New detector’s layout

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BULLKID-DM Collaboration Meeting

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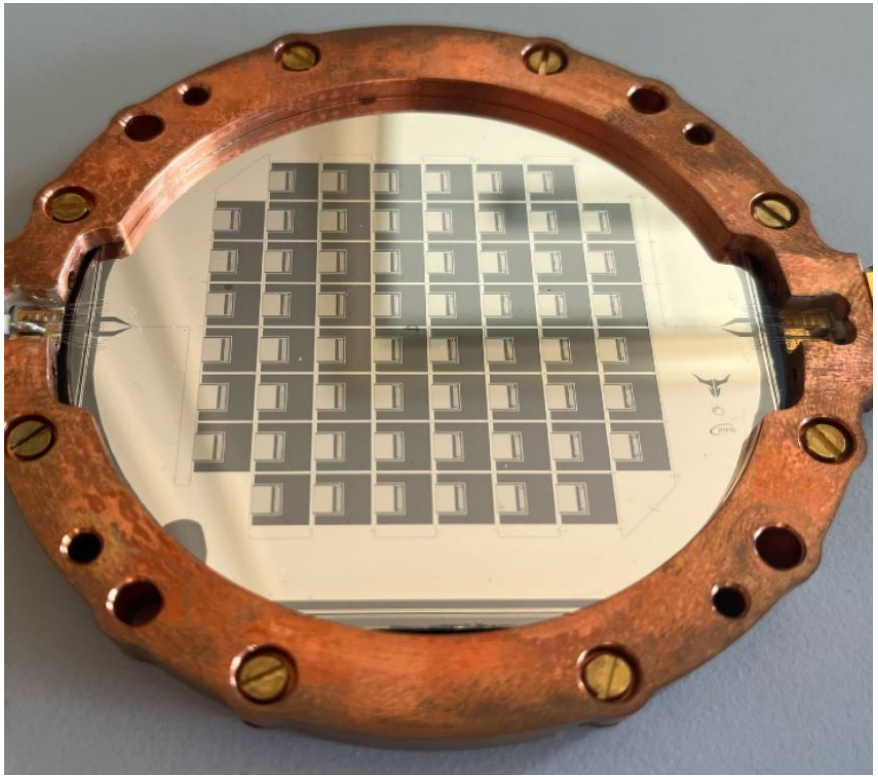
Content

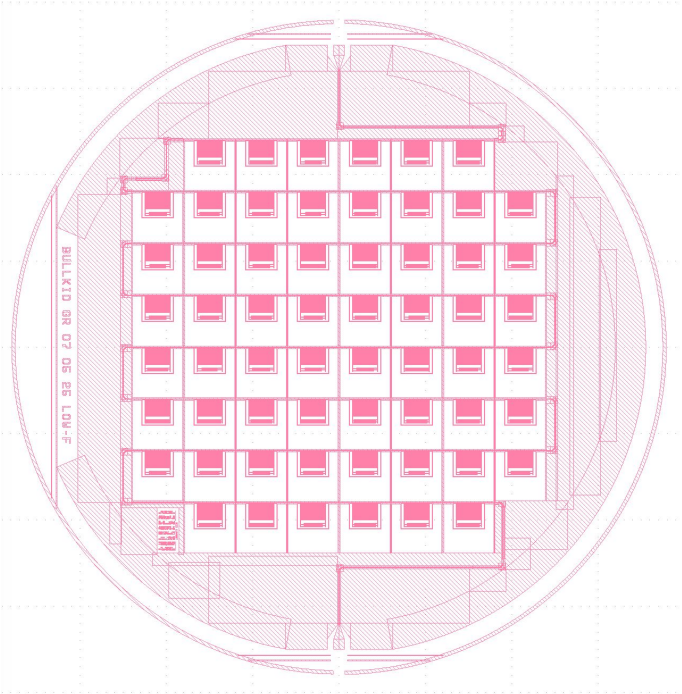
- **BULLKID 3-inches layout**
  - Current mask for BULLKID 3-inches
  - The need for a new layout
  - SONNET simulations
  - New 3-inches layout
- **Frequency map**
  - Current frequency ordering
  - New frequency ordering: random vs non-random
- **BULLKID 100 mm layout**
  - Current mask for BULLKID 100 mm
  - The need for a new mask
  - Status of the new mask



BULLKID 3-inches layout

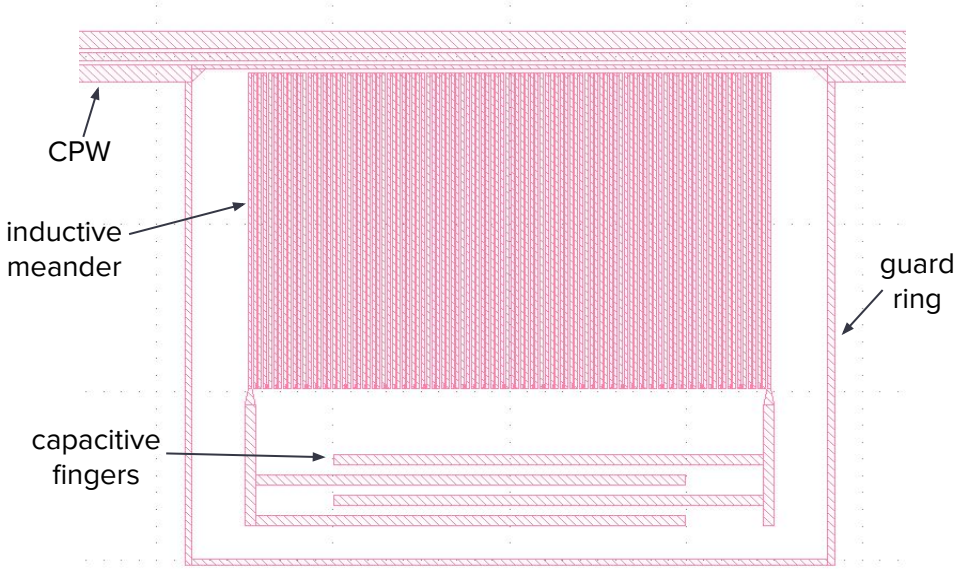
Current layout

- Layout of recently measured STACK-04 wafers



Entire wafer

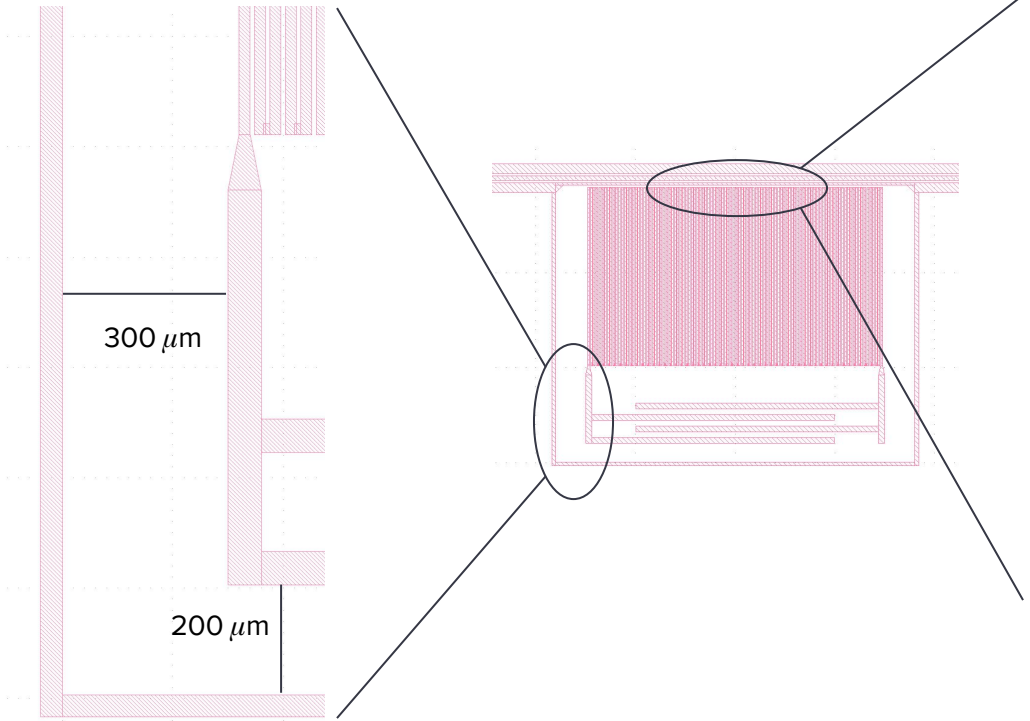
- Inductive coupling with the CPW via the meander
- Resonant frequency tuned via capacitive finger length

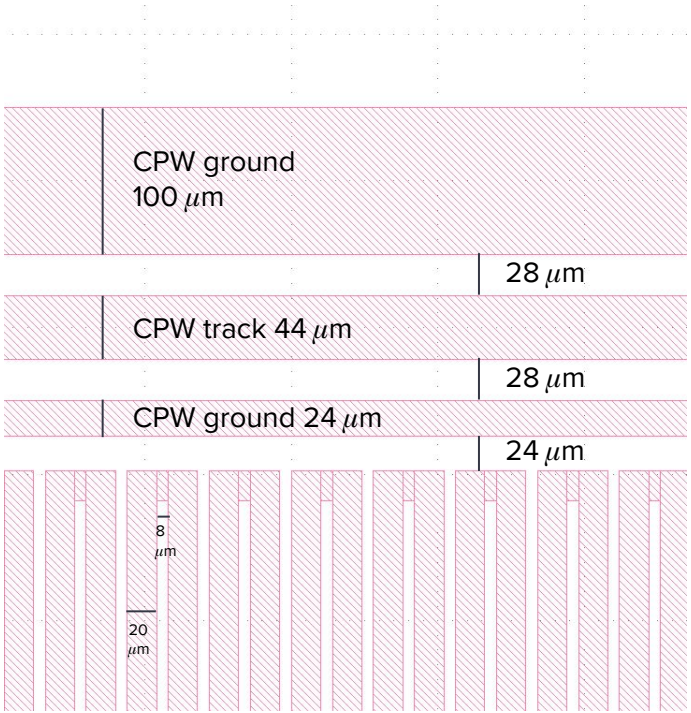


Single KID

Current layout

- Some (important) dimensions

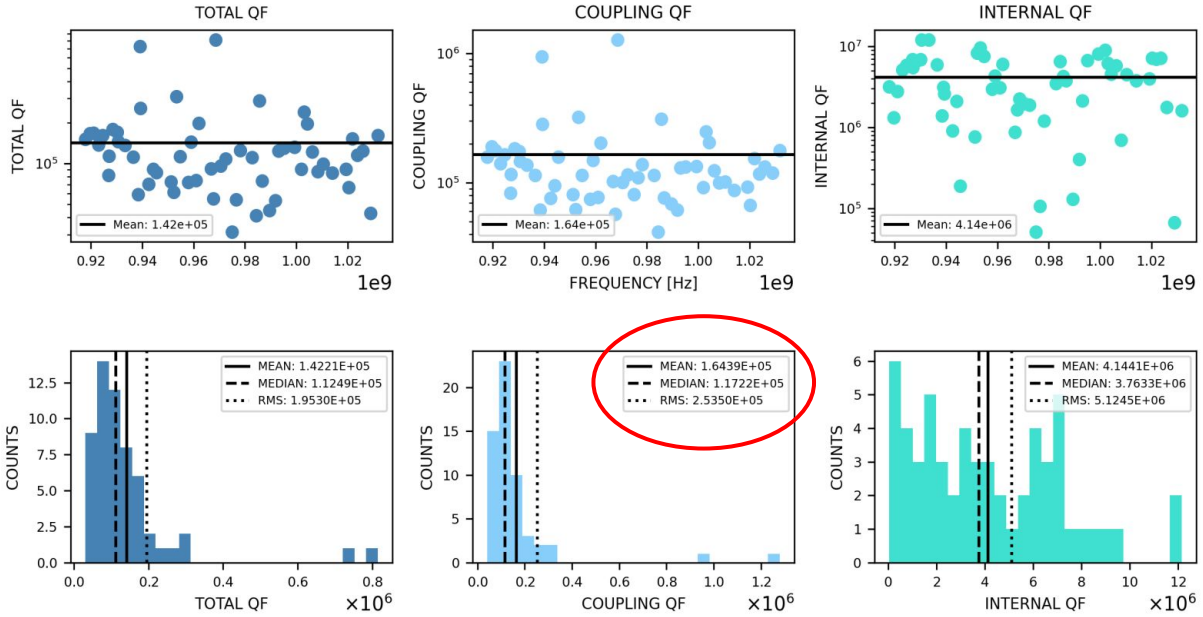




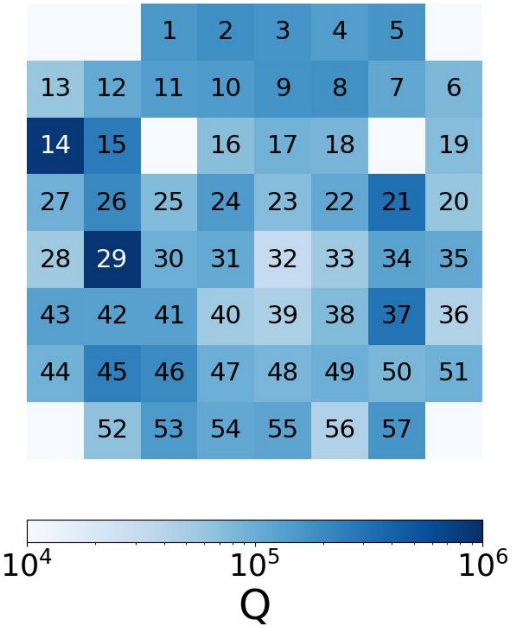
Meander dimensions 20 μm / 8 μm

Current layout

- With this layout, the **coupling quality factor** Q_c is **around 100k**



The **measured value** for the coupling quality factor (median of 117k) **matches simulations** of 103k

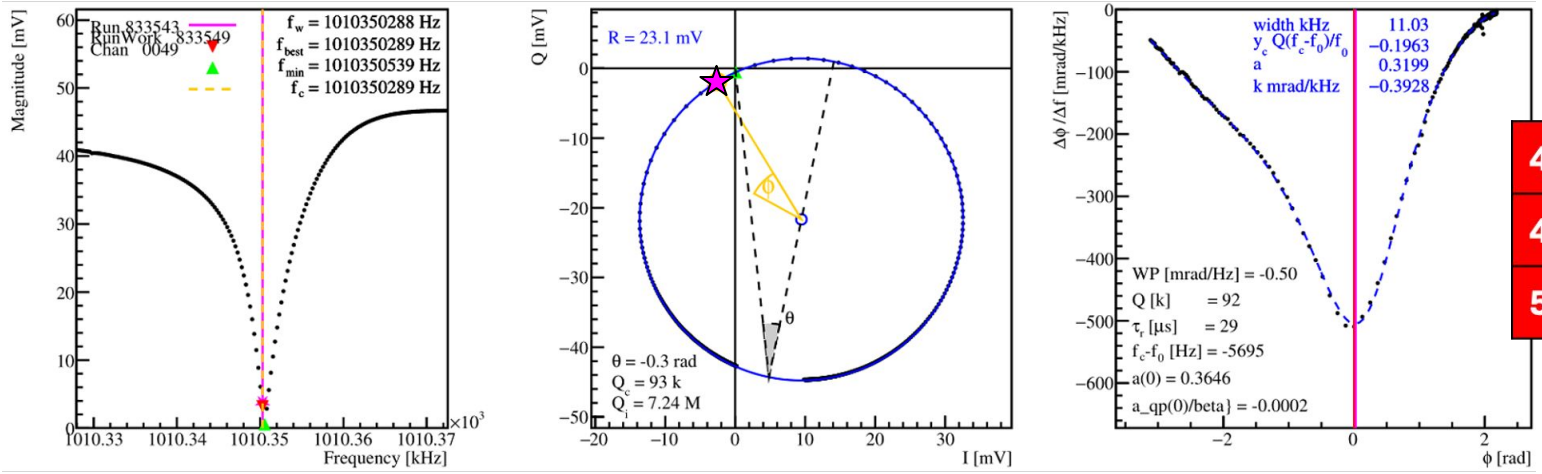


Distribution of the total quality factor over all the wafer

The need for a new layout

- **Cross talk** observed during background run **when neighbouring pixel are biased at their optimal power**
  - The working point of the central channel changes if neighbour channels are biased
  - We decided to keep the power on neighbour channels as low as possible

Pixel 49 at Optimal Power, Neighbours at -40 dBm



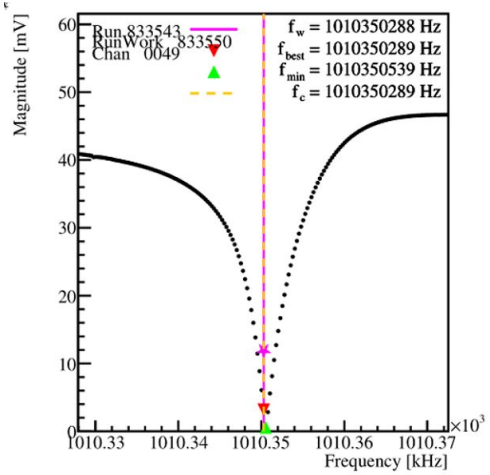
40	39	38	36	37
47	48	49	50	51
55	54	53	52	

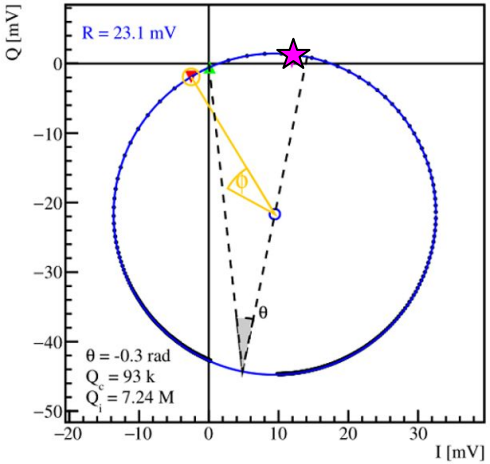
@Study by Davide Quaranta

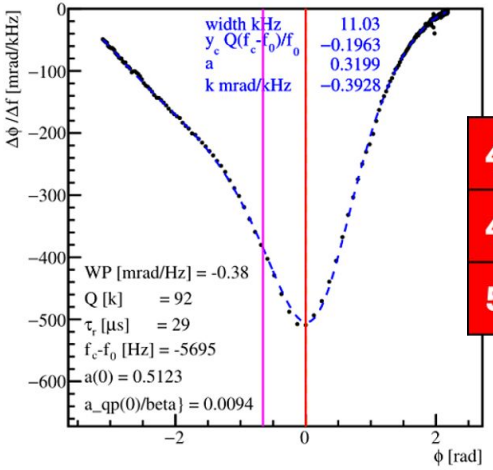
The need for a new layout

- **Cross talk** observed during background run **when neighbouring pixel are biased at their optimal power**
  - The working point of the central channel changes if neighbour channels are biased
  - We decided to keep the power on neighbour channels as low as possible

Pixel 49 at Optimal Power, Neighbour 48 at Optimal Power, Neighbours at -40 dBm







40	39	38	36	37
47	48	49	50	51
55	54	53	52	

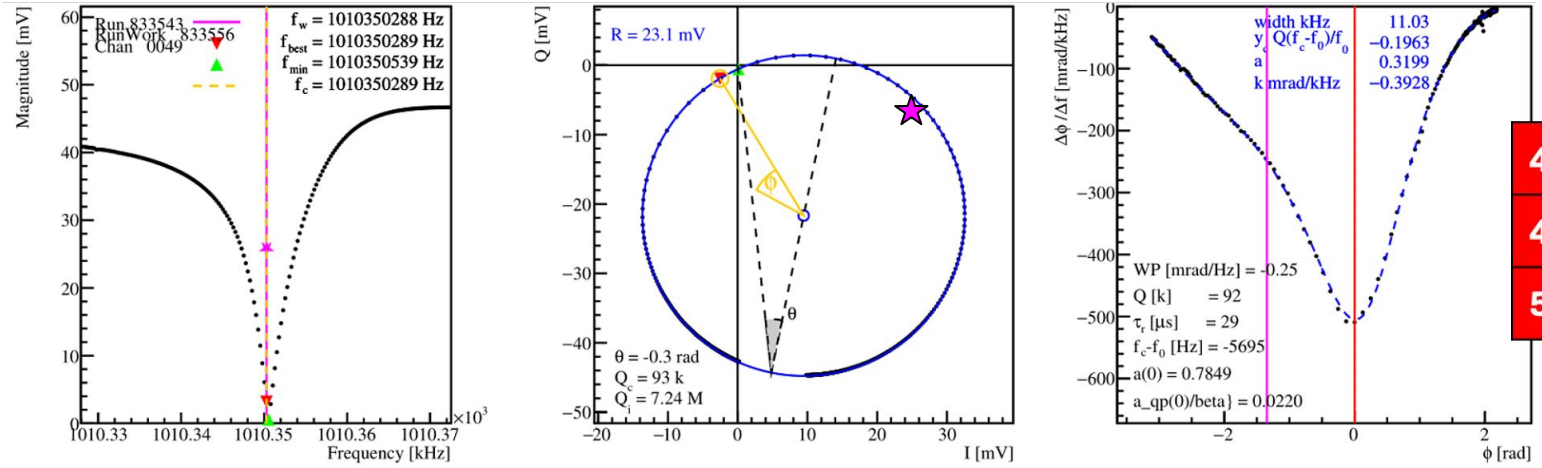
One neighbour (left), visible cross talk

@Study by Davide Quaranta

The need for a new layout

- **Cross talk** observed during background run **when neighbouring pixel are biased at their optimal power**
  - The working point of the central channel changes if neighbour channels are biased
  - We decided to keep the power on neighbour channels as low as possible

Pixel 49 at Optimal Power, Neighbour 48 and 50 at Optimal Power, Neighbours at -40 dBm



40	39	38	36	37
47	48	49	50	51
55	54	53	52	

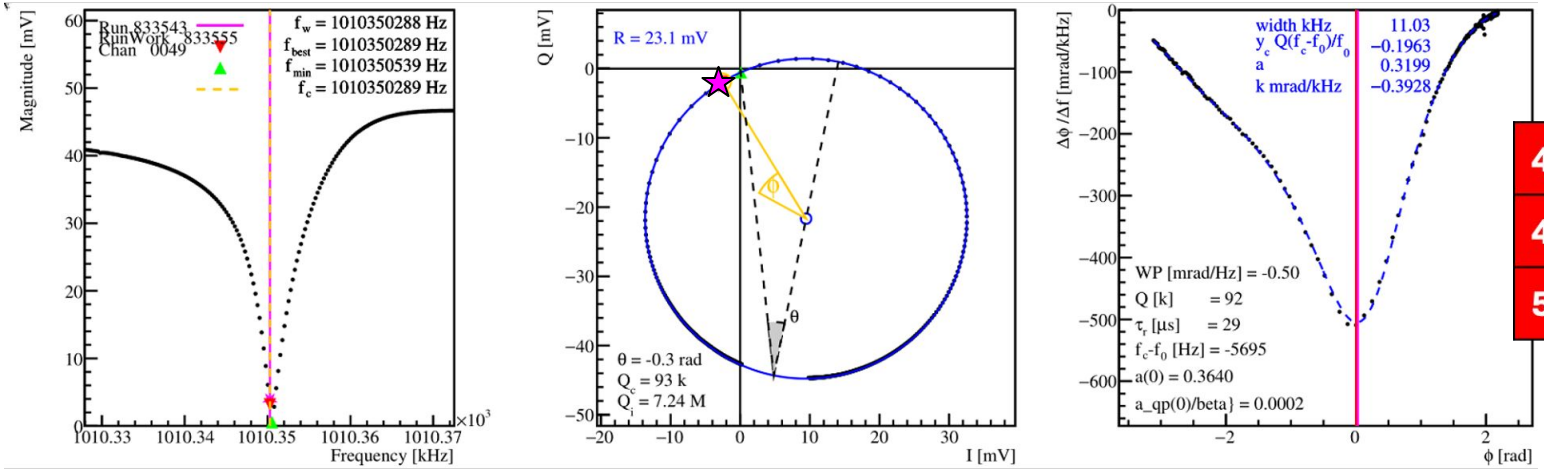
Two neighbours (left right), even more cross talk

@Study by Davide Quaranta

The need for a new layout

- **Cross talk** observed during background run **when neighbouring pixel are biased at their optimal power**
  - The working point of the central channel changes if neighbour channels are biased
  - We decided to keep the power on neighbour channels as low as possible

Pixel 49 at Optimal Power, Neighbour 38 and 49 at Optimal Power, Neighbours at -40 dBm



40	39	38	36	37
47	48	49	50	51
55	54	53	52	

Two neighbours (top bottom), no cross talk

@Study by Davide Quaranta

The need for a new layout

- **Cross talk** observed during background run **when neighbouring pixel are biased at their optimal power**

- The working point of the central channel changes if neighbour channels are biased
- We decided to keep the power on neighbour channels as low as possible

- This cross-talk is likely **electromagnetic cross-talk** (resonators near in space and frequency influence each other)

- Possible solutions:

- **Increase resonators quality factors** so they need less power
- Keep neighbouring pixels **far in frequency**

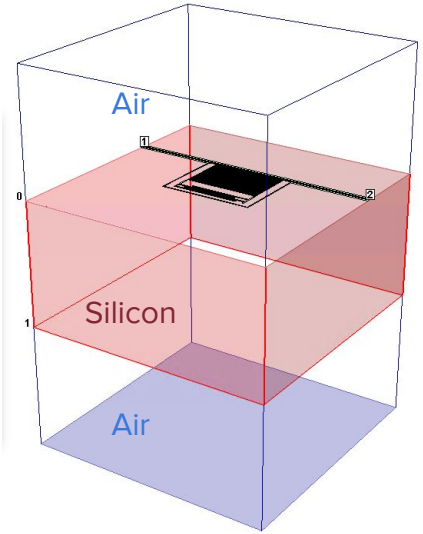
New pixel design to increase quality factor from 100k → 200k

New frequency mapping to maximise frequency spacing between pixels

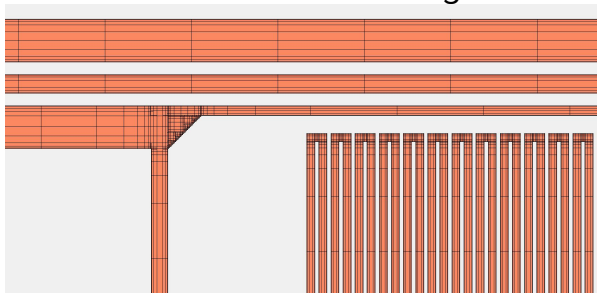
SONNET simulations

- To choose the new pixel layout, we **simulate its frequency response with the SONNET software**
  - It works by sub-sectioning the circuit and solving Maxwell's equations for each pair of subsections

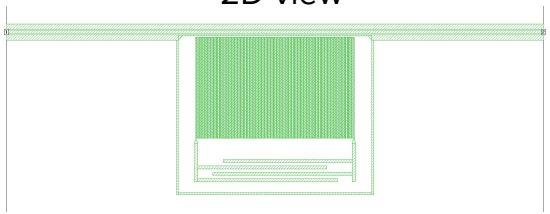
3D view



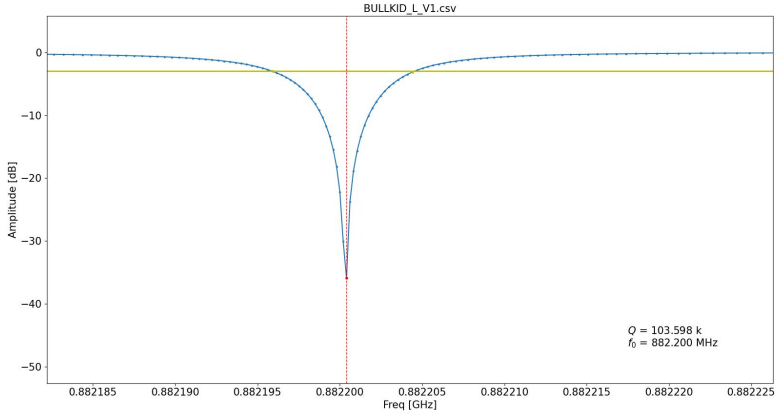
circuit sub-sectioning



2D view



- Extract the Q-factor by the simulated | $S_{21}(f)$ |

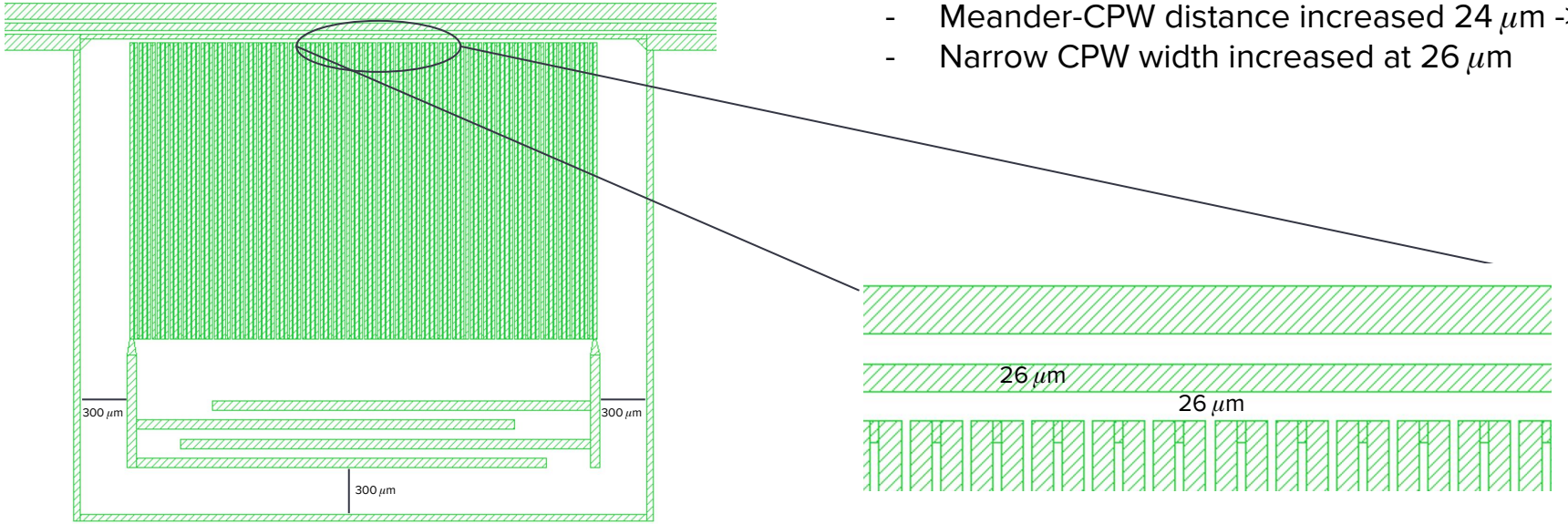


Simulated Q-factor is 103k for the current layout

New 3-inches layout

- **After many simulations…** (simulations very sensitive to meander-ground distance and other specific parameters) **the new layout has been identified**

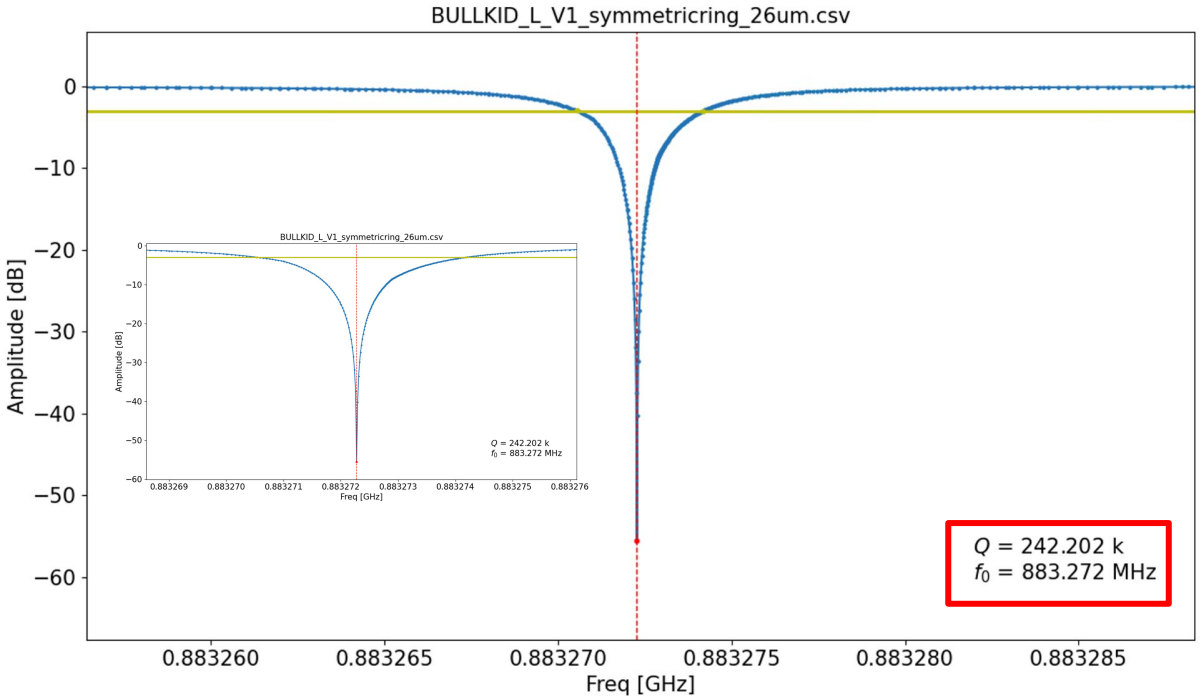
- Guard ring distance is 300 μm in every direction
- Meander-CPW distance increased 24 μm -> 26 μm
- Narrow CPW width increased at 26 μm



- **Key element:** guard ring distance provides an efficient and stable way to control the quality factor
  Increase distance wrt current layout ➔ resonator is less coupled to the circuit ➔ Q increases

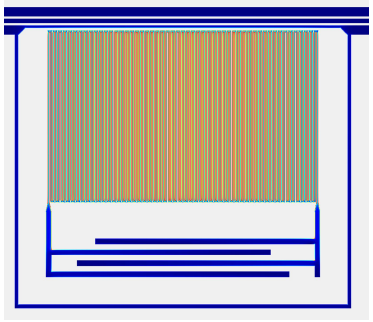
New 3-inches layout

- With this layout, we get a **simulated Q-factor of 242k**

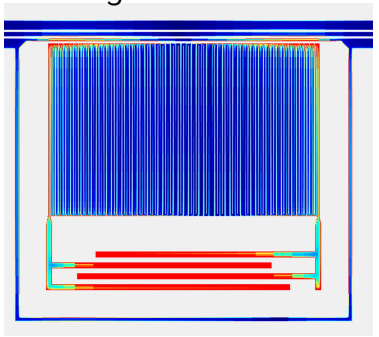


The simulation of the resonance is well performed

Current density distribution



Charge distribution



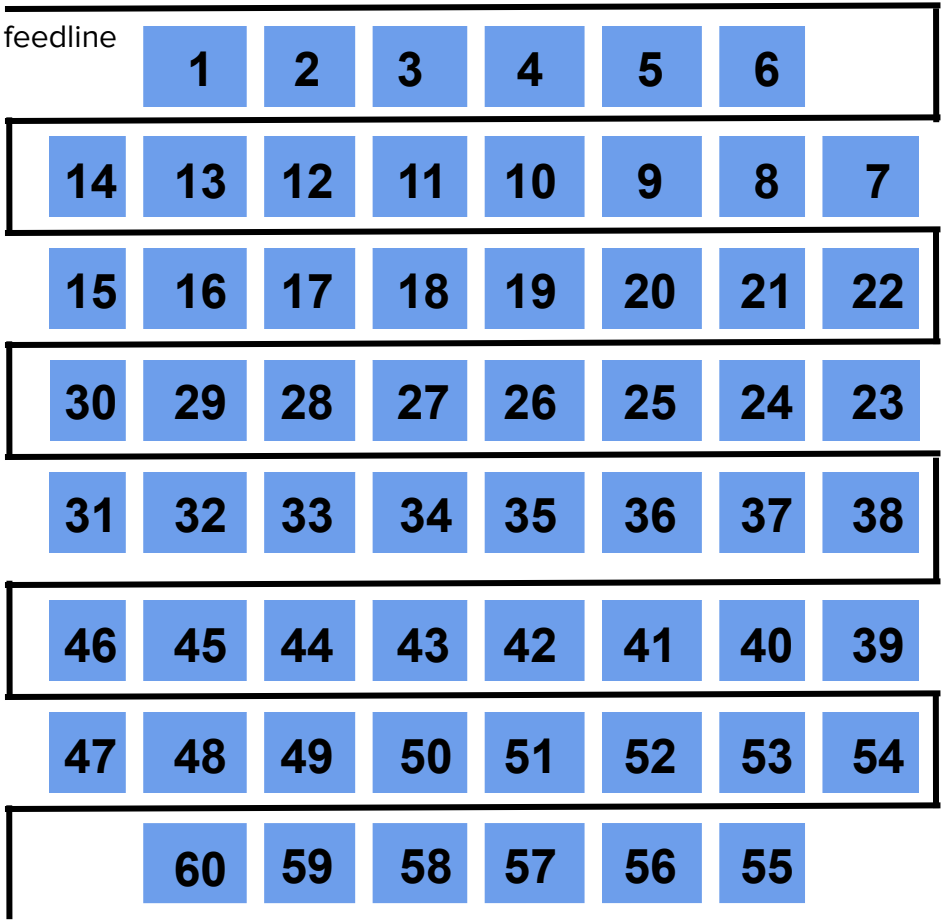
Uniform charge and current across the resonator

Frequency map

Current frequency ordering

- 60 resonators, 1 feedline
- Resonators that are **close in space** are also **close in frequency**

- **Electromagnetic cross-talk** effects can be problematic

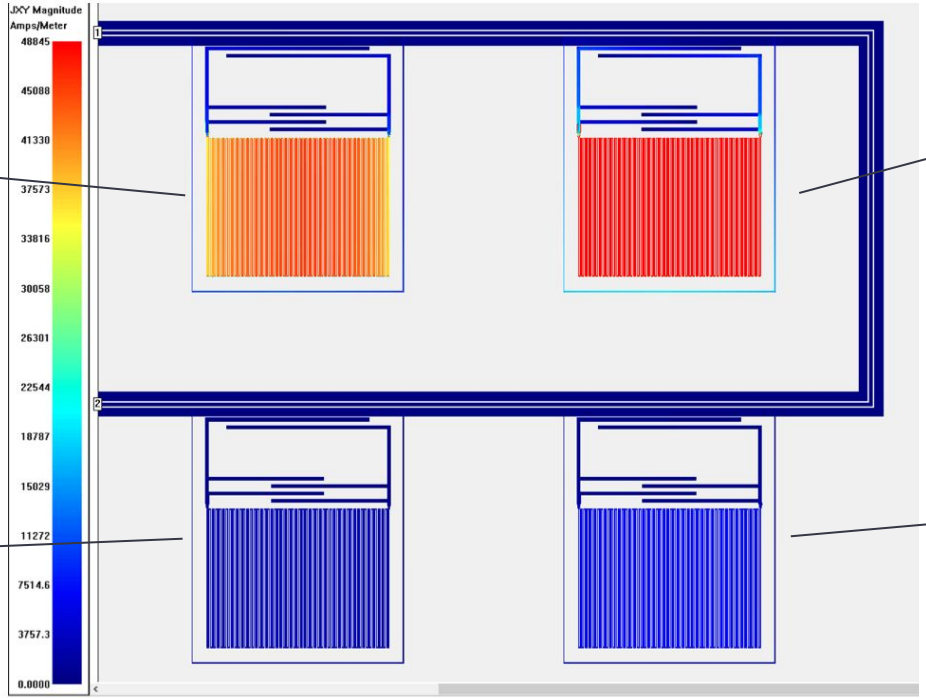


EM cross-talk effects

- Simulated **current density distribution** at the resonant frequency of top-right KID. Visible **cross-talk effects** due to electromagnetic coupling.

@Work by Gianluca Pesce

High electromagnetic cross-talk due to proximity in space and frequency



Resonating KID

Less electromagnetic cross-talk (far in space and in frequency)

Less electromagnetic cross-talk (far in space)

New frequency ordering (random)

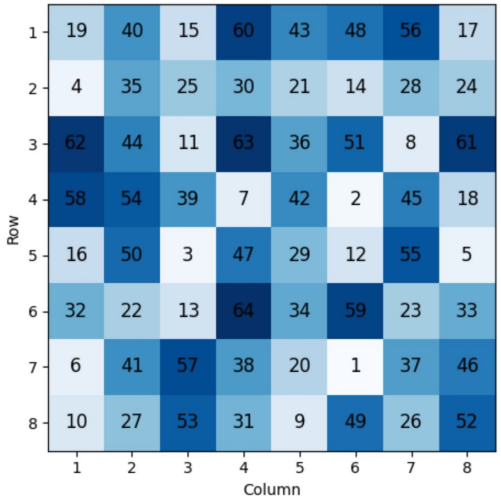
- **Idea**: maximize the difference in resonant frequency between neighbouring pixels. Not a trivial mathematical problem
- **Random ordering** (first proposal)

KID LAYOUT

X	22	43	12	54	23	3b	X
15	7	31	1	42	1b	45	14
32	41	18	57	8	24	58	35
11	25	9	2b	49	17	44	20
52	60	2	39	5b	4	30	37
13	40	53	28	47	19	50	5
21	33	6	38	59	10	34	27
X	46	55	48	29	3	51	X

The matrix is filled randomly with the constraint that the **distances from the nonet is >= 7**. But there are some second neighbours with distance 1 (e.g. 25 and 26)

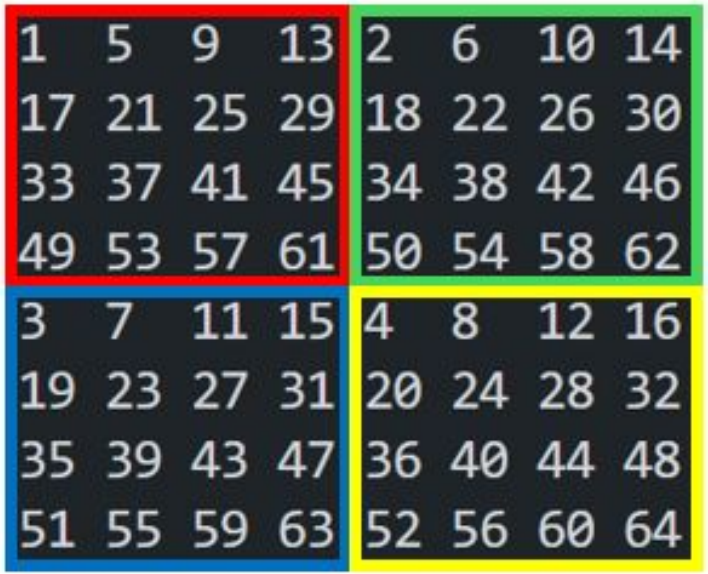
- **Random ordering** (second proposal)



Here **distance from the nonet is >= 4** and **distance from second neighbours is >= 3**

New frequency ordering (non-random)

- **Idea**: maximize the difference in resonant frequency between neighbouring pixels. Not a trivial mathematical problem



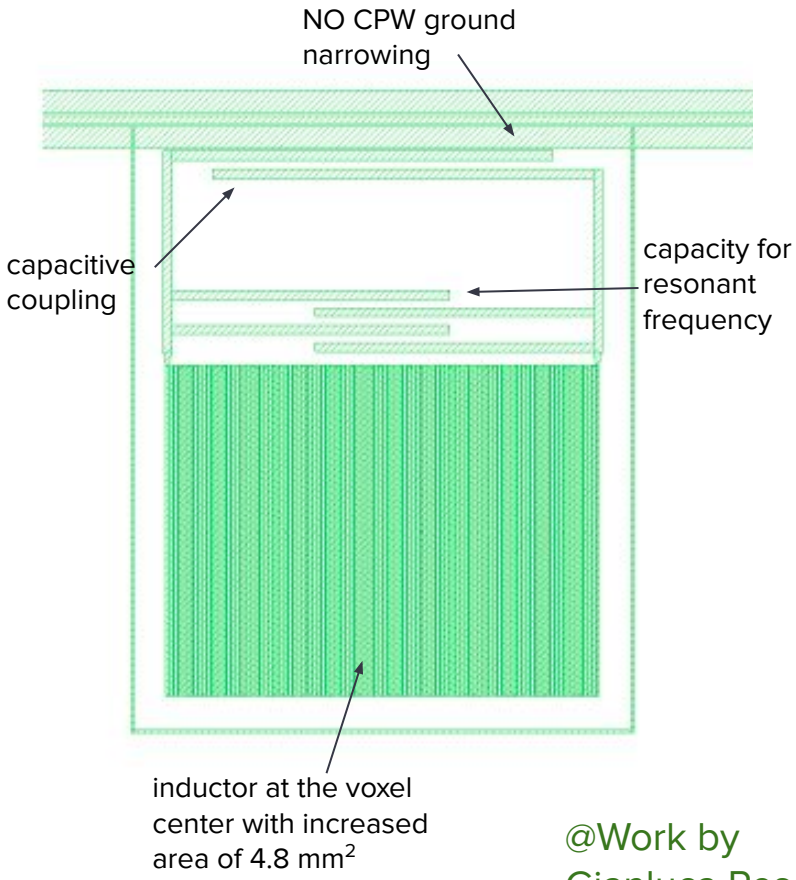
Distances are >= 3 up to the third neighbours.

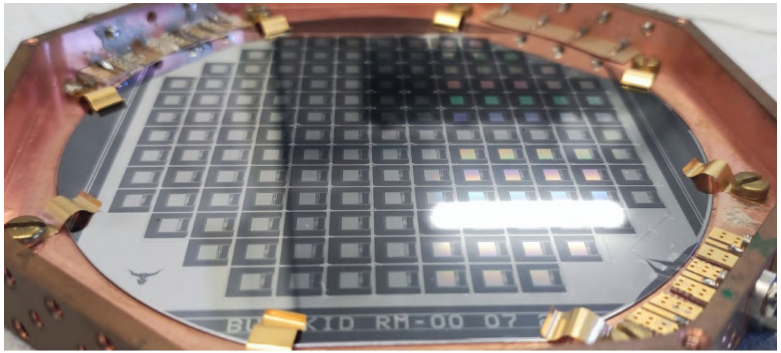
- **Pros**
  - High frequency spacing ensured for many neighbours
  - Pattern for easy frequency identification

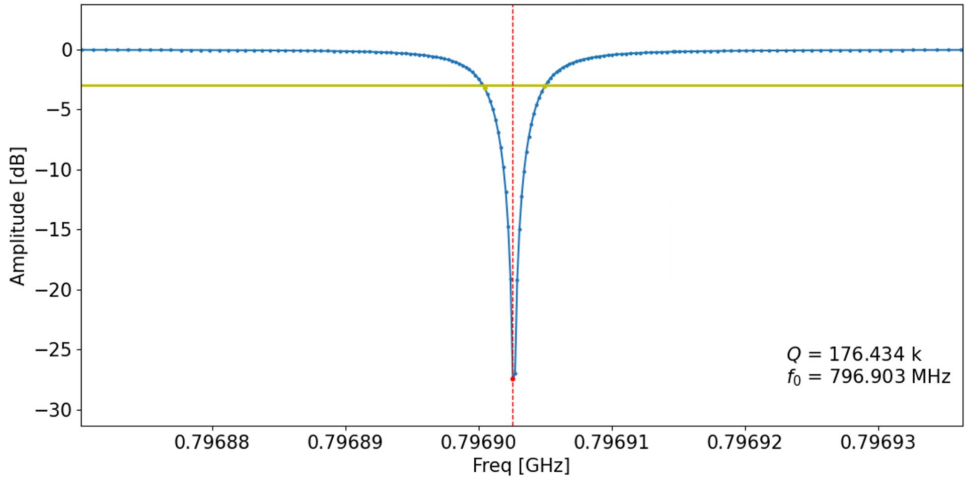
- **Cons**
  - Possible interference caused by higher harmonics?

BULLKID 100 mm layout

Current layout for 100 mm array





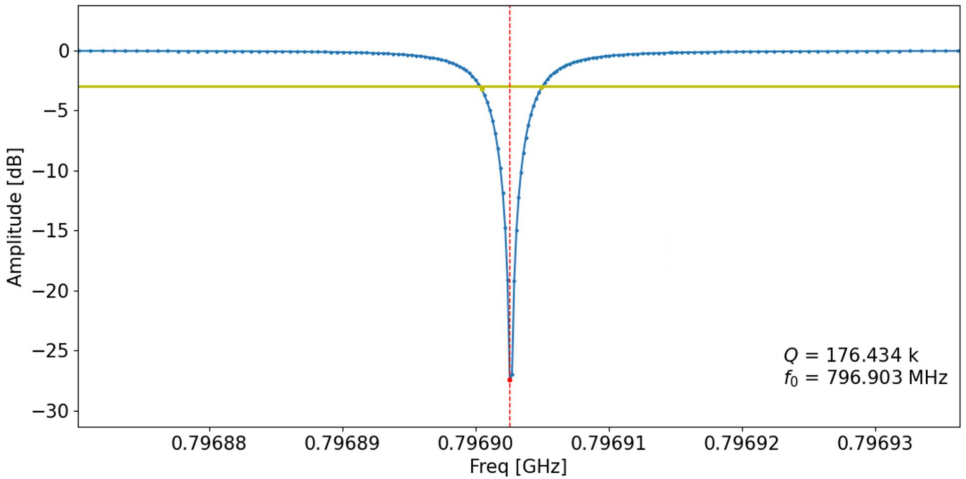


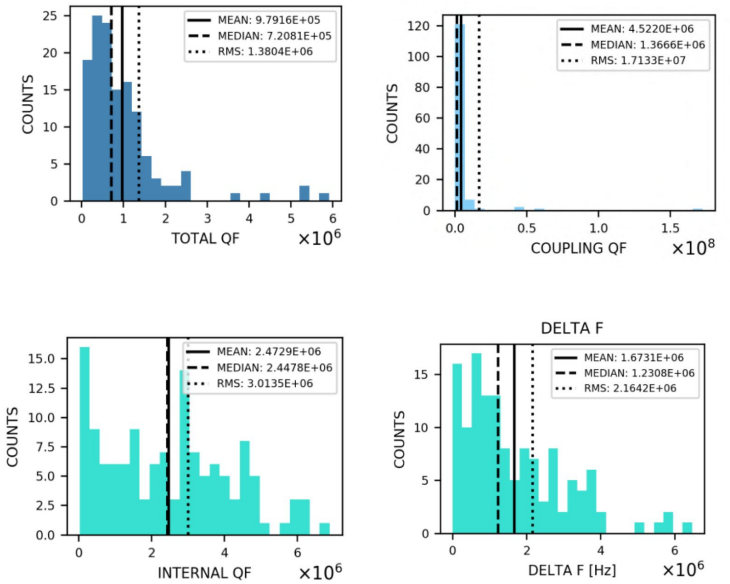
@Work by Gianluca Pesce

- Simulated quality factor of 176k

Quality factor mismatch

- **Mismatch between the simulated and the measured quality factor**



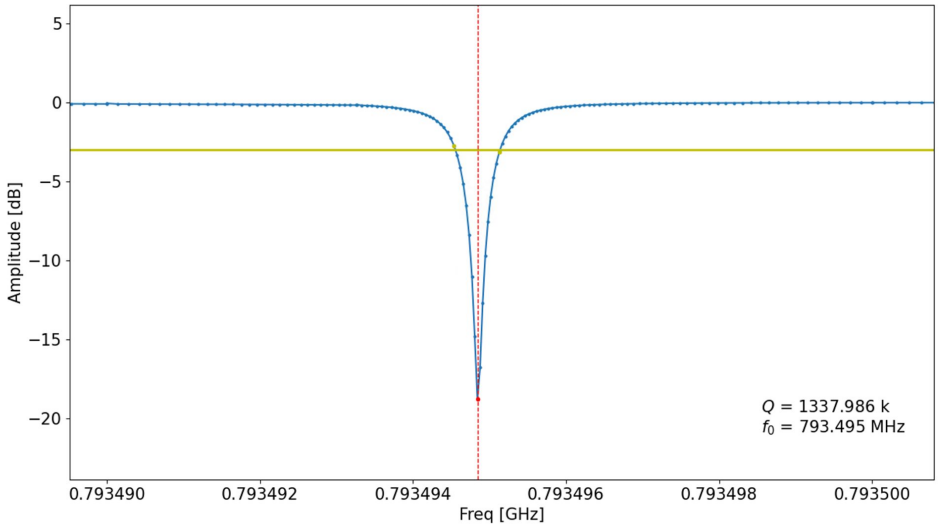


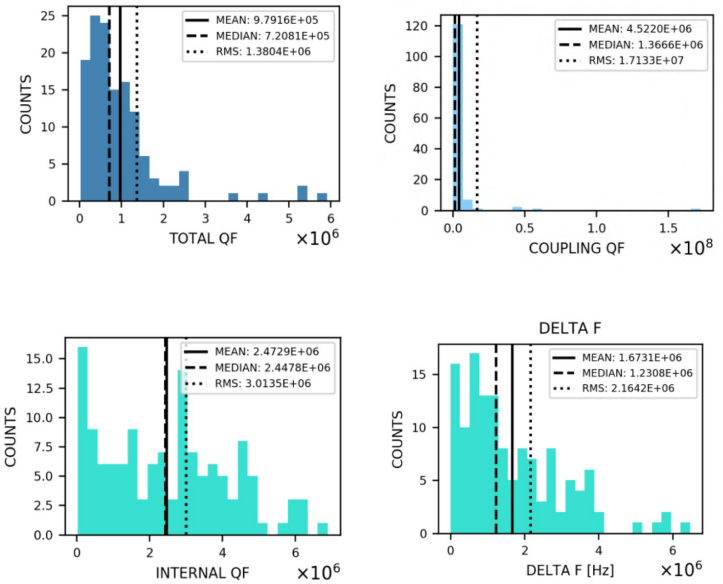
- Simulated quality factor of 176k
- Measured quality factor of 1.4 M

@Work by
Gianluca Pesce

Quality factor mismatch (solved)

- **Mismatch between the simulated and the measured quality factor**





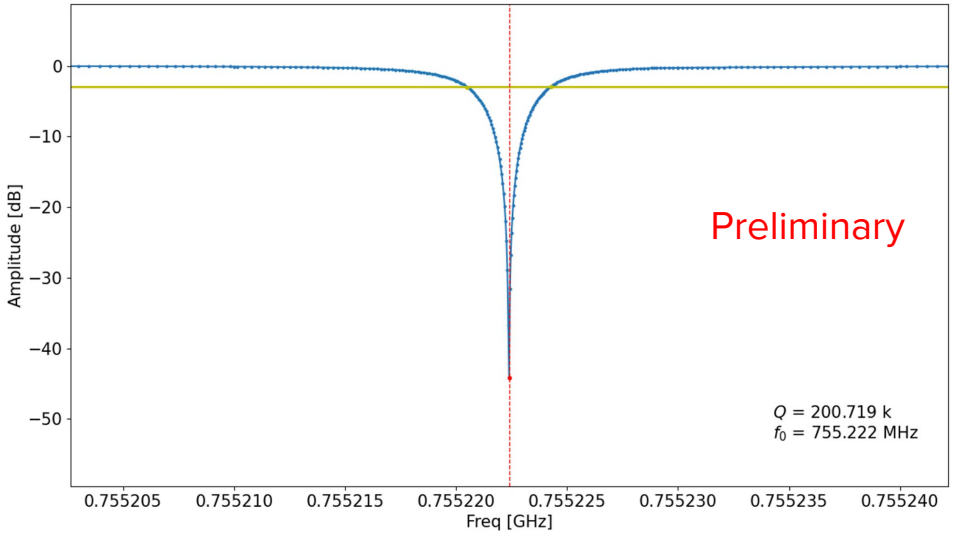
- Simulated quality factor of 1.3 M
- Measured quality factor of 1.4 M

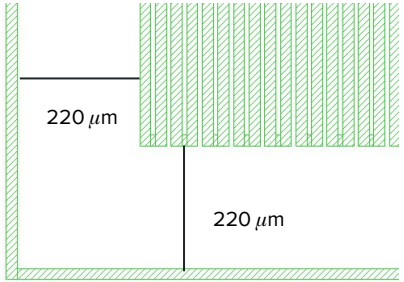
Solved by re-performing the SONNET simulations with more resources

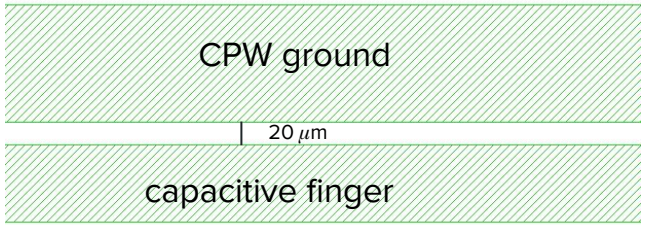
New 100 mm array layout (preliminary)

- A Q > 1 M is too high: we need to **lower the quality factor**

- CPW distance increased to 20 μm
- Coupling capacity length increased from 2.6 mm to 2.8 mm
- Now guard ring is symmetric and its distance is 220 um from the meander







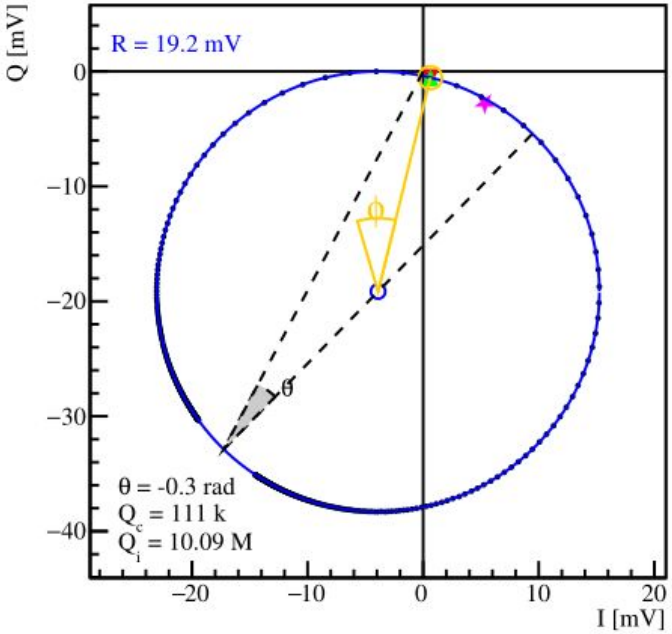
- Simulated quality factor of 200k

Thanks for your attention!

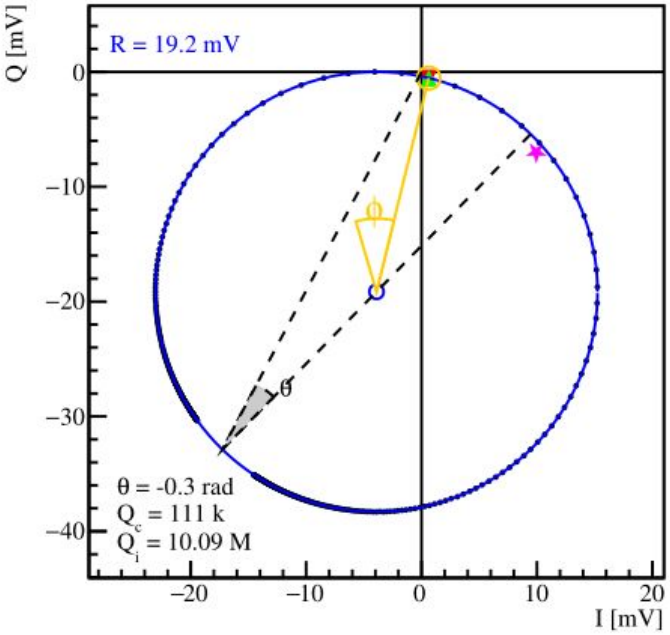
Backup slides

Cross talk during background run

- **Cross talk** observed during background run **when neighbouring pixel are biased at optimal power**
- The working point of the central channel changes if neighbour channels are biased
- We decided to keep the power on neighbour channels as low as possible



One neighbour

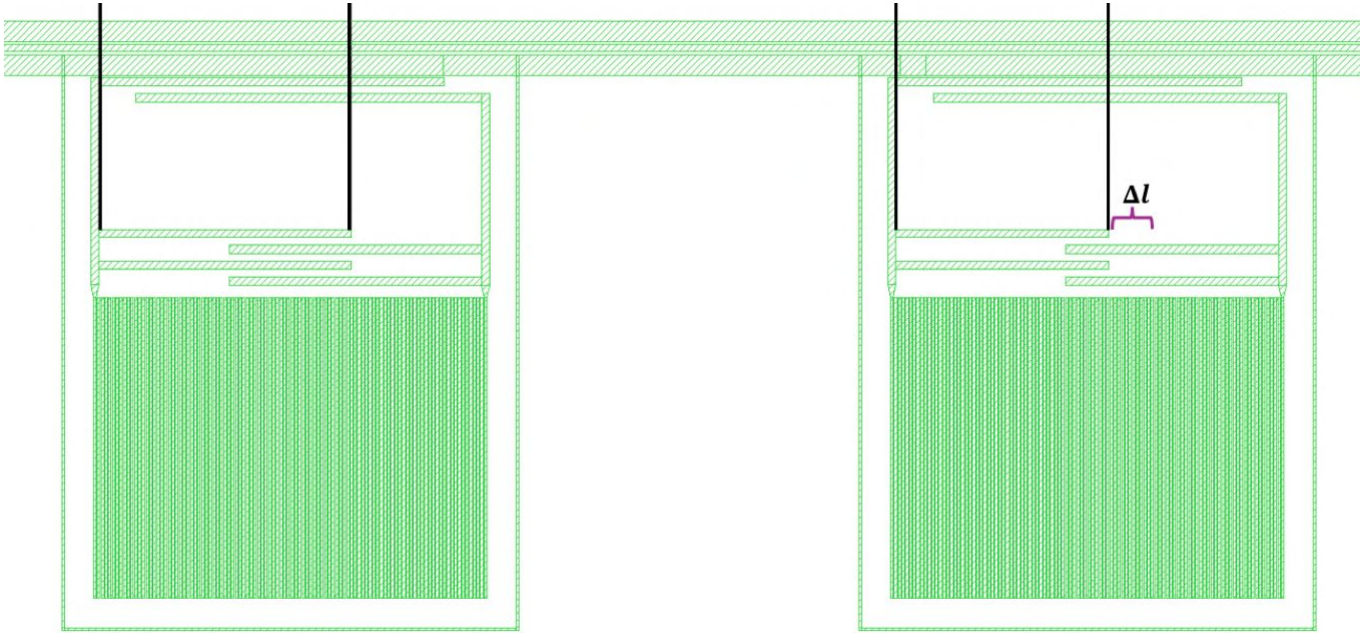


Two neighbours

EM cross-talk study

- Simulate two adjacent KIDs, varying the resonant frequency of the second by varying the capacitive finger length Δl

@Work by Gianluca Pesce



- Study the resonant frequency behavior as a function of Δl and when $\Delta l \rightarrow 0$

EM cross-talk study

- Study the resonant frequency behavior as a function of Δl and when Δl $\rightarrow$ 0

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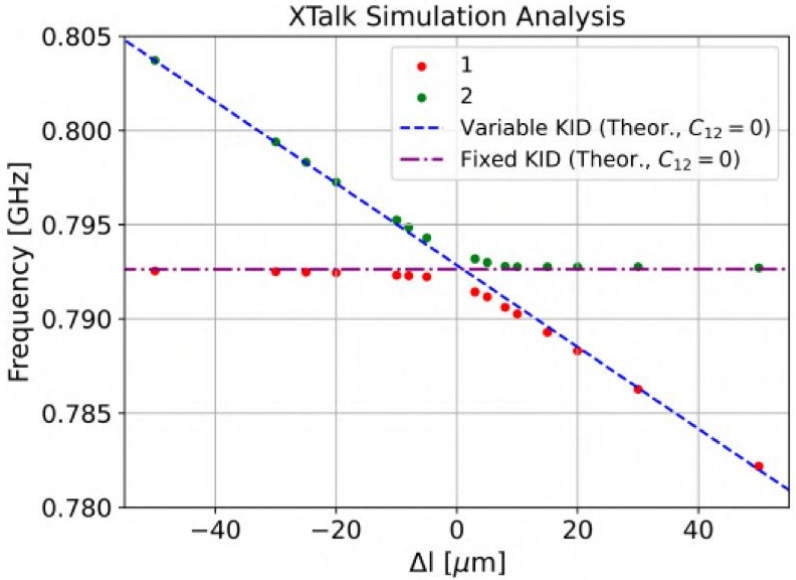
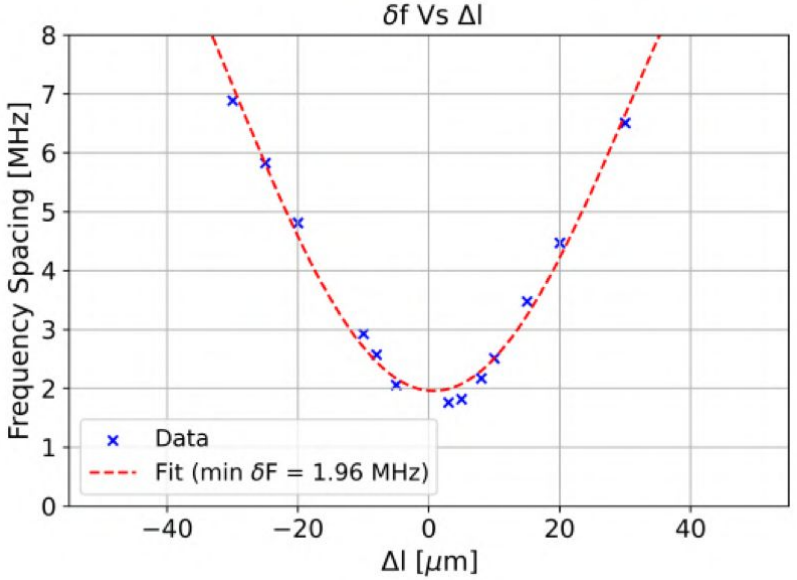
Gianluca Pesce





- When Δl = 0, the resonant frequencies of the two KIDs are not equal, but they differ by ~ 2 MHz