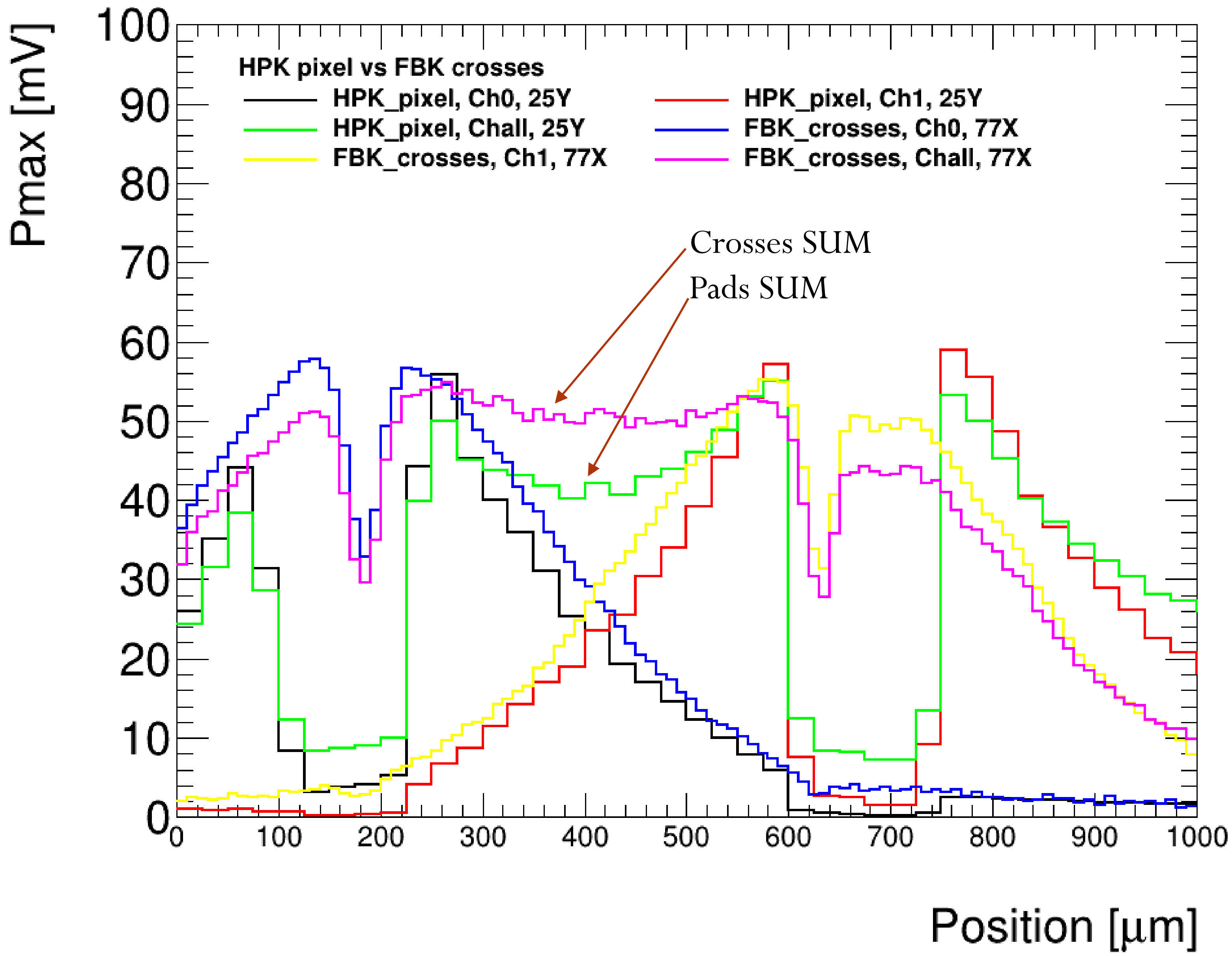


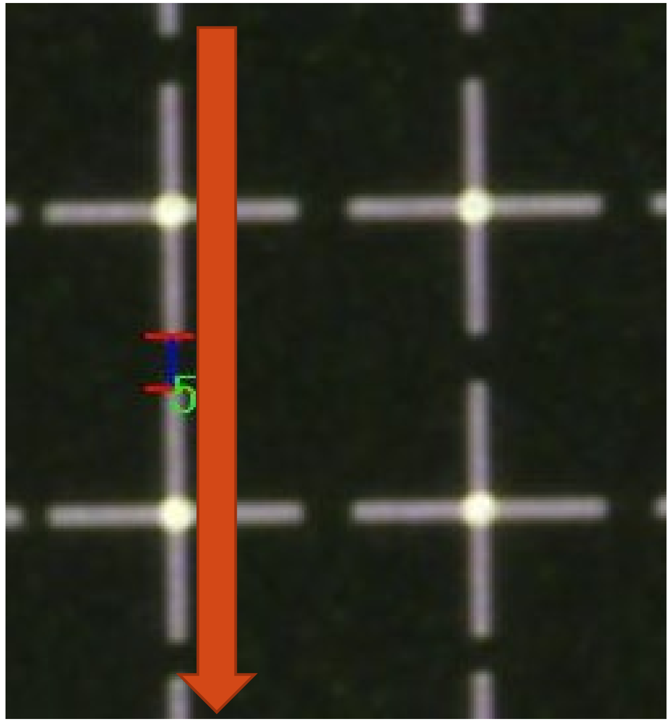
Scans are off-center
(to avoid arms)
But in the same positions

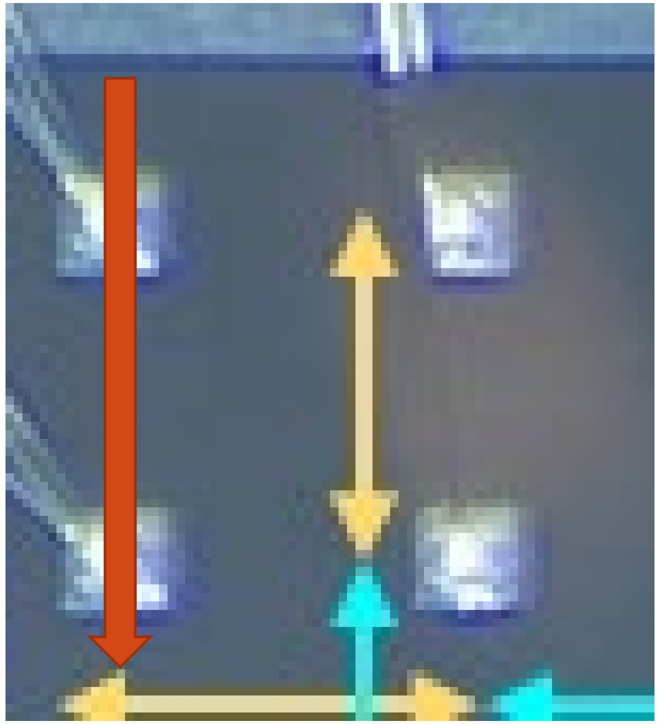
HPK pads



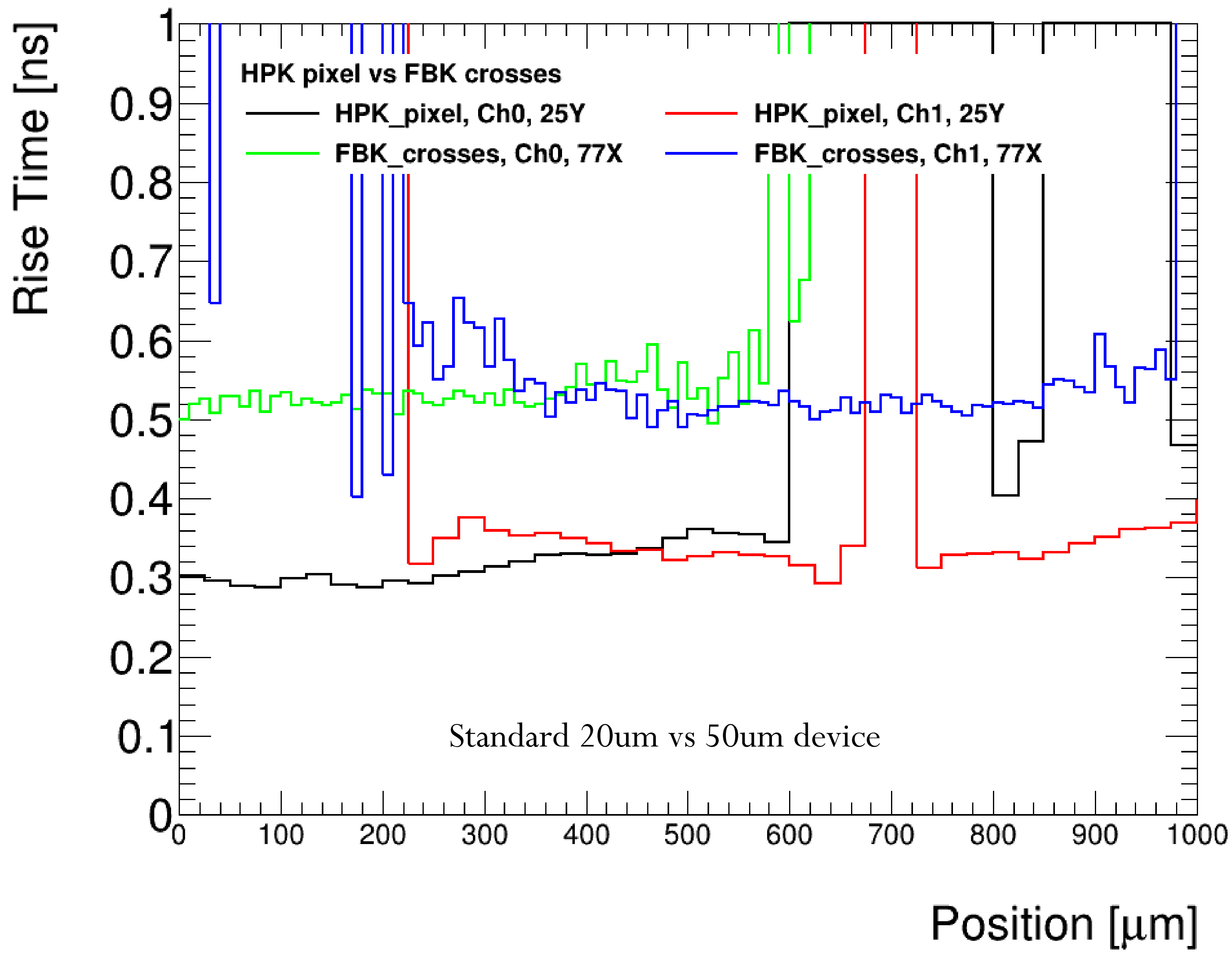
New geometries - crosses

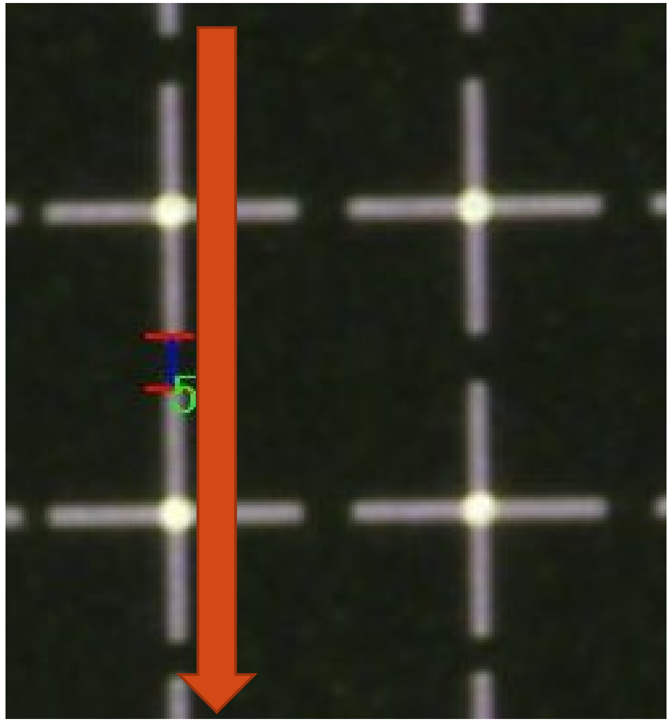


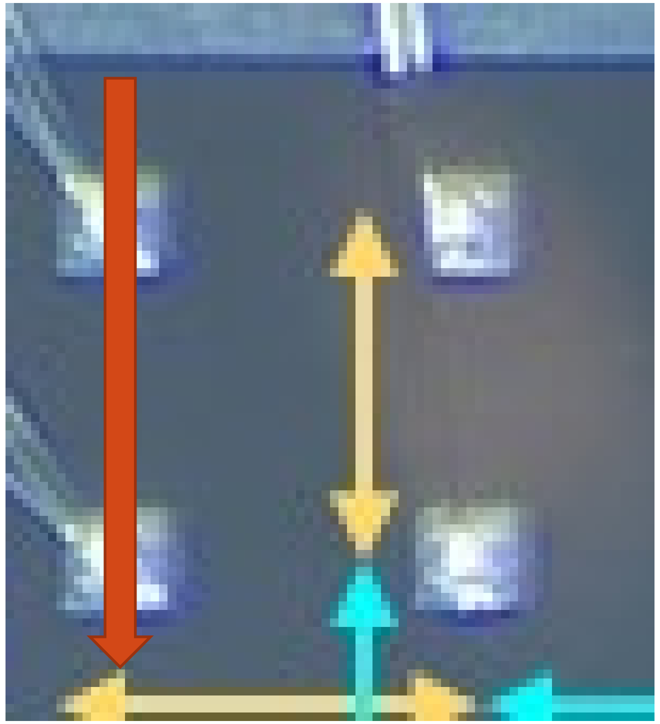




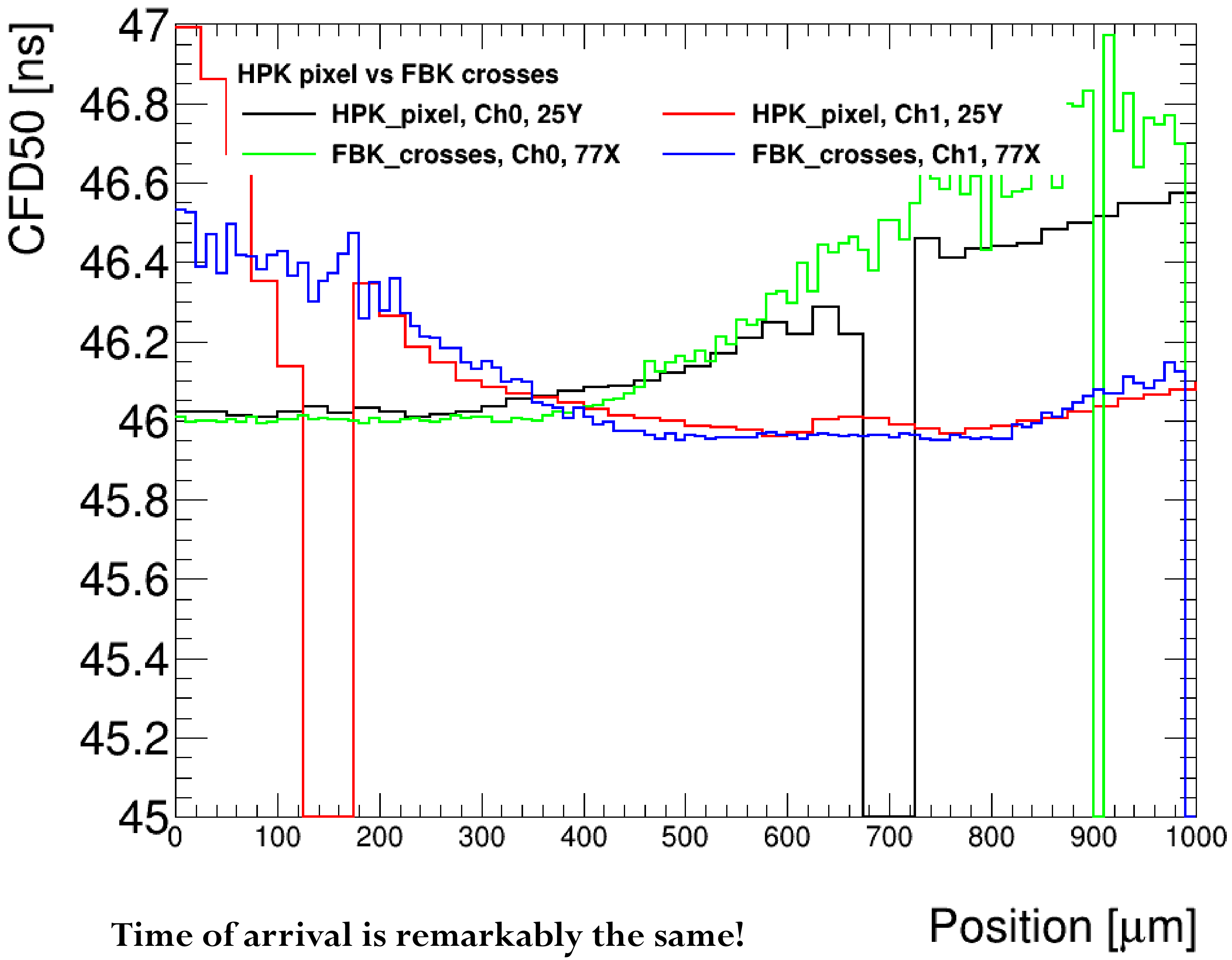
New geometries - crosses

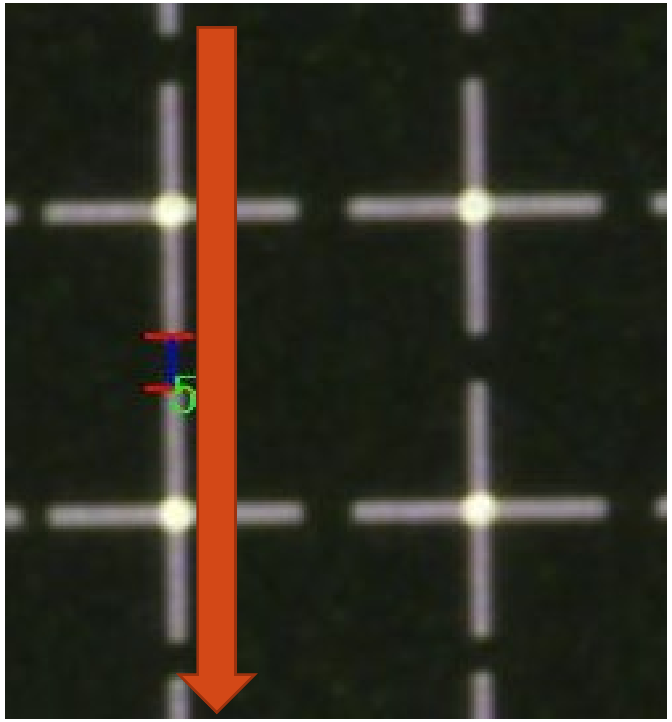


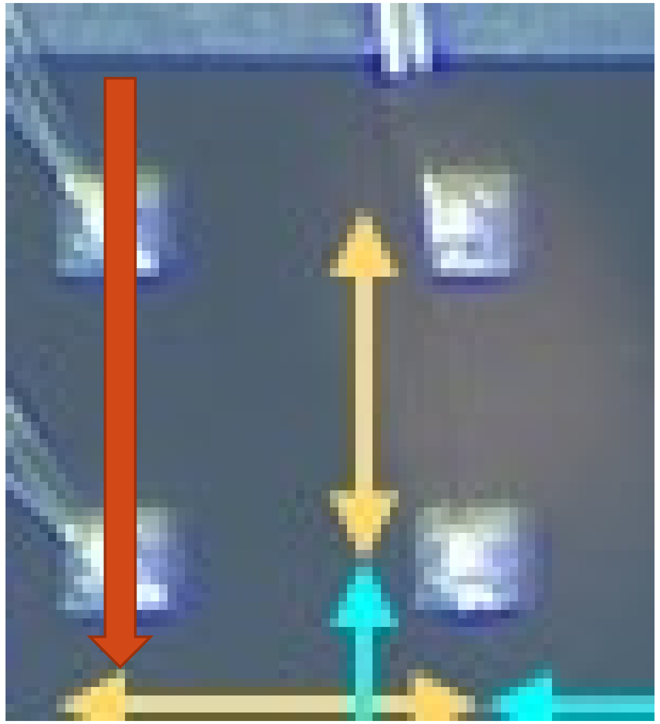




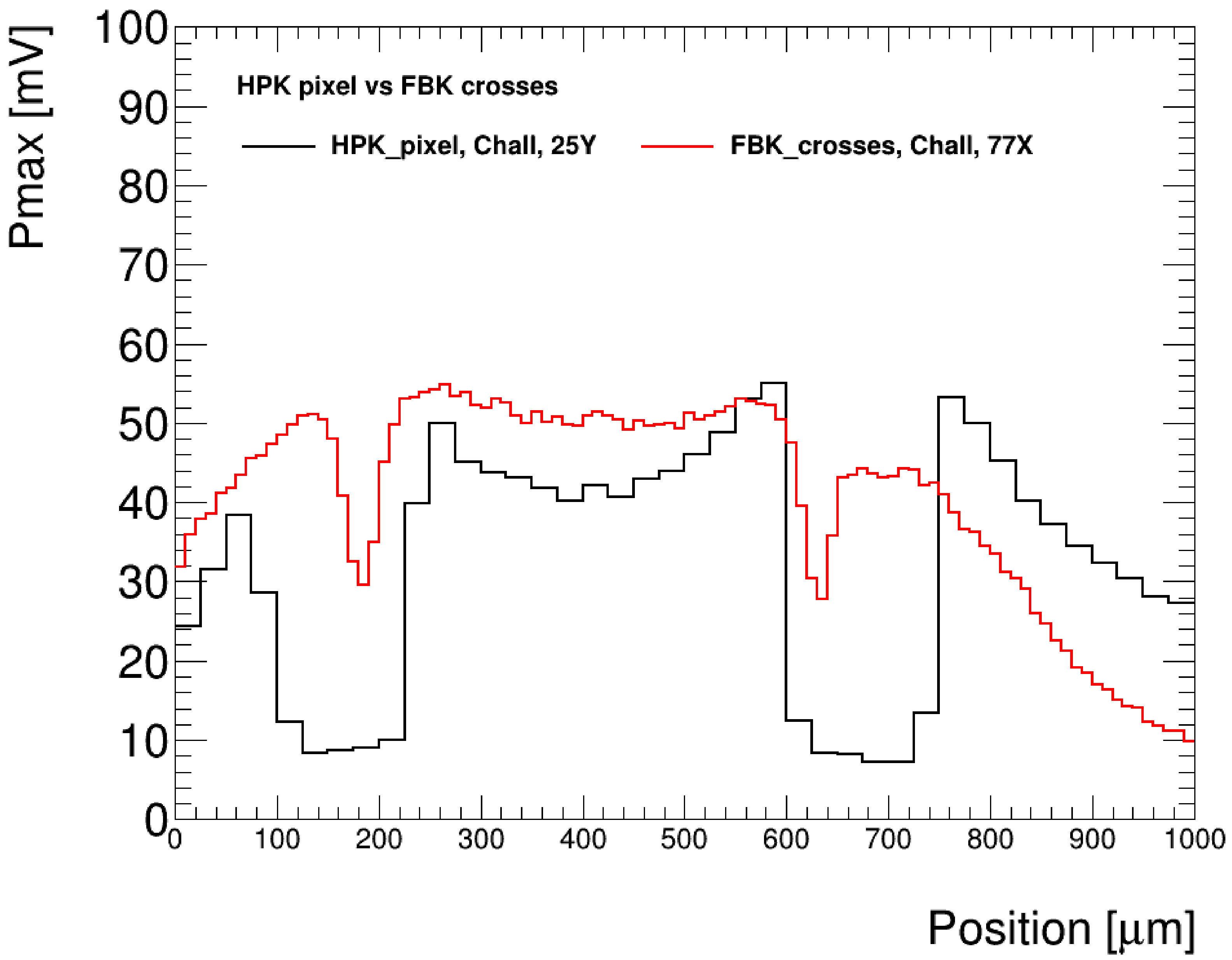
New geometries - crosses



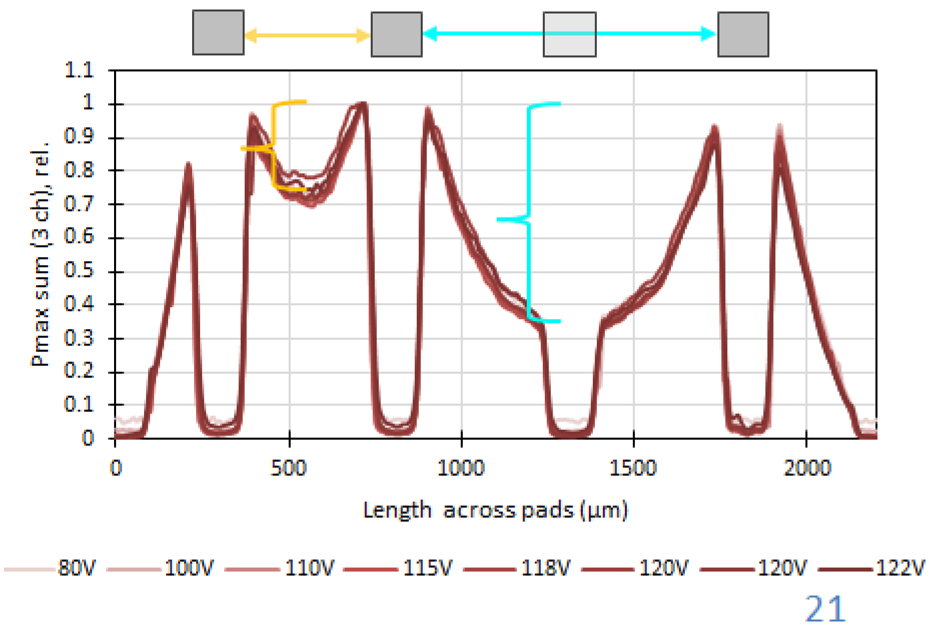




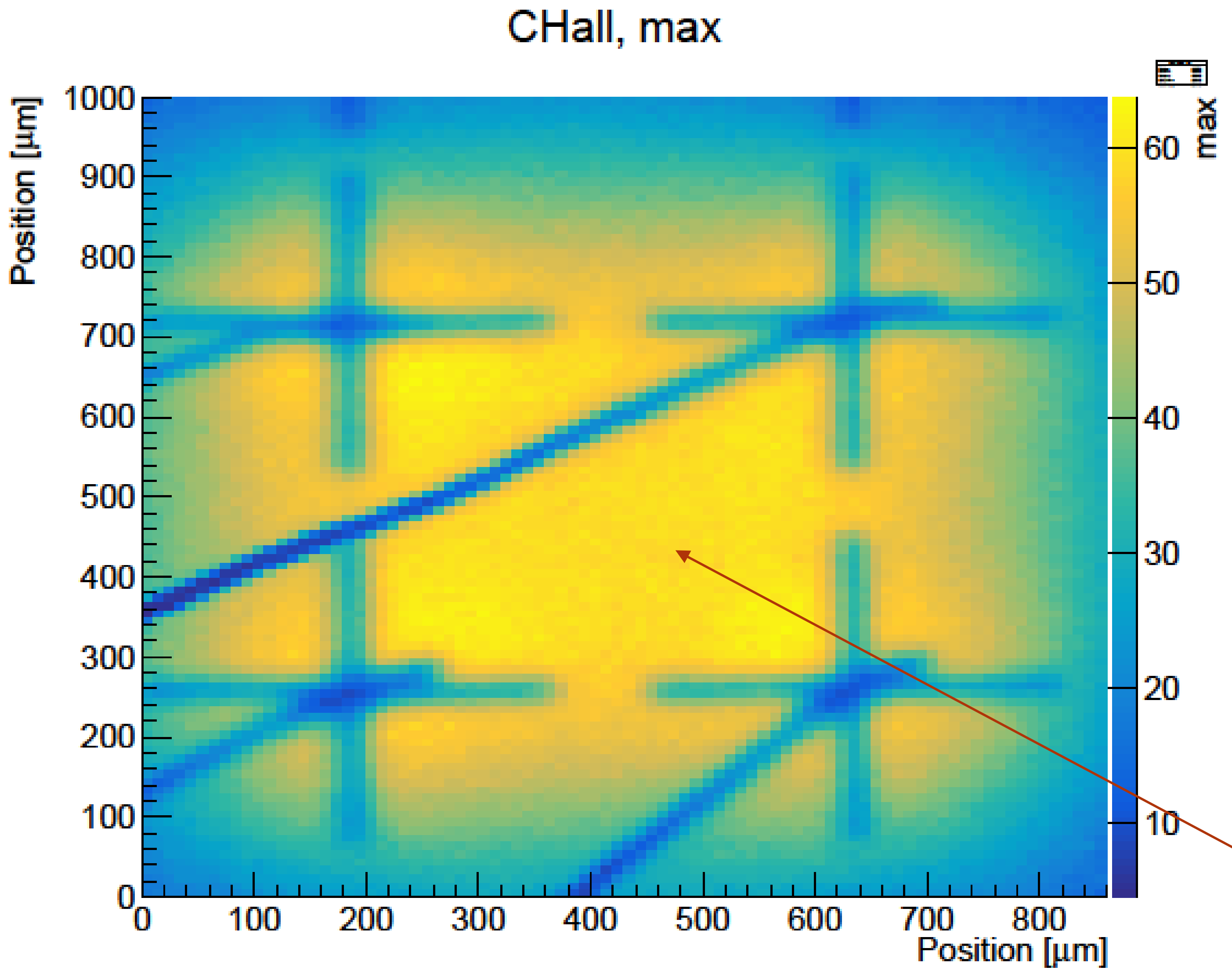
Time of arrival is remarkably the same!

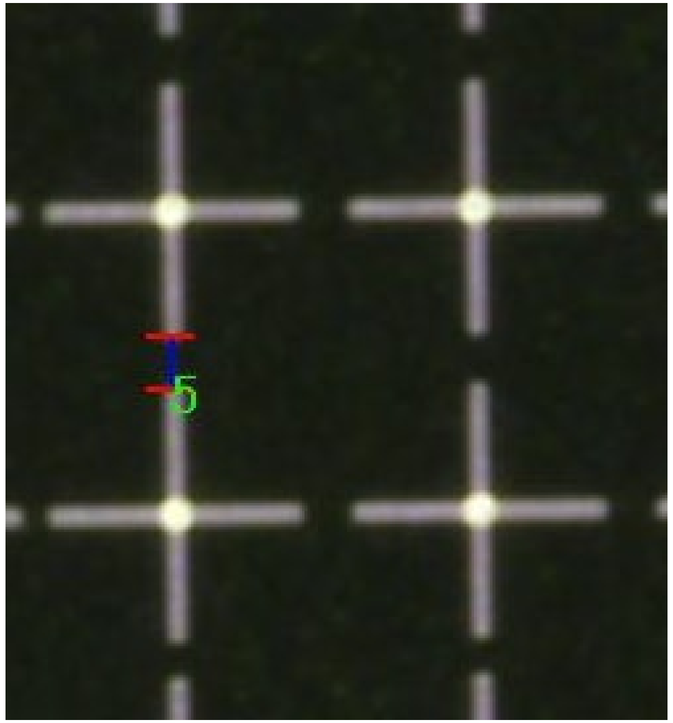


Better scan for pads



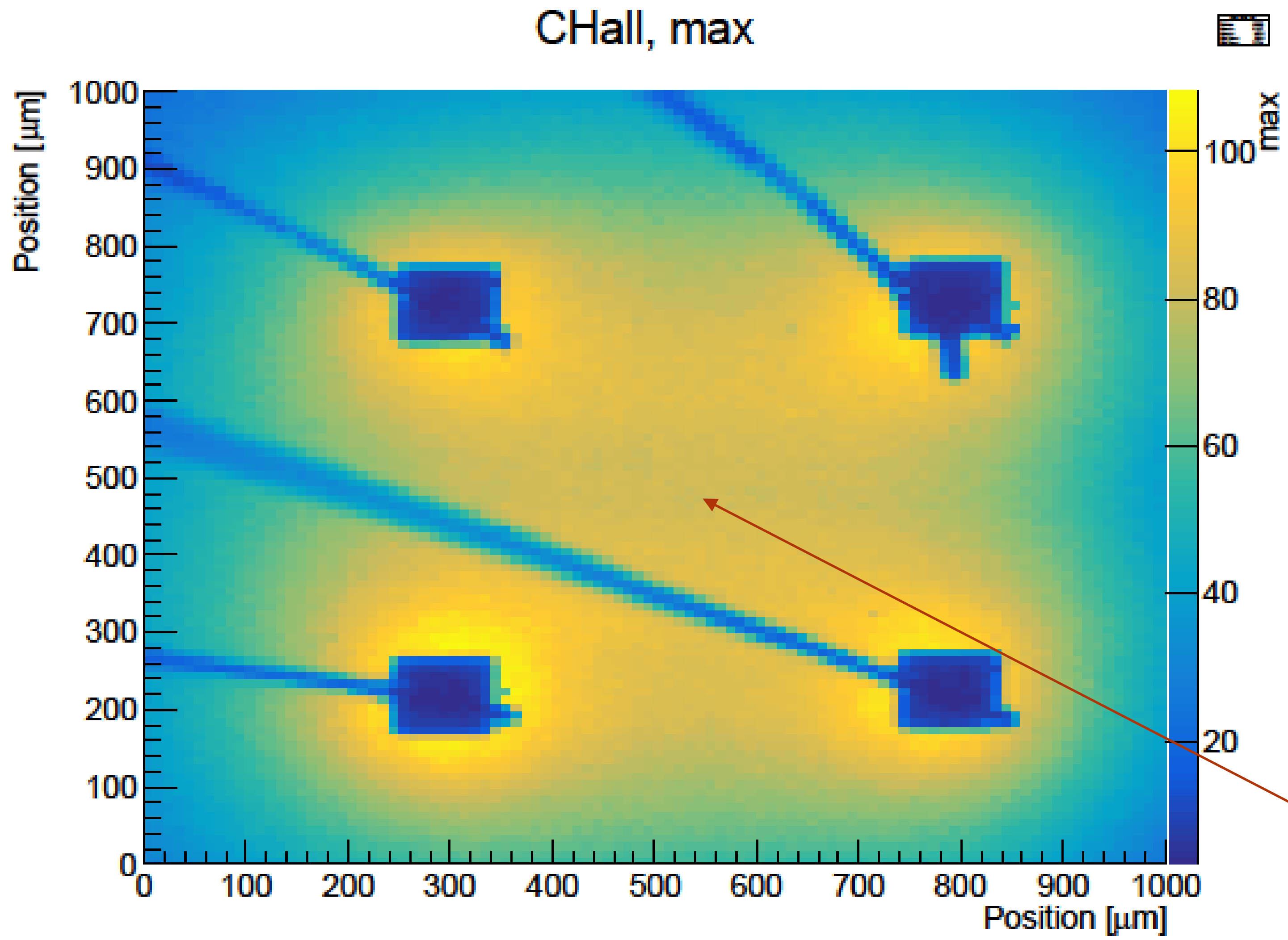
New geometries - crosses

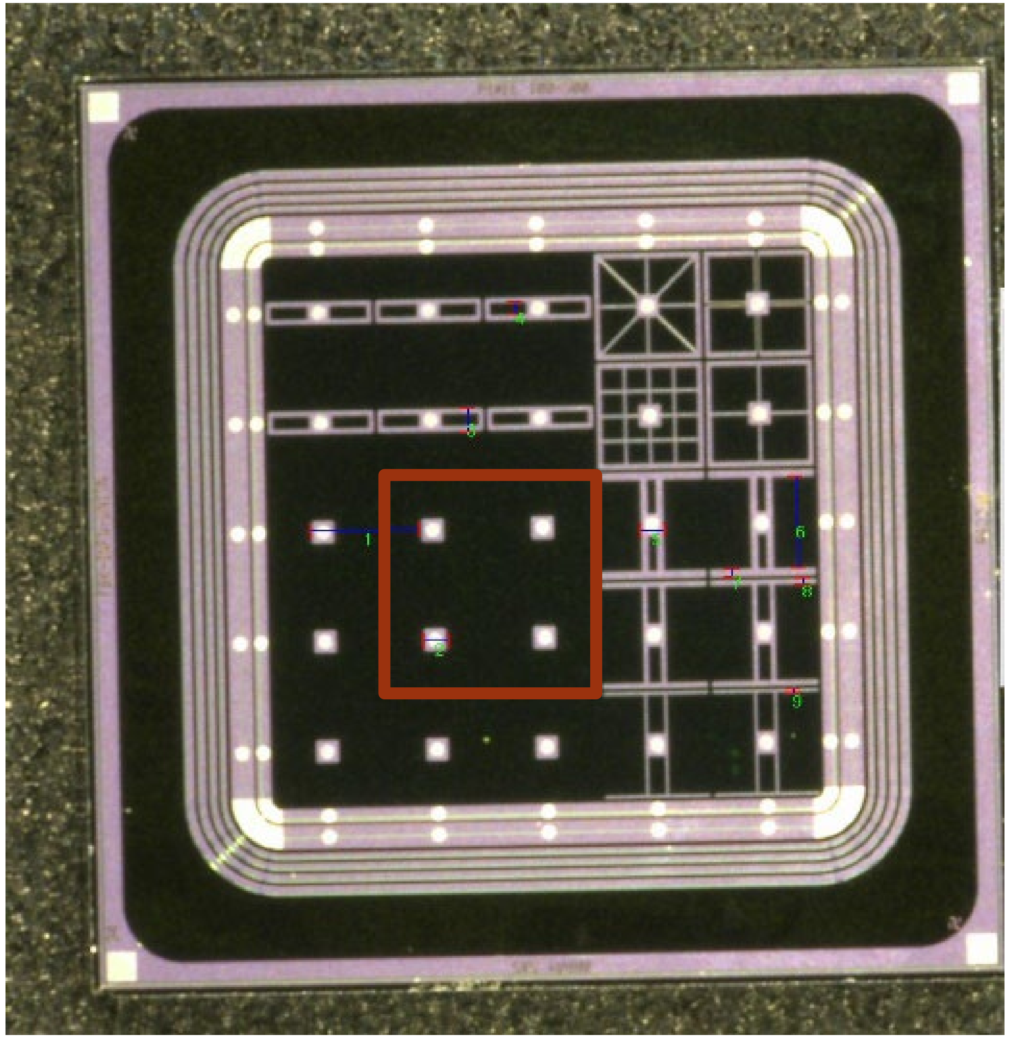




Sum of all signals pretty constant even in the center

FBK pads sensor

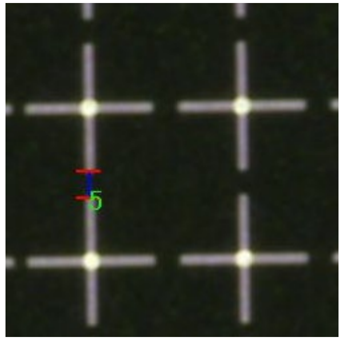


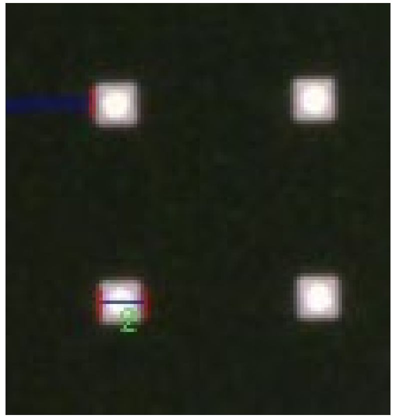


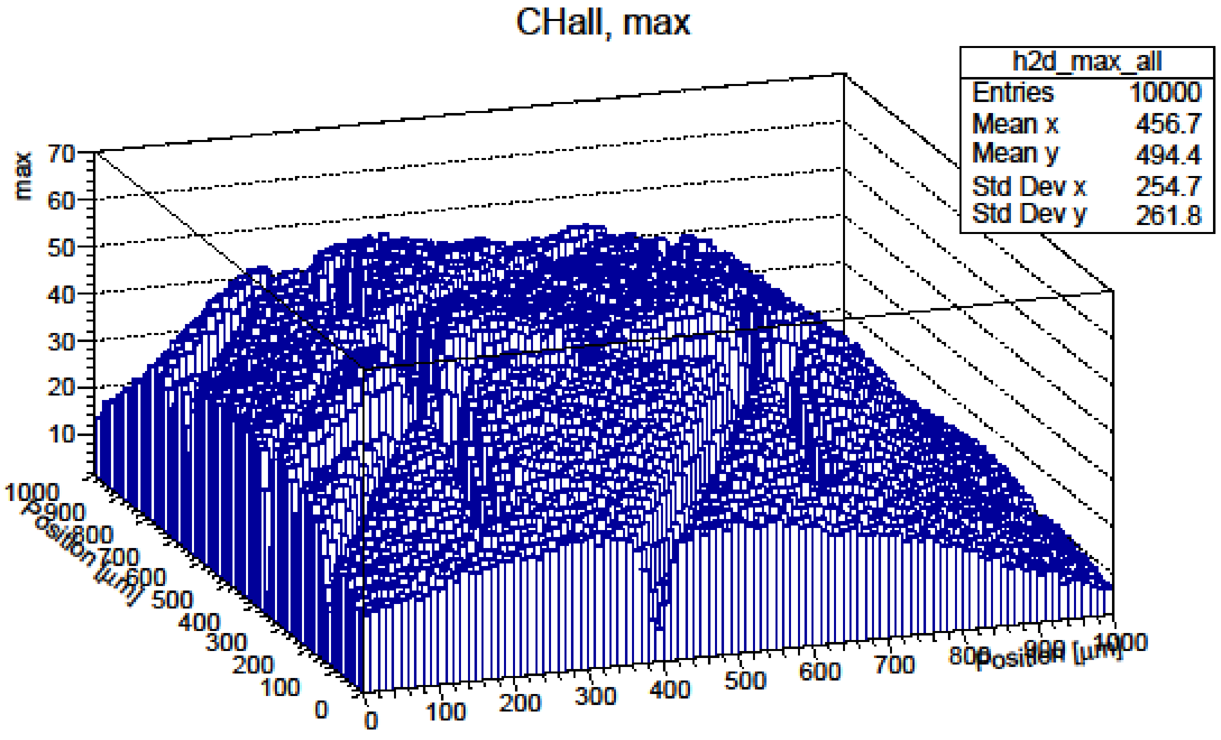
Signal 'dips' even more in the center

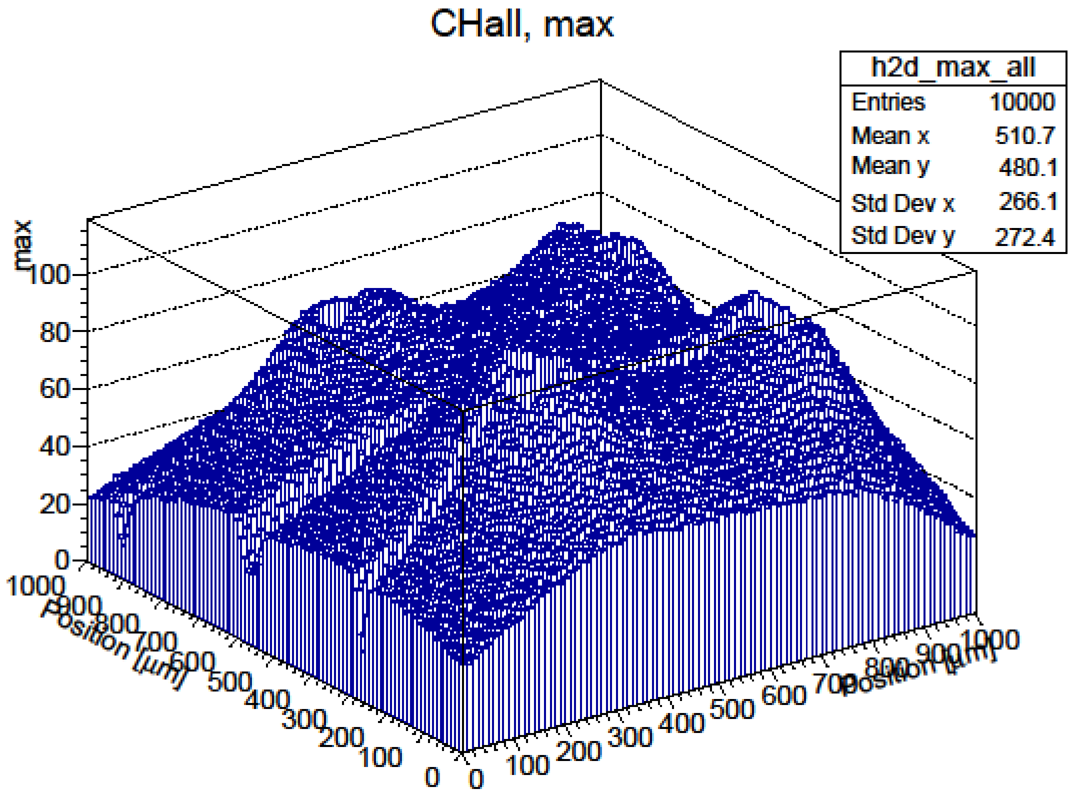
Unfortunately, no data on the HPK sensor like this for now
→ Will do next

New geometries - crosses



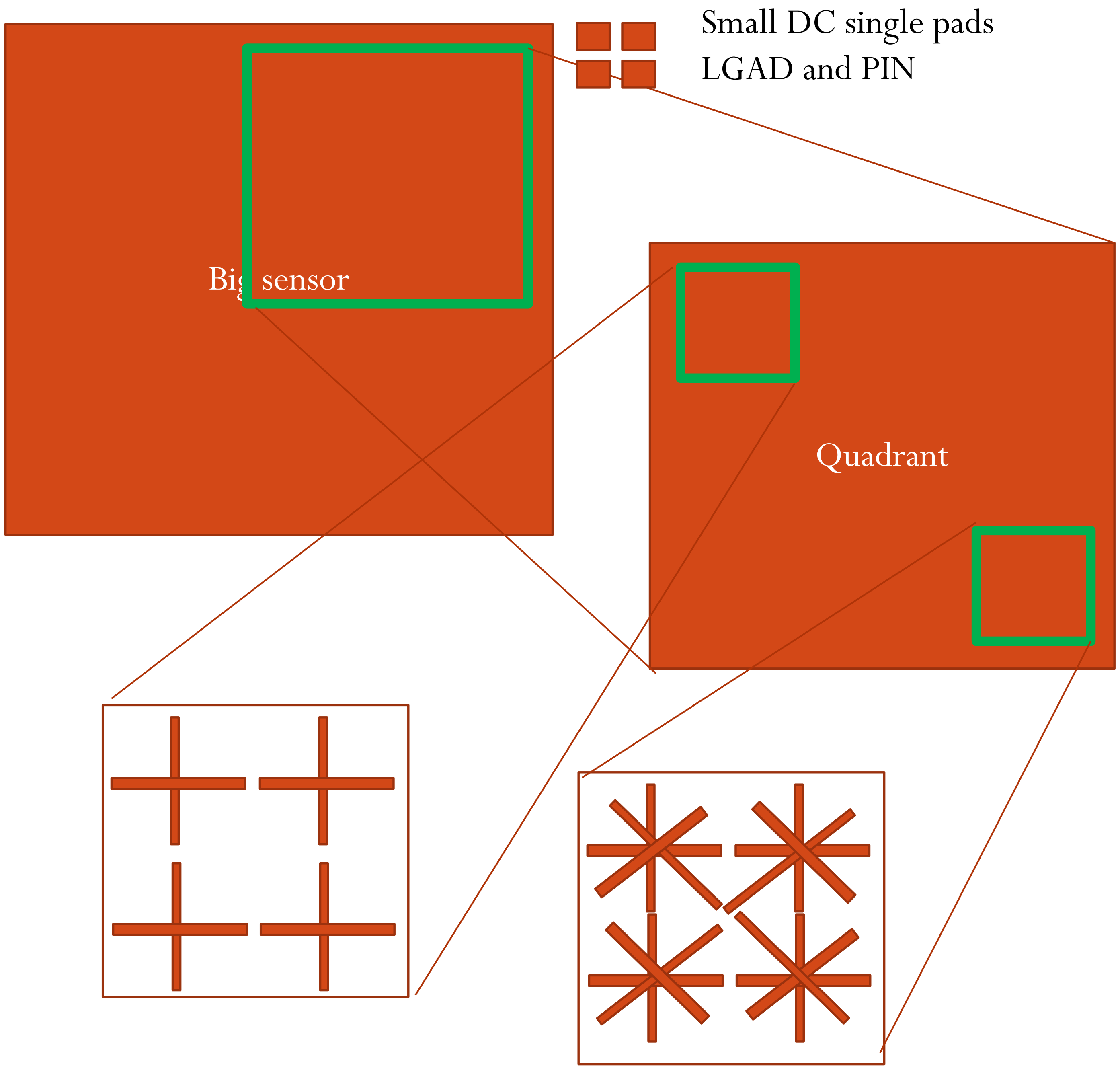




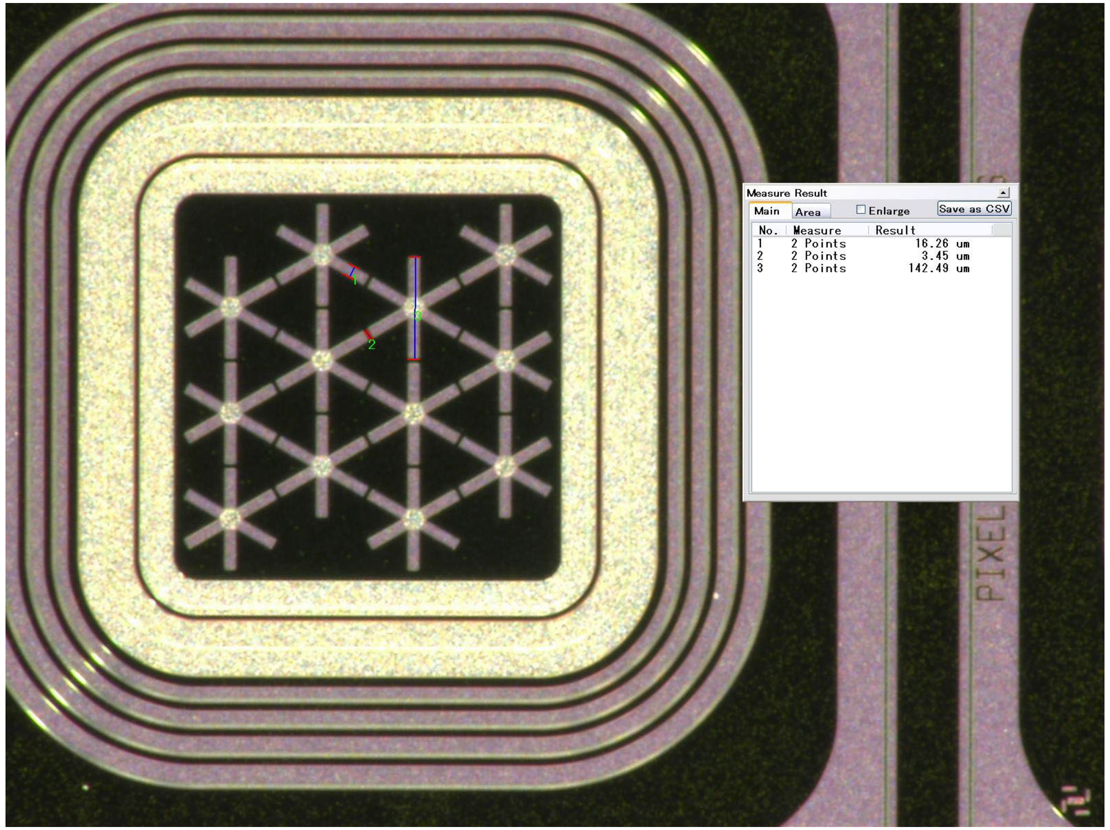


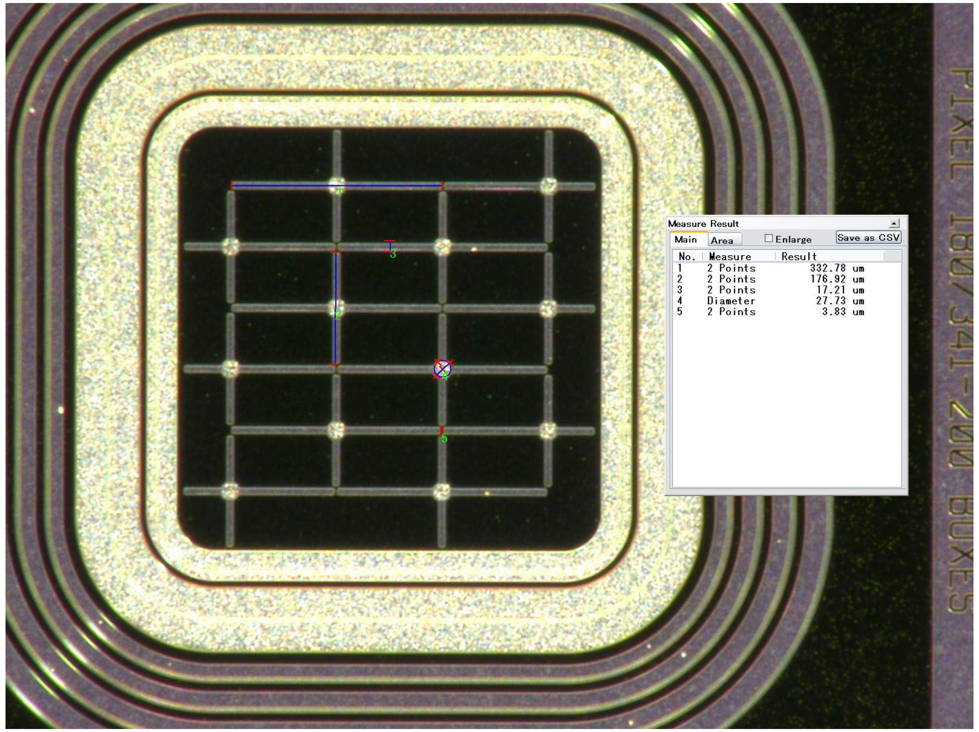
Proposal for HPK run

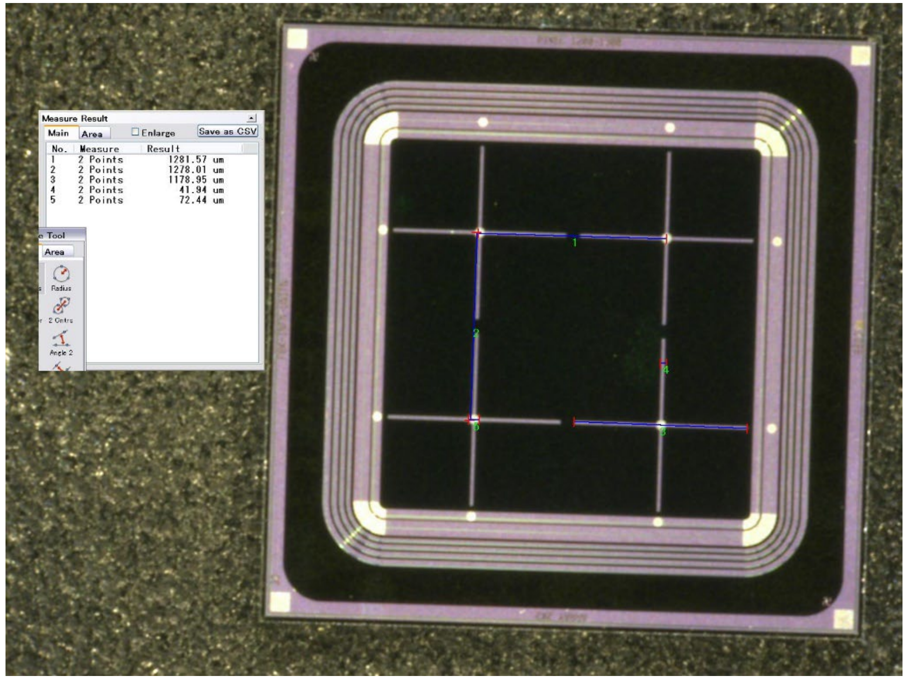
- It's clear that a 'cross-like' geometry can help in maintaining the S/N constant across the entire sensor area
- We can try in a subset of the large detectors the following geometries
  - Crosses
  - Snowflakes
- Can be clusters of 2x2 or even 3x3
- In addition **some single pad DC devices ~mm PIN and LGAD at the side of the wafer**
  - Invaluable to test the absolute charge collection and best possible time resolution!
  - Useful to study the interplay between N+ and gain layer doping
  - Different sizes → can test the effect of input capacitance on readout chip



Other available geometries…

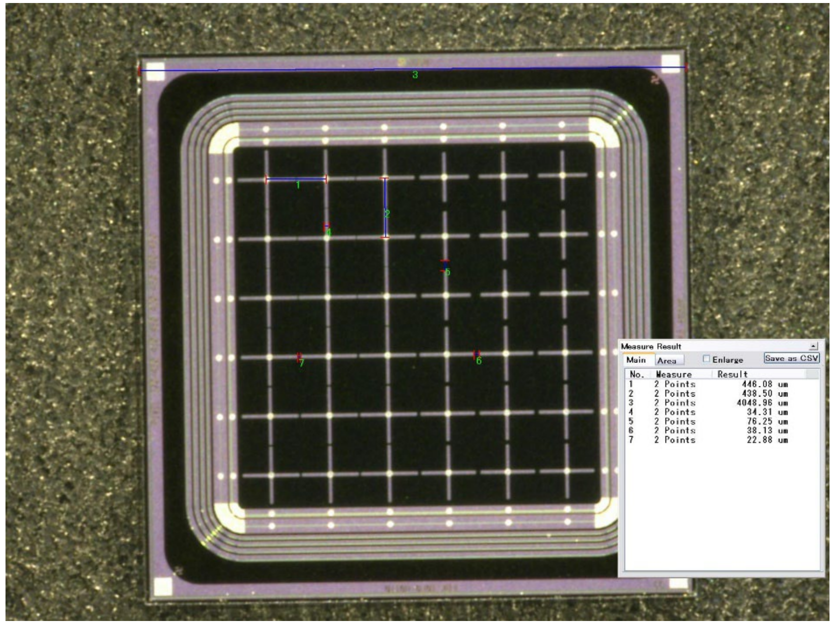






Conclusions

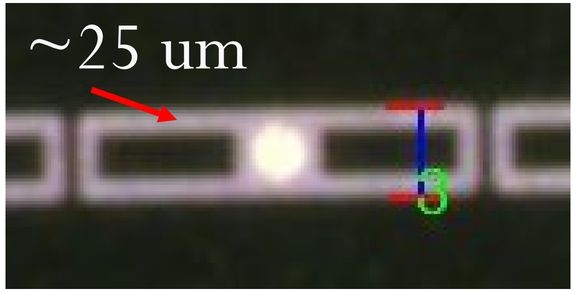
- Signal 'reduction' in between metal electrodes
  - This effect is increased with larger pitches
- An effective way to reduce signal reduction in between electrodes is using metal structure to increase the charge collection efficiency
  - Crosses seem to be a good working candidate
- Propose to put a few of these geometries (including 'snowflake') in some of the full size sensors from HPK
  - Can be just clusters of 4 or 9 pads at the corner for each quadrant
- Proposal to add single pad devices (LGAD, PIN) at the side of the wafer
  - Test absolute gain of the wafer and best time resolution achievable
  - With dimension 0.2mm, 0.5mm, 1mm (2mm?) to check the effect input capacitance on the readout chip

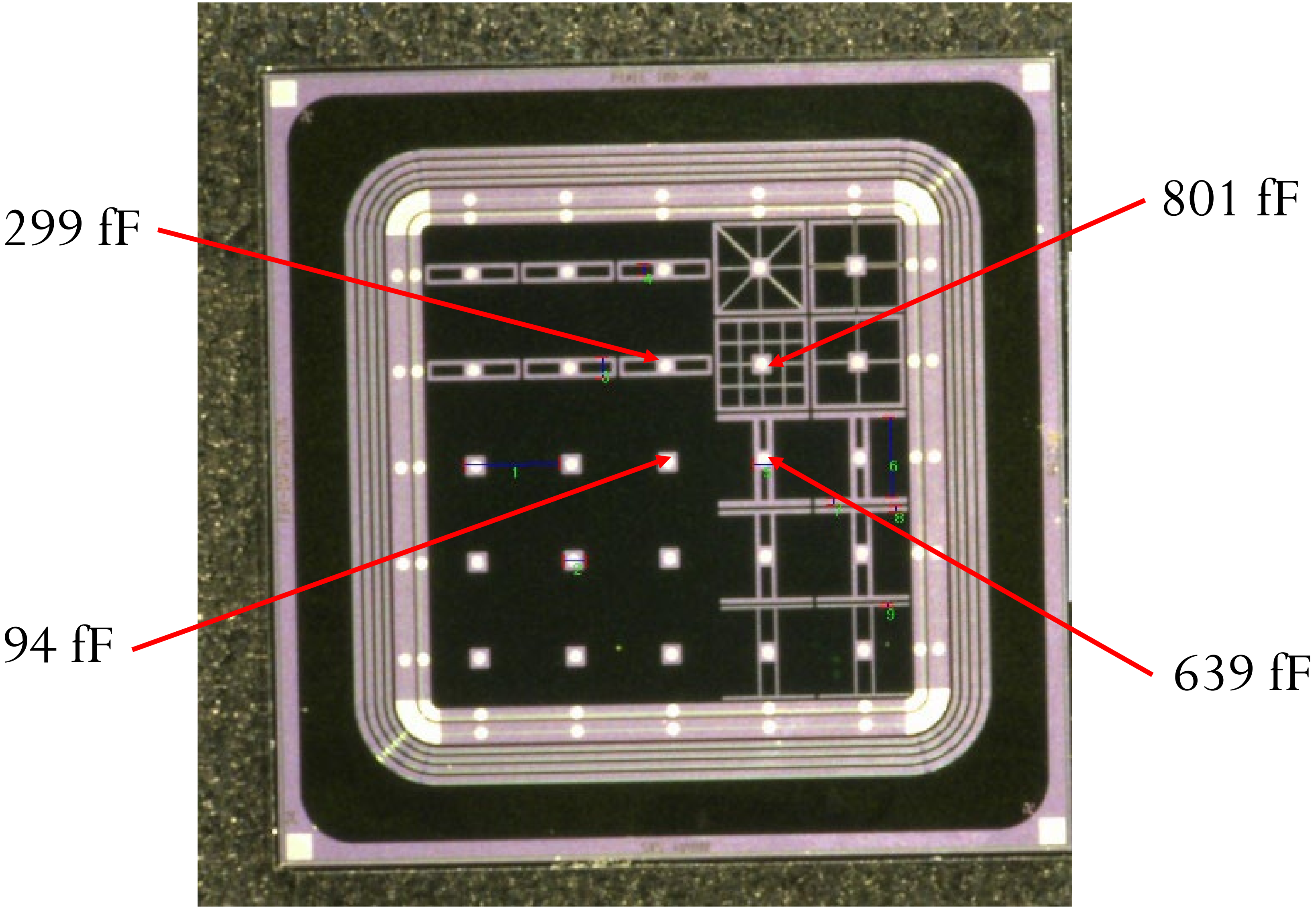


Backup

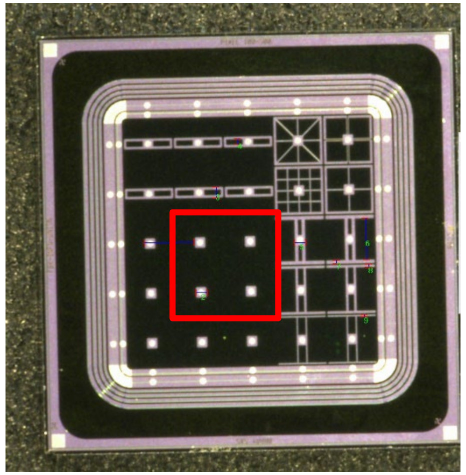
AC-LGAD AC-capacitances

- Measurement of the pad capacitance for each different type of pad
  - HV from the backside, N+ and guard ring grounded, capacimeter connected to top metal
  - The rest of the metal pads around it are floating
- Pad's capacitance scales will amount of metal coverage on top as expected
- **Opening in the metal does reduce the capacitance**
  - Micro-strips are ~100x500 um but the capacitance is not 5 times the one of 100x100 um pads
  - Capacitance is only ~3 times
  - Scales with the (2x) 175x50 um area of the opening
  - H-pad measured has thicker arms so the capacitance is significantly higher

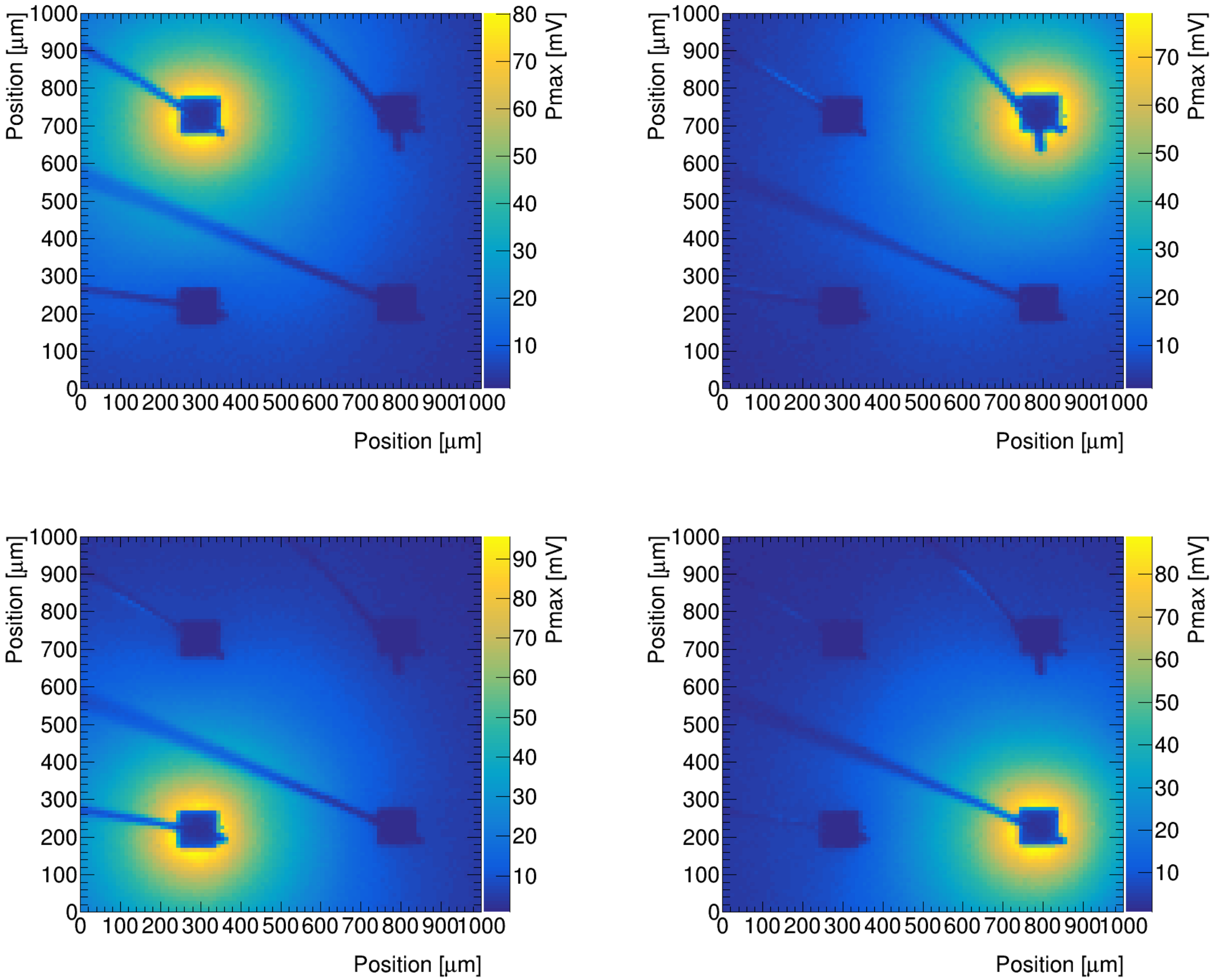




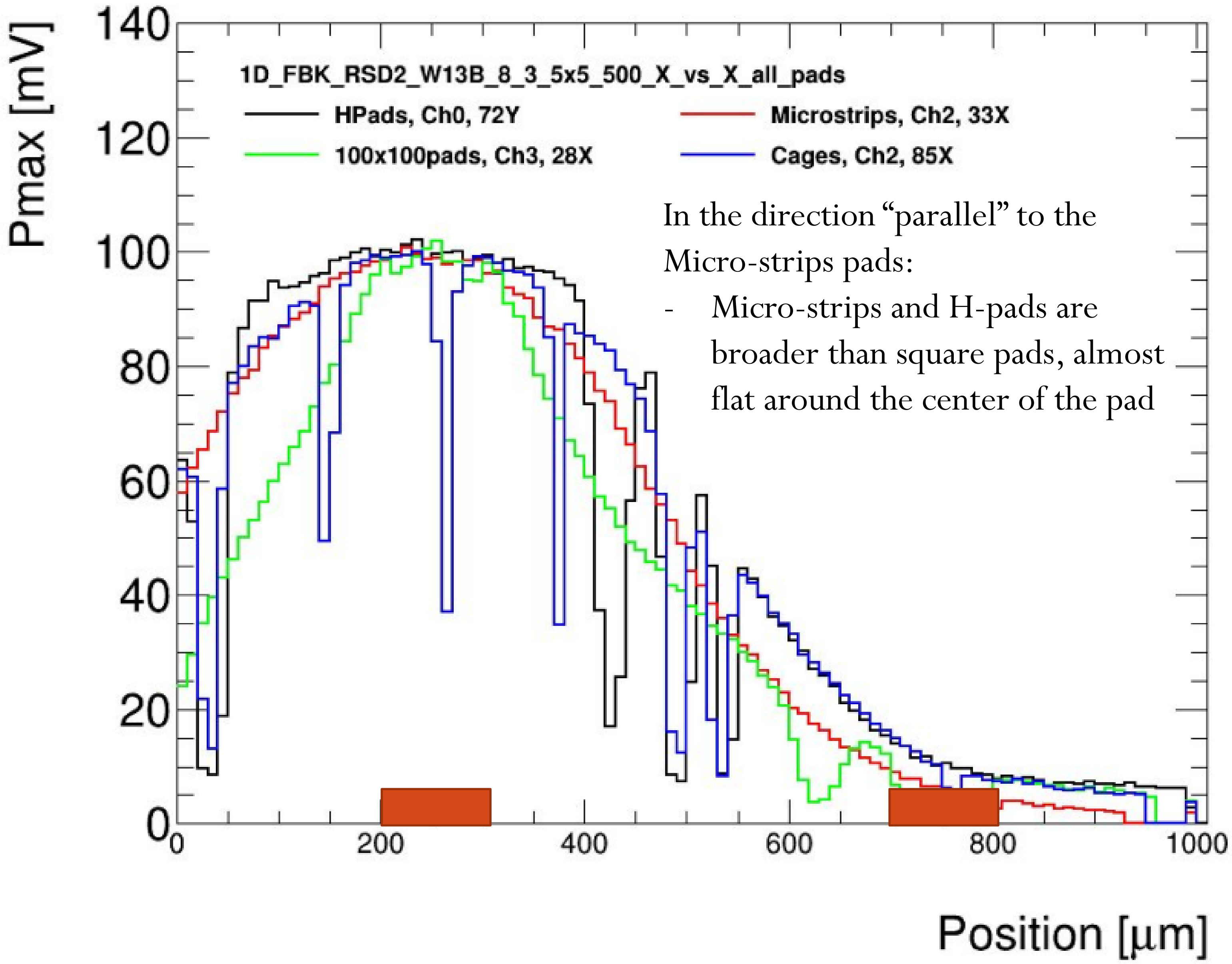
AC-LGAD 100x100 um pads



- Pro
  - Homogeneous in X-Y
  - Likely good reconstruction in the region in between pads
  - Small input capacitance
- Cons
  - Smaller signal



Comparison of 1D profiles, all pads - X



In the direction "parallel" to the Micro-strips pads:

- Micro-strips and H-pads are broader than square pads, almost flat around the center of the pad