## 00:00:00 Intro

Chris: I am Chris.

Mira: And I am Mira. We are associated members of ML4Q

Chris: and you're listening to ML4Q&A – a show where members from the Matter and Light for Quantum Computing Cluster talk about their careers, their research and the future of quantum.

Mira: Today we are recording our 20th episode. Chris, can you tell us how ML4Q&A started.

Chris: ML4Q&A is the podcast of the ML4Q Cluster of Excellence, which brings together scientists from the universities of Cologne, Aachen, Bonn, Düsseldorf and Forschungszentrum Jülich. The podcast was started by Jonas Kölzer in 2021. I came in only for the second episode and it's already the 20th now. Actually it was Jonas who came up with the name, contributed the music and the catchphrase "future of quantum" .

Mira: Yes, and I joined you quite recently. But there are also a lot of members who work behind the scenes whom we need to acknowledge. It's fun interviewing researchers and learning about so many different aspects of physics directly from them but the real hard work is the journey before it reaches the audience.

Chris: This podcast wouldn't be possible without the support of the Cluster Office and the Marketing Department at the University of Cologne. Special thanks to Marian Barsoum for dedicating countless hours to editing, and to Alex Jahn for managing all technical aspects and creating the fantastic illustrations featured on the website.

Mira: We should also not forget to thank all the guests who have been hosted here by us as well as by previous hosts Jonas, Kathrin and Federico. But who are our guests in this episode?

Chris: We have an exciting two-guest episode today, starring Jan Goetz, CEO and co-founder of Germany's upcoming start-up IQM and Frank Wilhelm-Mauch, researcher at Forschungszentrum Jülich and university of the Saarland.

Mira: Frank has been involved with a lot of projects at the national and international level, including QSolid. He has also co-founded the start-up Qruise with a Q instead of a C, of course.

Chris: So let's find out what these start-ups are about and how they contribute to Germany's role in Quantum Computing. Given that Frank is still very much rooted in academia and Jan is fully in an industry setting, they discuss how both industry and academia have complementary roles in making quantum computers a reality.

Mira: Welcome Jan and Frank on the ML4 Q&A. We're very excited to have you both here today. Let's start with your early career and then your transition to becoming involved in quantum startup world.

00:00:48 **Jan's educational journey in Physics**

Chris: So Jan, really welcome. You came here from Neuss, which is where you were from, right?

Jan: Yeah, I was born and raised in Neuss. So just 40 kilometers up north from here.

Chris: And so you're back home in the Rhineland, but here's the Kölsch side of the Rhineland.

Jan: Well, Neuss has this particular situation that you can drink both Alt and Kölsch. There's a Früh Hofbräuhaus, but also Altbier breweries, and this is, I think, always a nice way to get out of this question.

Chris: We have two guests, so we will need to go through things quickly, but maybe we can go through your academic career up to the PhD. What was it like and how did you sort of get into superconducting qubits?

Jan: Well, I was studying physics in Munich, which was kind of far away from home, so to say. So I really wanted to go out a little bit of the region and see something differently. So I was at a technical university focusing on experimental physics and was then focusing on solid state. And this brought me into the superconducting topics.

And I was then doing my diploma thesis at the Institute for Low Temperature Physics where one of the groups was actually studying quantum effects, not only quantum computing, but also quantum physics at the heart, like ultra-strong coupling and topics like this.

So this is how I got into the topic and was super excited about it and then also did a PhD at this institute in Munich.

Chris: So was it more a deliberate choice or more that the research group was there and you sort of grew into the field?

Jan: Yeah, I like the solid state lecture and the professor giving the lecture. So this brought me to his institute, so to say. And then, well, of course, when you start, you don't really know what it all is about.

But I really got excited by the people there and the team. And then also the topic, I think, was really fascinating at the forefront of physics. And this is what still fascinates me actually about the field.

Chris: Yeah, this was Rudolf Gross, right?

Jan: Rudolf Gross was then also my doctor father in the 80s.

Chris: And yeah, he does have a popular book also on solid state physics, right? Exactly. So you did, of course, research on superconducting qubits but also a lot of sort of, yeah, a qubit adjacent research, right?

How do you see that like, how do you see the relationship between research on like hardcore quantum computing versus, for example, you did resonator coupling and things that are superconducting circuits, but not necessarily only quantum computing related?

Jan: Yeah, well during my PhD actually we still had to set up the lab so the equipment wasn't even fully there to make really multi qubit experiments and things like that. And of course then you do what you need to do as you pick your kind of research topic and you publish stuff.

But I think it's super important that we also have this kind of supporting research so not only the fancy kind of quantum computing papers but also the people really trying to understand what are the loss mechanisms what is really happening on the chip and I think also there you really learn how to look at details and how to explain things that are happening and this was for me at least it was super exciting.

Chris: Yeah, I'm sure and I guess the experience of setting up a lab is a good experience to have had once you become an entrepreneur in the topic.

Jan: Yeah, of course you learn a lot. You learn planning project management, but also procurement and You learn how to deal with limited budgets and all of this is of course very helpful later on.

00:06:27 Frank's career journey

Mira: So Frank, can you quickly walk us through your career?

Frank: Quickly is a challenge because I'm really old. So I studied physics at what is now called the KIT, the Karlsruhe Institute of Technology. I did a theoretical PhD on the proximity effect, which now of course in some areas of ML4Q is important because it's what you're using for induced superconductivity. And in the end, I was bored with this project.

But then I had the opportunity as we are recording this 25 years ago, minus three days and as this is uploaded 25 years ago plus a few days to start working on superconducting qubits as a postdoc in the group of Hans Moy at TU Delft as an experimental group and I was an embedded theorist. I did this for about two years.

Then I went to Munich, but actually to Munich proper to the LMU. And I did my habitation in the group of Jan van Delft. So habilitation for international listeners, the famous second German doctorate. And then I was looking for long-term positions and independent long-term positions. And if your profile was, hey, I'm doing theoretical physics with the goal of building and improving and using quantum computers at this time in Germany, you were kind of notrecruitable. You were between the pillars of university departments.

But there was a great place in Waterloo in southwestern Ontario in Canada that had just started this quantum institute. It was fairly mathematical to the point that after I started people asked me where my lab is because somebody like this guy must be an experimentalist became an associate professor there, stayed there until 2011, then became a professor at Saarland University in Saarbrucken. So there I had my own proper group.

And then in 2020 I got, I think the proper English term is seconded to the Forschungszentrum Jülich. I'm now the founding director of what is called the Institute for Quantum Computing Analytics. That's part of ML4Q and my academic home is still Saarland University. So this is where my students graduate and where my lecture takes place.

Mira: And does your research focus now on optimal control theory?

Frank: Optimal control theory is one aspect of it, but it's only one of the tools we have. I'm now in the situation that I have an institute with multiple research groups. We are also looking at early applications. We are also looking at mathematical methods. We're looking at quantum simulation applications and also this is an artifact of the project coordination work I do.

We have a research group that does system integration and analysis, helps people to, if you build a quantum computer with many components to make everything fit in the end and to do risk management. But it's also a group where we're writing studies for the government.

So the real message is that people tell us that the quantum computer, as every computer, has all of these technology layers. And this is what they are. Everybody's working in some technology layer. You work on high level software. You work on low level software. And we are saying, well, not so fast.

We are saying that people should work together who understand multiple layers to really kind of push the envelope. And this is why I think it's important that people on different layers work together.

If you look at the career, one way to put it is that when I started with Hans Moy, the question was, could this new qubit that we have, the superconducting flux qubit, potentially work or are we making a basic mistake? And I think my research profile has kind of grown with the superconducting qubit. Algorithms were a complete science fiction 25 years ago, but now we can do it, but without losing the old skill.

## 00:10:45 The introduction of DRAG pulses

Chris: Maybe within superconducting qubits one of the things that you are known for is introducing DRAG pulses.

Jan, did you work on transmons? Did you run into DRAG pulses already during your PhD?

Jan: Yes, for sure. I think the community is still very small and if something new comes out you immediately learn it, that it's happening and then you want to try it out. So I think this was one of the things that was very fast adopted by the community.

Frank: And DRAG pulses have an entertaining origin story. I think we're here to tell these stories, right?

So the one thing is that when I finished in Munich, one of my students went into a conference that was mostly spin qubits. And of course the spin is the true original two level system that was pre-transmon but the phase qubit also had these higher levels and two big ego theory colleagues who shall remain unnamed would disagree on everything but they did agree that spin qubits are superior because they only have two levels and I thought the next thesis I'm giving to somebody is to use optimal control theory to prove the opposite. And it actually worked, but it was completely unrealistic.

And then a year later, a person who is known in the community, namely a really talented postdoc, Jay Gambetta, now vice president, quantum of IBM. And a master student with a promising research career, a certain Felix Motzoi, who's also an MLA4Q, said, hey, these experimentalists, they have this thing called an IQ mixer. There's another degree of freedom that we could play with in our theory. We'll try this while you go on vacation, Frank.

And we came back and we had numerical results that always showed the same trend. Then we spent three months on understanding them, and then we wrote the paper in reverse order. We came up with this magic analytical scheme, why this works, and then there were some numerics, but this is a-historic. We had the numerics and we did try to explain it. But there were these multiple motivations to try this rather strange method.

Chris: And I guess, for us as transmon experimentalists, it's really important that the speed limits from not being a qubit are not so limiting after all.

Jan: Yeah, I think at the moment, we are mainly limited by the electronics usually and the speed of the electronics. Because we are having such methods that really allow us to shorten the pulses.

Frank: And I mean, and the speed limit that the higher level still limits your speed is still there. DRAG only allows you to go up to the speed limit and not you know stay in order of magnitude away from it. We are not, it's a bit it's theoretical engineering if you want so.

**00:13:49 Joint work between theorists and experimentalists**

Mira: How easy is it to convince experimentalists that their experiments can benefit from theorists?

Frank: It depends. I think the one thing is that between theory and experiment the timing is really different. In theory, you know, you're working, you produce a result and you have some output. In experiments, there rather seems to be many cases. Nothing works for two years and then everything comes out in a very short time span. You have to scramble to get it together because now you experiment using data.

I have made the experience that of course on a high level, it's great, you know, we can do, we can propose lots of things and they get taken seriously. We now also in the academic world have the opportunity to use an experimental setup on a high level where the experimentalists, you know, they keep the setup alive but they don't do the experiment themselves. But specifically with DRAG, there is another component. The experimentalists need to be slightly desperate.

If they are at the end of, if you propose something that is a bit of a paradigm change, in this case, this very deliberate pulse shaping, then if they have suffered a little bit before, they are a lot more open to make this big step, rather than saying, oh, but before I do this, I have these 15 other engineering ideas that are already in my tool set, because application theory in our community is done by experimentalists.

We are – as theorists – teaching experimentalists how to do things. So to teach them a new tool, to give them a new tool, then it's good if they would first try out all the things they can already do, and only if that's fails then something a bit more disruptive can be used.

Chris: Jan, how was this for you during your PhD? Did you have a lot of relationship with theorists or did you rather do the theory sort of like I mean in superconducting qubits we often just design the experiment then we do the experiment maybe there's a theory proposal

Jan: But I mean, when I started the PhD, and I think this is often the case, of course, we had to think about what is my project. And then you have a lot of exciting, maybe proposals there from theorists, which you can try to implement. So you pick one and then try to build the sample around it.

And maybe at this point, you don't yet have so much interaction with the theorist behind it. But then when you start to measure it, of course, you measure something that looks completely different than what was predicted. And then you call the theorist and say hey I have these results here and I don't know is it a bug or a feature that I'm seeing and I think this is then when the real interaction starts and this was also the case during my PhD so in the beginning of course we were designing a lot the experiment thinking about parameters and what could be done.

But then when the actual measurements began and when the results came, of course, then there was a more lively discussion with the theorist and even some debate, because sometimes it's not clear whether what you measure is real or just some crazy artifact or so.

Chris: How was it for you? Was the theory, I guess, theorists sometimes design experiments but they often forget about realistically achievable parameters. Was it that for you the proposal was immediately a good fit or did you have to redesign a lot of things?

Jan: Well, usually you get these kinds of parametric regimes, right? And then you have to think about, can I hit all of them? And sometimes you have to make compromises and maybe you don't see the full picture in your experiment than theory predict but of course the beauty is to find those papers which are very promising from a scientific perspective when they make the proposals but also realistically to implement and this is I think the key for a good theorist is to kind of create those kind of papers because anyone can come up with crazy ideas right and say okay we fly to the moon and do this and that but actually to predict something that can really be done in the lab and is still bringing out really exciting physics that's I think not so easy to do.

Frank: I once had a great PhD student who visited an experimental group in the US and came back to say to me, " Frank, our ideas are in principle correct and all slightly wrong. Slightly unrealistic. But another thing in this experience which I have learned is that theorists, at least of my generation, excel in concepts and abstraction, and experimentalists are often a lot better at handling complexity.

So oftentimes when one visits an experimentalist in our field, one also sees here, like the IQ mixer, here are all these other degrees of freedom which I didn't think about that they are actually relatively easy to play with. I had a long-term experimental mentor, John Clark at UC Berkeley, who I visited essentially for exactly this.

The theory-oriented experimentalists there could teach me degrees of freedom and little tweaks they could do that I would have never have come up with.

### 00:19:16 Jan’s Postdoc time in Finland

Mira: So Jan, after your PhD, you moved to Finland for a postdoc. Did you have the idea in mind that you wanted to pursue an academic career?

Jan: Yeah, this was what brought me to Finland. So I was then lucky enough to also get the Marie Curie Fellowship there. Some people called me crazy because I had other opportunities in Barcelona and the US and then I decided to go to Finland, which maybe is not the obvious choice if you have really nice cities that you could also go to. But I was really impressed by two things.

One was the infrastructure that they have, so I learned to build chips in a university clean room, single PhD making all the mistakes, and they had this very professional clean room run by VTT which is a kind of Finnish Fraunhofer organization and then also the team seeing also there with kind of how little resources they could produce really nice papers on a very constant and high level over the years and I think for me this was then the main driver.

Also I knew that I could get a quite senior role within the group because one of the key scientists there was about to leave for Australia. So it was clear that immediately I could take some responsibilities. And yeah, then I had two great years as a postdoc at Aalto University. They don't have habilitation, but they have what they call docentship, so kind of a lecturer.

So I did this and I started actually teaching, which I really enjoy a lot as well, working with the students, I had my PhD students, so I was actually about to make the scientific career move.

But yeah, then when my contract came to an end, these typical two years that you have, and I was discussing with the professor, Mikko Mottönen, and I was working with, then he said, okay, I have this idea of starting a company, why don't you stay here and we start a company together? And then this was kind of an overnight end to my scientific career.

Mira: And how did the name IQM come about?

Jan: This is a good question. Nobody actually really knows the answer. It was registered like this, but when it was registered nobody asked what these letters actually mean. We still don't have an explanation for this, so it's just three letters.

It was registered by Mikko, the professor I was mentioning and we have this kind of joke that whoever guesses right what the three letters stand for gets a prize from Mikko but this is still kind of to be done so no one has given him a reasonable good answer what those three letters stand for.

Chris: So it's not International Quantum Machines.

Jan: I think this is not what it is.

Chris: And did IBM ever complain to you guys about sort of you know they are also a very active quantum company and the name is.

Jan: I haven't heard any official complaints. When we were registering it and when we were making the announcement, actually other companies that are called IQM out there, they have written to us that we should change the name and things like this, but obviously we didn't do this then anymore.

Chris: We will come to IQM in a second.

00:22:14 Frank's postdoc work on NMR

Chris: But maybe we can just finish up with the career stuff with Frank. Like I don't know there's many things we can ask you but for the optimal control thing maybe one of things is what role did NMR play for sort of your ventures into optimal control theory was the existing you know NMR body of work important or did you?

Frank: That is what got me started mostly on a methodical level. I understood while I was attending conferences a postdoc that control by cult shaping is a thing somewhere and there is science behind it. And then I fished around who could teach me how to walk and how to try things out. And I was in Munich and Munich is a big place and you can arbitrarily not know people who are also in Munich. But after a while I found a really great research group in the Bavarian Nuclear Magnetic Resonance Center. It's part of organic chemistry. And yes, the building smells like a chemistry building, who had just come up with a very easy to understand, reproduce and apply optimal control algorithm. It's great. In optimal control, you need to do acronyms. That was mostly applied to various NMR settings and we translated a very simple superconducting qubit setting from this but this is how we learn to walk.

Then we understood that when you really want to make it reality there's many things you can change because for example in NMR the theoretical description of your system is extremely well-defined and precise because there's decades of experience with this. And in superconducting qubits you are often, you have an optimized solution and they realize, oh, I am exploiting something that was an approximation. But I learned a lot from this community. I'm still in contact with somebody who's a colleague, Thomas Schulte-Herbrüggen, who's actually now basically working on the mathematics of quantum optimal control who's writing poor mathematics papers on things like Lie wedges and his first doctorate was in medicine so he has two doctorates in medicine and physical chemistry but he's now in a very mathematical trajectory so he now makes proofs of existence and structure but now this was extremely crucial and it was a big exercise in translating jargons and lingos into each other.

Chris: Yeah, I mean, these connections in the field. I also find it kind of fascinating that Michel Devoret's supervisor was Anatole Abragam, who's one of the big NMR people. So I don't know, there is definitely a connection from there into the qubit world.

Frank: I mean, look, they did the first single qubit rotations in 1948. And it didn't work because the relaxation time was too long. They needed relaxation to observe the signal and they needed to change the signal detection. So they just didn't call it that way.

Chris: I don't know. In superconducting qubits initializing by T1 is not so problematic.

Jan: It's getting there, right? It's getting annoying. You start waiting, a major part of the execution if you wait, because there is progress also.

Chris: I still make some transmons myself and Cologne and to be honest, we don't really much exceed 10 microseconds and then it's okay. But yes, if you go to 100 microseconds, your repetition time suffers. What's the best qubit you ever fabricated?

Jan: ...... Personally? Below 100 microseconds, I think probably 30 microseconds or so.

Chris: Yeah, it's actually kind of hard to break into this 100 microsecond territory, right?

## 00:26:25 Founding IQM

Chris: So we are going to talk about both of your quantum startups.

Frank: Very different scale

Chris: Yes, on a different scale. But yeah, let's start with you, Jan. Like, can you briefly introduce IQM and sort of, I mean, we already talked that you founded it, but as the company's vision goals.

Jan: As I said, it's a spin-out from Alto and also VTT in Finland. So a pretty strong ecosystem there, a few hundred researchers in the field. And we started with the plants in 2018, end of 2018. And then we got the first investment into the company. So basically the company went alive early 2019.

And the vision was to build a globally leading quantum computing manufacturer from Europe. So we have seen big investments in the US in 2018-17 earlier. Google has started to build quantum computers and had this very famous quantum supremacy experiment in 2019 so we thought that if we do something then we really want to make it big out of Europe because we thought there's kind of a need also for a big European player so this was always the ambition level and of course this means you are competing with very big names and this means you need to have a certain substance otherwise it doesn't make sense you can have a different strategy of course to keep it very lean and maybe focus on error correction and long-term things, but this was never the case for us.

So we wanted to be a system integrator who brings products to the market fairly soon and really be there and define basically what's happening in quantum. And this is how we see ourselves as a system integrator who uses kind of in-house processors.  So this is what we still do on the innovation side mainly is the design, the fabrication, the packaging of the processors, but also a little bit of algorithm efforts, how to map algorithms on processor architectures, but then the rest of the systems we buy from third parties. And from this perspective, yeah, we try to engage of course with quite many startups also out there and be an active contributor to ecosystems, also like the ecosystem we're having here.

Chris: How is it like you say system integrator, maybe the most important one of the most important system components is the fridge, right? You are sitting sort of not so far from Bluefors, right? Was that a factor?

Jan: Well, of course, it's not a coincidence. So I was working there in Finland at the Low Temperature Institute and Bluefors is another spin out from this lab. So basically our two companies have the same origin. The first Bluefors that was ever kind of built and sold still is there in the low temperature labs. And of course, we have very good connections to them. So our factories are like 10 minutes. We're joking now, there's a new tram line which starts at our office and then goes across the campus, VTT, Alto and then to Bluefors. So it's the quantum line, this is how we call it.

Mira: You started with transmon processors, so are there ideas to switch to other superconducting qubits? For example, like the unimon or fluxonium.

Jan: Yeah, of course, we kind of observe the progress that's happening very carefully. We have this unimon concept, so a different yet another type of superconducting qubits. At the moment in all the computers that we kind of build and deliver for customers, it's all transmon-based because they are just the workhorses. They are so easy to fabricate and so reliable compared to the others. But of course, we see that, for example, with fluxonium nowadays, there's great progress. And this is something that we are discussing internally, but at the moment we are still completely working on the transform based processors for every kind of computer that we build that goes out either in the cloud or to our customers.

Chris: Do you agree that the unimon is actually the real transmon? And the transmon should be called different. Something else?

Jan: Well, these are these acronyms. I don't even remember anymore what transmon means. But for me, these are names. And of course, there are concepts behind those. But for me, the transmon, basically, the beauty in it is that it's so simple, right? It's basically an LC circuit with a little bit of anharmonicity. And the unimon is a little bit more complex which then if you do it right, then you, at least what the theory shows, you can get great results because there's less charge noise and things like that. But at the moment, the fact is that transmons are just so easy to fabricate that they're still the workhorse for most things.

Chris: My point is that the, I mean, the trans stands, I think, for the transmission line. And the unimon is sort of made out of a transmission line. So, you know, in a way, the transmon itself doesn't really require a transmission line at all.

Jan: Of course, nowadays you can have all kinds of fancy geometries there and people call them frogmon and swissmon and I don't know what-mon depending on how it looks.

Chris: So, let's get back to IQM. You already mentioned IQM is a full stack company. So what can be outsourced and what has to absolutely be done in-house?

Jan: Well, I mean, if you look at the semiconductor industry, basically everything is outsourced, right? But the thing here is, for example, if we are limited by the hardware at the moment, the processors are just not good enough, you really need to kind of focus on what you're good at. And this in our case is producing the quantum processors. So this is clearly what we are keeping in-house. We have actually built our own fab.

So we started in this VTT hosted fab but meanwhile we are running our own fab and the reason is that only if you really own kind of the complete process and if you do the same thing over and over in the machine without anyone else touching the machine you can systematically improve things.

So this is what our strategy is. It is very clear that the processors are what we design and fabricate and develop ourselves. Most of the other things we are either already outsourcing or we are thinking about it. We are also using our own control electronics to give an example but the reason there is not that we can do it better than anyone else. This is purely a cost argument because what you find in the market at the moment it's just very costly. And for us it was a business case to just design the electronics ourselves. So there's from a performance point of view there's actually no reason to do it.

And I think this is in the end always the question: what is the driver to do it yourselves without using third party solutions. And then, for example, if you talk about optimal control and these things and you see that there are teams out there with tens or maybe even up to hundreds of people in some software startups, it's very unlikely that we can do the same thing with just a few people. So this is the thinking there that what is not our core competence we would outsource and focus really on building the best computers based on the QPUs that we have.

Mira: And is it the same for software?

Jan: Yeah, especially on the software side. And at some point, if you then go towards, for example, remote access, this is what people call cloud nowadays. I mean, there's no way we are going to compete with the big Microsoft Azure or AWS cloud offers, right? As such.

So clearly we are integrating into their offers because we are not a cloud company. We are building quantum computers. So the higher you go in the stack anyways, the more we do just integration work and maintaining then the interfaces and discussing of course on the technical level what are the functionalities that for example you have in Qiskit or Braket or so that this is then reflecting also the reality in our computers.

Mira: Do you mainly aim to sell quantum computers or computing time?

Jan: I mean, fact is at the moment there is a market for these early-stage quantum computers on the scientific computing side. So these big computing centers, like you have one around the corner in Jülich, for example, they see themselves as innovators and early adopters when it comes to new computer technologies and also they see themselves as re-operating the computers that's their kind of business model and then giving the computing time to the scientists.

And this is what we see around the globe meanwhile is that these big scientific computing centers are willing to buy and also universities are more and more willing to buy and this is why we have actually designed a product which we call Spark specifically for universities which is very open and modular to support the education.

And then if you think about the end users and the commercial use there is also the fact that many companies are preparing themselves by building up internal quantum teams so many of the big kinds of pharma and chemistry companies. And of course they want to test the algorithms and maybe create IP but they are not willing to invest millions into a computer which is then only used a percentage of the time so they rather go into the cloud.

But the revenue that comes from the system sales in our case and I think in most of the cases out there So system sales is contributing much more to the overall revenue profile compared to the clouds today. The question is what is the long term and there of course if you have a crystal ball then it's easy. But if you ask these big consultancy firms like McKinsey or Boston Consulting they say that the revenue will shift largely towards the cloud maybe 80/20, 70/30 distribution between on-premise and cloud offerings.

## 00:36:05 Communication strategies

Chris: You just released a 20 qubit system paper. Do you want to walk us through some of this and maybe then we can also briefly talk about how you communicate as a company because you released this paper, Google releases a lot of papers but IBM for example also releases some papers, but it's a different communication strategy? How do you think about this?

Jan: I mean, communication in deep tech is challenging because on the one hand you need to please investors and politicians and business people with kind of exciting and shiny stories.

On the other hand, you need to be attractive to the scientific community because this is where we are hiring from and you cannot kind of fool them and bullshit around. And this is a very fine line actually in making predictions or even promises.

On the one hand side, and being technically sound and open and transparent in what you do. This is what we try in our communications and in general. We have the policy that we do publish scientific results. Of course, we still also protect, so we file patents then we also publish our technical achievements and we have done this already for the 5 qubit and now for the 20 qubit because we think it's still so early and it's a little bit also the duty of all ecosystem players to be open on how their systems work and kind of what are really the specs and how things are done.

And in our case for this 20 qubit we are really trying to push the quality of the two-qubit gate fidelity because I think the feedback that comes from people who use the computers is that what is limiting at the moment is mainly the low two-qubit gate fidelity. And here we have achieved, I have to be careful, but I think 99.5 average two-qubit gate fidelity across the chip, which we think is quite decent compared to what you find in the market.

And this is why we also want to be open and of course a little bit proud about this and say, okay, this is what you get from us if you buy a 20 qubit computer today.

Chris: Frank, in this sense, you're more a consumer of the literature that comes out on all this. How do you think about these communication strategies? There's big differences between how much we know about what goes on in different quantum computing.

Frank: Yes, that's true. I'm actually a consumer also understands that we are kind of updating a study of the status of the field for the German Information Security Office, which you can read if you go to their homepage and it is in English. Indeed, I mean strategies are very different. I do not expect that companies explain the secret sauce to me. They shouldn't. There is IP and competitive academic groups also typically, if they have communicated any kind of technical details, they would do so very late. If you now go to a conference and ask five academics how they clean the surface of a flux control line, you will get no answers.

I think what is important is that the communication is honest and transparent, so the claims in there are all substantiated. Why can we claim this? Do we have some statistics about the results? And I would say that there are only very few companies in quantum computing who are not doing this well. And I would say none of them in solid-state.

Sometimes we see a trend which I started to call “benchmarketing”, which is when somebody comes up with a benchmark, somebody else is better in this benchmark. And now this company publishes another benchmark. And it just happens that their own device looks really good in this. Or when we certify performance sometimes we see this strawman situation. So we are beating something but we have constructed everything so the thing we are beating is actually really bad. And that sometimes happens but I think all in all our community is doing a decent job in communicating this.

And parts of the community are also doing a decent job in calling out – in a constructive sense – claims that may be exaggerated or that sometimes when we specifically come to these claims of a quantum computer outperforming a classical one we are entering a field where the classical computer is also a moving target. So I think this is what I can say about communication strategies. There are some companies that shall remain unnamed. But if you look at what I'm doing on LinkedIn, I'm always asking them when they have a big press release. Oh, by the way, what is your component performance? And I never get an answer.

Chris: Yeah. I mean, even for me, I would say, you know, I've been working in superconducting qubits for 10 years. It's kind of hard to follow all the developments, especially as the companies become more silent. So it's a very important thing to follow.

## 00:41:39 Founding Qruise

Chris: We should come to your startup, Frank, which is a software provider, right? So we will also, of course, later ask Jan if there's some outsourcing potential.

Frank: We are collaborating in projects already, like in Qsolid, for example.

Chris: So please Frank, what is the startup you co-founded?

Frank: Okay, so the company is called Qruise. That with a Q. The origin of the name is we had a proposal for business development to write the deadline three days ago. We thought, ah, we take this title. I came up with this. So the origin story is clear. And it's meant to be cruise control for your quantum computing. So it is taking the optimal control ideas that we have that also Tommaso Calarco’s Institute had and it's putting them into professional software and it has developed in I think having three purposes. One is what optimal control always did is it helped you to get the best performance out of given hardware, get closer to speed limits, get closer to noise limits.

The second thing which we realized is that it can also be good in keeping the hardware high-performant. Everything drifts. Quantum computers have an analog component in them. The interaction is digital, but there's the analog component. And like you have to tune your instrument every day, or sometimes more frequently, then you also have to re-tune it. And it's a big difference in your cloud service, whether this is fast or slow.

And the third thing that our software is aiming for is to also accelerate development cycles by first of all doing the initial calibration a lot faster. So from your chip to your chip performance it can be faster. And also to not only do optimal control but also from the control data build an improved digital twin that maybe helps you to find little bugs or say issues for improvement that by humans are very hard to find.

So it's living kind of in the dark middle of the software stack. It's not something that the end user would see other than by good and consistent performance. It's a bit like, you know, the bias that appears, say, depending on your brand of computer when you're maybe watching an artist's impression of fruit. So this is what we would like to replace. It's a lot smaller, but we are far getting traction. I'm a co-founder. I used to be managing director for a while because as a German company you need a German speaking managing director for a while. But now I'm not employed by the company. I'm one of the founders and I try to help the company this way.

Mira: And do you target quantum computing companies or would it also be useful for academia?

Oh, yes. No, we definitely target both. We target companies, but we definitely target academia. We also have an academic scale product, because we feel that this type of automation is making specifically young researchers work more efficiently. The calibration which is skilled work because you need to know the tools but it's always the same as repetitive. You should outsource as much as possible to a machine.

Now two examples:

One is there was an initial success we had with a very early version in 2014 where we worked with John Martinez at this point in UC Santa Barbara free Google and with the calibration of their 7 qubit chip we got the time down from 7 hours to 10 minutes. So, that means basically if you have two shifts in your lab both shifts can measure versus one calibrates the other one measures.

The other analogy I like to use is that it's a bit automation; you know a young researcher is then telling the software what is the goal function, what would we like to optimize for today. So it brings this work to a bit of a meta level. There is this statement that I wished I had coined myself. I believe I invented it independently. Then I googled it and found somebody else does it. Artificial intelligence is the Spinning Jenny of knowledge work. So we use AI and the Spinning Jenny is the machine that made spinning yarn automatic that put a lot of workers out of work and then gave them jobs as machine operators. And if you like the history of the workers' movement, it's also mentioned in. You know, that type of work, but ultimately this is extremely important in academia, specifically because there is so much experience with finicky lab equipment that is hard to pass on between student generations that maybe having this in a well-trained algorithm is the better thing.

## 00:47:29 What role do AI and machine learning play in scaling quantum computers?

Mira: So pertaining to that, do you think AI, machine learning and automation could be a game changer for scaling quantum computers?

Frank: I think AI is a game changer for all kinds of knowledge work. But it needs to be applied in the right way. I think so the way how we do it and how we deliberately do it is white box or reproducible AI.

It helps you with things that hopefully in the end you can understand because it should teach you also how to, for example, fix problems in your system. So we shouldn't do it that we shouldn't do it blindly. I think this is important. Maybe the last few details, you know, why do we, why does our path have this little wiggle and not the other wiggle that maybe something we cannot explain but most of this should be explainable.

The other thing we need to pay attention to is that the classical AI is lightweight and fast enough that we are not drowning our potential quantum advantage in the calibration process. Just throwing optimal control on a 100 qubit chip is impossible because it should include simulating a 100 qubit chip and that is impossible.

So we need to think about what is the subset, the tile of the processor that we can use with other methods, and how do we deal with the statement that this tile of the processor is not alone, that it's interacting with other tiles. So we have to kind of do this in a hyper-controlled way. I think it's the short version of this.

Chris: Jan, do you already have machine learning experts working in the company on tune-up automation and things like that? Or is it more sort of more, I don't know, just a simple tune-up with Nelder-Mead algorithms?

Jan: Well, most of the people who work at this part of the stack, I think, are still physicists in our company. But of course, AI is playing or beginning to play a role there, machine learning in particular. Yeah, this is a major challenge. It's not only, let's say, how you maybe calibrate at one point, one large processor, but actually the whole testing is a bottleneck. Because we are still on the fabrication side, we are still in a situation where not 100% of the qubits are always in spec when we tape out a new chip.

And you can do maybe some analysis optically or maybe even measure resistances but still kind of checking the processors and testing and giving the feedback back to the fab is a key challenge and every minute we kind of gain there is a good minute because we can then test more chips so I think this is an effort that is very much needed I think it's appreciated that it's very much needed and it of course also comes with investments because testing a chip means there needs to be a full system there with all the electronics and everything.

So it's actually not only the time that you invest, but you also need to have all the hardware there. So this whole testing, benchmarking, calibration, I think this is often underappreciated in the whole field of quantum computing.

Chris: How much faster is it than when you were a PhD student?

Jan: I cannot really say because I've been working on two qubit chips tuning up things myself because we were still setting up the lab and you needed to figure out how the pulse generator even works and so it's really hard to compare but of course the goal is to automate as much as possible and I think there is of course the initial tune up but then also what Frank was mentioning then making sure that the system is stable

Especially nowadays when we talk about quantum computers that go into the cloud, maybe even with third-party cloud service providers, there are commercial contracts. They specify how the uptime of the system has to be. So I think it's important that we somehow develop tools that allow us to keep the system always up and running, so to say, and don't fall out of spec.

### 00:51:46 IQM and Qruise working together

Chris: How do you communicate with let's say startups like Qruise or I mean also others I mean that this market of quantum computing consulting software, consulting companies, is also there. How do you keep track of this and how do you communicate with the companies?

Jan: I don't know if you would call yourself a quantum consulting company, but with Qruise we are discussing on a technical level. So the technical teams and I think this is very fruitful. Of course, there are software companies which are living higher up in the stack and really do this kind of project work. But with them, we don't have so much interaction actually.

Frank: I mean one non-negligible part of software is also the staff that runs the electronics which is where we're sitting just above.

Chris: For Qruise, one of the things that is difficult is that you have your own software that you want to run, but then you have to glue it in with this software layer. And I mean also related to what I said before, do you see yourself there as partially like we provide the software but you also have some consulting things like it's a mix of providing solutions and you know also just consulting with how things should be done I suppose.

Frank: Yes, so you know it's also learning from each other. In a much earlier stage in IQM, it's learning from each other, but if the product is running software that gives an advantage, then you come in with software that you have, you build the interface, you make sure that whichever, if processes need to be adapted either in the software or the customer, the process that's easier to adapt gets adapted and I mean for us that was also important the transition of doing this at the research institute versus a company in this case. We do have the people who are also able to write things like device drivers which you know if you give this to a PhD student that would be abused unless they wanted a PhD on the comparative study of device drivers which probably would not be accepted at least in the physics department, maybe in some electrical engineering departments there is something but you know. But you know this is also because we are a relatively small player we are typically adapting to others but even in the world of control electronics there's only so many versions so knowledge can get transferred.

## 00:54:16 Dig for gold or sell shovels?

Mira: So here's a question that we would like to have both of your opinions on. So in the quantum gold rush, is it better to state your claim and dig for gold like IQM or is it better to sell shovels and supplies like Qruise?

Jan: I mean, you need both, right? And this is the thing, because if you only are selling shovels, but no one is buying the shovels, it also doesn't work. So you need the diggers, the gold diggers as well. And I think this is what it is about when you build up a new industry and an ecosystem and it doesn't work alone. You need always kind of the complete set.

Frank: What do you mean by better? I'm doing optimization for a living, so when you say better, better has a component. How can I build a stable company? Maybe some people even want to become rich by a company, not our original motivation. But I think that clearly as a tool maker on the one hand having real income to the company is maybe much closer than if you have a really big claim. But that being said, IQM is selling. We occasionally read this on social media.

But ultimately, for me, this came down to, you know, if I want to start a company, I need to do something that I'm good at. And from how we work, it's not full stack. From how we work, it's making experiments and software integration easier and better.

Chris: When do you expect your respective companies to make a profit?

Jan: That's hard to say because it depends on so many things. And of course, sometimes, basically, if you want to grow, for example, you don't even want to make a profit at this stage. We are, of course, investing a lot also in infrastructure, the fact that we have all the test systems. So for us, of course, it's important that we ramp up the revenue and kind of grow with the market.

If and how this would then turn into profitability is hard to say, but of course we are aiming for this and we are having financial plans, but in each company you have different scenarios, more pessimistic scenarios, more optimistic scenarios. But if you believe that the market is growing in the way it is currently growing, it should be possible for companies to become profitable with quantum computing as a product.

Frank: Same here all on a smaller scale but the one thing that is before profits which I think when starting a company is the game changer is when you move from having partners to having customers.

So that is and then you know the customers should pay the money and be dominant enough so you're making a profit but the retransition into a company I think is first of all when you have customers.

Chris: Yeah, how is the transition from being sort of investment driven to being commercially driven?

Jan: You know, there are different ways of doing it. If you look at us, what we have done differently compared especially to many US companies is that we were focusing first on selling computers before putting them into the cloud. Many US companies went first into the cloud and often then the feedback also wasn't that great because maybe the systems are not yet at the level where they are today.

And what we have done is we have actually decided on purpose to do it the other way around because when you sell systems you have far less customers, right? We start with the first computer that we sell and deliver and this means we can work very closely with the customer and we kind of teach each other and I think for us this was a big learning curve for the whole company having a commercial contract with clear specifications, so you have to deliver fidelities and a number of qubits and this and that.

So I think for us this was a big learning and I would encourage every entrepreneur to really think early on on what is the product and how to maybe find these first friendly customers who do it together with you.

### 00:58:32 A short Q&A on predictions

Chris: So we asked you to write down some future predictions and we can maybe compare your, compare your results. And it's on purpose a bit, you know, like gear or timescale predictions and short answers.

So the first question was, will there be useful quantum computation without error correction? Sort of yes or no.

Jan: I have given it a yes and of course the question is what useful means here in the sentence, but for me also topics like education and scientific research is actually a good use of investment. So for me this is a clear yes.

Frank: You started with the adjectives. So I don't have to feel bad as a professor that I'm also answering the question and then rephrasing what I actually answered. Very good. So yes. And I also say yes, because the initial error correction may be very incomplete. It may be some error mitigation and some partial error correction.

Chris: So would you say that with error mitigation you can solve an "interesting" problem that you couldn't on a classical machine?

Frank: I mean, what error mitigation does is, I mean, first of all, you have to make sure that you're not treating yourself in the foot by creating some overhead that doesn't scale badly. But it moves the crossing point. It moves the break-even point. And partial error correction could also be that we're only correcting actively one type of errors.

A competing company of IQM is currently promoting this idea, whether this specific version of this ideal will work, I don't know. But having some tools to take out leading errors with some overhead and part of this could be error mitigation I think has a high potential.

Mira: How many qubits will one need to solve a commercially viable problem?

1:00:06-1:00:09.......... Frank: 1000 because we are burning a few of them in my partial error correction.

Jan: Okay, I have 300 but I think the question is are we talking about logical qubits or physical qubits because obviously there are people who are still believers in this NISQ and that there is some use case with then maybe 300 noisy qubits in a specific case but I think if you then go to the logical side and have maybe $10^{-10}$ or so error regime then with 300 I think you should be doing some really great stuff.

Chris: When will full stack companies be able to provide a computer that is commercially viable where all sorts of people use it and solve some problem that actually earns their money back?

Jan: Well, I wouldn't have the last part of your sentence with earning the money back because for me the first use cases also on the industry side are in the R&D departments.

Chris: And that is happening.

Jan: And this is why I gave it a 2027 where I think that R&D teams in some pharmaceutical companies or chemical companies are using quantum computers to better understand quantum physics in a quantum simulation sense.

Frank: I actually reversed the priorities in this answer. So I said 2035, because I would think that we want to get the same type of quantum advantage, where we can clearly say we couldn't have done it without a quantum computer. And then this will be commercially inefficient. And this will happen around 2030 and then to make it not horrendously expensive will take another five years. But I think in this case, we answered slightly different questions.

Mira: What will the first commercially viable application be?

Frank: It will be in the surroundings of chemistry and material science.

Jan: Yeah, I give it a quantum simulation. But I mean the same thing. So basically it's simulating quantum effects in material or chemical problems.

Chris: What platform will be the first to cross thousand qubits in the paper convincingly like and sort of controlling all of them so let's say D-Wave doesn't count (maybe you can say that they should count).

Jan: Well, of course, I gave it a superconducting here because I'm a big believer. I don't think it matters so much who is the first one, maybe 1000, because so many other aspects obviously matter like connectivity, gate fidelity and all of this. So I think what's really important is that one keeps the whole system kind of under control and it's not just about putting 1000 qubits on a chip because this can be done in many platforms but it's really about creating entanglement across them and topics like that.

Frank: As much as I also believe in work on superconducting qubits, I wrote down neutral atoms who currently have a very good path to scaling up. Let's see what the fidelities will do there. They are promising, but at some point the current big acceleration will get in the plateau of engineering.

And D-Wave has one new product generation with qubits, which are a lot smaller machines in qubit count than the ones that we hear about, where the qubits have a lot of temporal coherence. So they are good enough that you could in principle also run a gate model algorithm. And I feel that this should count. It's still with a very restricted control, but if the noise is low enough, I feel that this has some similarities with neutral atoms, where also getting full control is kind of the big challenge. But the traditional D-Wave offerings there if you embed a problem solution you are actually not using all your qubits and that has kind of a very intrinsic reason. So in this sense it should partially count.

Mira: And will there be a quantum winter?

Jan: No.

Frank: There will be fluctuations in the weather and I think there is some hype and some – you could call this – frivolous investment. But if that goes away, it doesn't hurt us. And I think we have a good balance between the public sector and private sector. That means we can stand the fluctuations of the weather. And we should keep in mind that when I started, it wasn't winter. It was already exciting. It was more exciting than the proximity effect. But compared to anything we're talking about, it was the ice age.

## 01:05:29 Academia vs. Start-ups

Chris: All right, maybe we can move back a little bit into this journey from academic to founder and explore a bit the academia startup sort of relationship.

Jan, like we have already covered a lot of things but maybe one question is how different is getting research funding I mean you got them you got the Marie Curie grant for example how different is that from getting startup funding and finding investors how different is this.

Jan: It depends on the type of funding. Of course, the goal would always be to sell to customers, right? That should be the highest priority. For example, if you think about the public side for a startup, I think it's relatively easy because in many of these projects that are being financed by the government, you need to have industry participation. And whenever there's a new call out that's published, we actually get a lot of calls from researchers who want to do something with us because they also need the industry side. So I think getting public money is not that hard if you have a good idea, a good team and then some good collaborators.

The investment, of course, then is a more tricky part because it depends on so many factors. And for example, when we started 2018, 2019, the world was completely different. There were investors like Tiger Global, they were investing blindly in 20 minutes, million dollar checks. Nowadays the kind of market climate has changed and the interest rates have gone up and investors are much more diligent. So it's not that easy anymore to get funding. But it's not impossible and usually it only means that the quality goes up because the good companies will still get funding. So if you have a good plan, if you have a good team, good technology, you're still kind of on a very good track to get funding, I would say.

Chris: And maybe a similar question is also, I mean, academic research groups are like 10 people (ish), usually, right? And then maybe sometimes they scale a bit more. But the really fascinating thing is how do you scale a performant team that focuses on a goal beyond this sort of academic research group level and into a company? I mean, your IQM is now in the 200 people level. I guess that's just something that doesn't exist in academia anymore.

Jan: Yeah, I think it comes from defining a common goal. And of course, if you have one product, which is the quantum computer, that's rather simple. Let's say that we say, OK, we all work towards this goal, which is designing, building, producing, selling, and delivering quantum computers. I think the challenge is really the collaboration, especially on the R&D side, between the sub teams that we have. And this is often about communication but it's also about kind of project management and also inexperience in a sense that most of the people we hire they come right out of academia either after their diploma or PhD or postdoc part so they haven't been in industry and they don't know kind of best practices there and this is what we are trying to do to kind of now blend in professionals from semiconductor industry or others who help us, who work with our teams in order to make it a high-performant overall organization.

Mira: Frank, you became a founder much later in your career. So how is it different from or similar to being a professor?

Frank: I think there are structural similarities and then there are things that are dramatically different. So as a professor you have academic freedom. And then of course you have some outside funding, or the Forschungszentrum also is a mission-driven research institution. So if you're working orthogonal to the mission, well, it's not forbidden, but it's also not good. So you have academic freedom, so if you plan to do X and you see Y is a lot greater and you put everything on Y, you're getting famous.

If you have an investor or if you have a customer, then they ordered X and they want X. And if you want to send them, give them $\tilde{X}$, you have to ask them before whether $\tilde{X}$ would also be okay. The person who does your annual performance review as a professor, when I was in Canada we had that, has a much different reward system than somebody who has given you a lot of their money or the money they administer and wants to see a return. So this we have seen, but it's, I mean a lot of these more application or mission-driven projects like the BMBF projects or research ministry projects we have are a little bit in the middle. You have some academic freedom, but you also need to deliver what you have promised.

The other thing for me that may sound a little bit lofty is the risk structure is different because this is also why we need both. If I want to do something that is super risky in a commercial sense, for example, it could be a No-go theorem. I can do this in academia because if somebody proves a No-go theorem in their PhD, that will be a lovely thesis. We can do these very risky things, whereas of course the commercial world needs us to keep us to a timeline of deliverables. The investors remember what you promised them. In this way, you are actually I would argue can take a bit fewer intellectual risks but then of course if you have a great product it's much easier to scale. One important difference is hiring software architects on a German public sector salary is a challenge.

And so this is how a little bit I see the difference, the risk structure, the definiteness to which you're held to your promises. But I think we need both. So I'm happy that I'm mostly in the academic world, but I have also this connection to the startup world.

### 01:12:17 What do you look for in future employees?

Chris: You mentioned hiring, we do have to ask some questions on this because we have many young academic listeners who are interested in what they should do with their life. And I'm sure if we wouldn't ask Jan what he looks for in employees and how he sees what he expects from people who want to go out of academia and into the quantum industry, then we would do them this service.

Jan: Yeah, I mean we start actually we even have employees who are still doing a PhD in parallel. So we have in Munich in our team we have people with a habilitation and also in Finland who can supervise PhD students. So this is where we start but actually we also bring back people who have been now in industry for about 10, 20 years who have done a PhD in quantum back in the day, but there was no job. And then they now realize, hey, now I can finally work in a field where I got my education and they're super excited. And these are the people where I was saying we try to blend them into the teams and help.

So I think wherever you are in your career path, if you have a quantum background, now is the right time to enter because it's a growing market and I think a lot of very exciting things are going to happen in the next few years.

Mira: But does the background need to be in superconducting qubits?

Jan: No, actually one of our very early engineers, quantum engineers, has a background in cold atoms for example and he is now in charge of a big part of the processor development. Of course, you need to understand the concepts. But meanwhile, we are also hiring electrical engineers, software engineers, even mechanics for our factory. So the kind of portfolio of profiles that we have is very wide.

Chris: And do you have advice for students who want to get into the quantum industry? Like what should they prioritize during their study time? Is it more coding or really the basics of quantum mechanics? What do you look for?

Jan: Well, my guidance is always follow your heart because especially in the beginning you want to do something that you're really good at. In order to excel and to accelerate. And this only works if you're really having fun doing it. So I wouldn't advise anyone who is not enjoying software code to do software coding just for the sake of it. So I think that's the most important thing. Really think about what brings you joy in the work and then focus on that and get really good at it. And if you're really good at something, basically all doors will be open.

Chris: Frank, for you, is it different to hire people for like the hiring process and startups is very different from finding people for let's say a PhD or postdoc position?

Frank: Yes, I mean, I think it's the same thing that Jan said. We are a lot more open to I think the division of labor can be made a lot clearer in the software company. So our front-end developer, I haven't really questioned him or any physics, but it was also never a topic to develop a front-end or dashboard for a good software tool. You need different skills. You need to show data well. Our chief software architect is my age and has a master's in physics, which means he had a long, long, long career outside physics.

So I think this well-defined sharing of labor is for us a bit of a difference. We can be more interdisciplinary because in academia, say in a university, in most groups, certainly in Saarland, where I was, the goal is in developing your people to get them their next job. Because nobody besides the professor and the secretary has a permanent job. That was the reality in Saarbrucken. And this means you need to always also make sure that they are widely recruitable. That they have what it takes to become a physics professor if they're a postdoc, for example.

Whereas in the company we can specialize a lot more, people need to be open for this collaboration. People need to have discipline, so they need to make sure they're delivering on time, on budget, and that they communicate problems the right way. Of course, in the Forschungszentrum now there is a slight difference that we have a few people with long-term positions where also very interdisciplinary but the majority is still that we need to keep a keen eye that they have everything that they need for the next job because also here in our minds the majority of people have a temporary job I think that makes a big difference.

Well, you know, so if you're in an industry, it's not your responsibility what the next job of your employees is, but in university it is. The thing I'm highlighting when I have to send in an academic CV beyond the standard is where my alumni went, because that's also what I'm really proud of.

Mira: That's true.

## 01:17:40 Exit paths for startups

Mira: What do you think is the end game for a quantum startup? Is it to grow into a full blown company or in the end just be bought over by the big players?

Jan: The startup world is of course driven by investors and at some point they want their money back and then the exit paths are either you sell the company or you go public. I think there are very few ones who are so successful that they buy back themselves as a company, the shares of the investors. I think these are usually the two routes and of course this is depending then a little bit on the company whether you would be a target to be bought or would you rather kind of prepare to become a publicly listed company.

Generally, I think this is something when we weren't talking a lot about the academic and world, I think this is kind of a mindset that also needs to, or the mindset shift that needs to happen in the employees, that we are working for a product that we are selling and we are kind of aiming to become profitable at some point. So I think this ultimately, this is always the best goal is of course to become profitable because then you are in a position of strength and you can more or less decide yourself what the future will look like.

Mira: But would you also say that in a way IQM would try to protect itself because you said it kind of represents Europe in a certain way. Would you like to be a quantum computing company for Europe?

Jan: Of course, our goal is to become a profitable, independent company. But this doesn't mean that we don't do anything else. And sometimes you're stronger together with someone else. It can also be a merger, of course, or other topics. And I think these are things that one has to consider because you should always act in the best interest of the company and of course you can be very idealistic about certain topics but ultimately if you're only successful maybe with a certain partner or inside of a certain corporation or group then maybe that's the way to go but if you manage to be so successful in selling quantum computers or computing time then of course the highest goal would be to just be an independent company for the rest of the life.

## 01:20:09 Talking about managing major projects in Jülich

Chris: Frank, maybe you're not just a scientist, but also sort of active in science, politics and bigger projects like OpenSuperQ and Qsolid. And these have made Jülich an important player in the development of quantum computers in Europe and Germany. How do you compare these projects to the startups that are happening at the same time? Let's just start there.

Frank: I wouldn't call that politics, by the way. My colleague, Tommaso Calarco, is doing politics. It’s community service.

I think these projects that we have, which, for the listener, are putting together multiple partners, a mixture of companies, academics, but also research institutes like Jülich, Fraunhofer institutes, Leibniz institutes. I think they are important to build a really good knowledge base in the country. They are important in Germany to develop technologies and to also try things out. The architectural choices we are doing in QSolid are a bit of a gamble. We are aiming for the lowest error rate possible no matter what. So we're doing quite a few compromises. And I think this concept of trying things out, doing an ecosystem and building a meaningful system for people to have some deep access to. This is our mission.

To play with the hardware on a detailed level, on a level where at least some companies, I haven’t checked the terms and conditions at IQM, but some companies would say you can never do this because then you're finding out the things that are so much trade secrets that we don't patent them because we don't write about them. I think this is the mission that we have.

And we should do this at a very non-trivial size; at the size of qubits of quantum computers where we do not take any shortcuts that we can do just because it's small you know low yield if you only have three torsos and junctions you can work with a low yield and just do this so this is all we want to do but it's for this depth of access it's if we look at that we can really also educate people in using these things. This is our mission to do this at a non-trivial size.

It is not our mission that the system has the most polished experience for an end user from an industry that's very far from physics, say, finance industry possible. That's the role of companies. We don't buy cars at research centers. We don't buy watches at research centers. We don't buy computers at research centers. But we have this complementary role.

And specifically, when we talk about reaching and certifying quantum advantage, it's kind of important to work close to the metal. It's important to try out new programming paradigms. And I think this is our role. And of course, you know, this being huge corporations that are also set up and govern such a survey. It's, I think, a hybrid between blue sky research. It's very much not really blue sky research, but which we are still part of and have a lot more freedom than if you have really formalized handover. would assume that inside IQM people still have good freedoms for their happy, but I think in this case it's a bit of a transitional thing between traditional research and industrial research.

## 01:24:01 Talking about the role of ML4Q and the latest developments in Jülich

Chris: How do you see the relationship between ML4Q and the research clusters and these sort of more, more mission driven companies.

Frank: ML4Q has in my view multiple roles. One is to explore the things that for a research project are too risky. So for example, there is an overlap between groups at Jülich that have a big footprint in ML4Q, like the PGI3 and the PGI9, who use what they think is a very conservative way of making a new process of making Josephson junctions, which we think, oh my goodness, will this ever be reliable enough to get to the critical path? And we are seeing some successes there. So in this way, ML4Q is a lot more fundamental. There is this stencil mask fabrication without resist, if we can talk a little bit of fabrication. I'm a theorist, so I don't really know what I'm talking about, but this is an example.

I think the other thing is that nothing sparks users' and theorists' creativity as much as a system to play with. You learn how to work with the compromises it has, but then there are little things that maybe our system has unique features of. So on the theory side, I see a lot of interaction in what to do with it and on the longer term, maybe suggest changes in chip design which are still a very heavy thing for the people who are making chips. It's still a big thing to adjust the design of a large chip to the idea of a theorist but at least we don't have to put it into a corporate strategy so I think we can be quite flexible and we see great development here.

And then there is of course training and finding talents and giving people the opportunity to find out whether the type of R&D we do is something they do really enjoy. Also, we should keep in mind that a lot of the people who are now in Jülich are dissenters of the Q-Solid project, for example. Have been recruited partially based on ML4Q. I moved from being an external advisor to ML4Q to being a member at some point. The original proposal I gave nasty feedback in red ink.

Chris: So Jan, for you, it's also like you are involved in which one? Qsolid. Also in OpenSuperQPlus.

Jan: In both, yes. The first OpenSuperQ we couldn't because the company wasn't really there in the process.

Frank: Yes.

Jan: Yeah, I totally agree. These are important projects and we I think also as a company we have aligned goals because we see ourselves as a producer and then of course also provider of quantum computers, but we don't necessarily want to take the risk to try out each and every path that's possible. And of course if something great comes out of those projects we would be super happy to include them into our product.

So this is how we see it and as said we of course also anyways want to be very close to the academic community because this is where we find the talent from this is where we find new ideas from so this is why we're actually super happy to be part of these important projects.

Mira: IQM also sold a device to Jülich.

Jan: Yes, this is this Spark product that I already mentioned. So the smaller computer to the supercomputing center, which basically also I think fits into the story because this is then a device which can be used purely for academic purposes. So kind of training. What does it mean to run a quantum computer?

I think also giving access to the whole world of computer scientists to those systems but also actually it is so open in a way that if a research group would have a different amplifier or some other component they can just go and exchange it. So this is really the idea here. I think it should not be already there in Jülich and we are very looking forward to seeing how it's then being adopted there on site.

Mira: Jülich also has a device from D-Wave and from Pascal. So is Jülich in any way or would it try to benchmark these devices?

Frank: Absolutely, that's part of the game. To understand what they can really do, some of the benchmarks are technical in nature, so where you prove this is the proper benchmark, some of these are also developing use cases. And scientists are excellent first movers on this because we have some passion to try new things out. We often have a tolerance against technologies that are not super polished yet. And this is part of the thing.

So it's the mindset of the supercomputing center, which I'm not a part of, to offer the latest and greatest in computing. There's the whole issue that many people, including IQM, also working on how to really smoothly integrate these quantum computers in a high performance computing workflow that has a technical component. How do you make the communication completely optimal; so to make sure that your fancy quantum machine is connected to your fancy high performance computer is not waiting for anything stupid while you're running it.

But also the next level is when we put something on our phone, my phone has different kinds of cores and I don't know. Probably the face recognition is done by the AI optimized cores and not by the computer optimized cores. So this is also the next level. So this is also a kind of an active research direction.

And at this scale of large compute centers and of large scientific compute centers, you want to find this out yourself. You don't want to stick with one out of the box solution for this. And again, also, once the D-Wave machine comes out, the D-Wave machine is best in solving problems that are mathematically formulated in a certain way. It's called a QUBO, a quadratic unconstrained binary optimization problem. I once owned a car with the same name.

And once these came out, a lot of people checked: does my research problem fit into a QUBO and when they release new features a lot of researchers who are benchmarking this immediately fitted things on new features. I think this give-and-take, this back-and-forth is kind of the new upscaled version of the theory experiment workflow we talked about, I think it's now an hour ago.

Chris: Yeah, so Jan, is Jülich then going to be an important partner? For example, if you have a bigger system, would Jülich play a role in sort of independently certifying performance.

Jan: This is, of course, something that we hope for. I mean, getting customer credentials also for a startup is one of the best things you can get. And this is also something that, of course, investors and others are asking for.

And also, all of these supercomputing centers, they are somewhat connected, similar to the quantum world. he world of supercomputers is a small world and everyone knows each other. So, of course, for us, it is super important that they do use the system, but then also that the results are good. And then they go to their friends in the US or elsewhere from the supercomputing centers there and talk about it. So from this perspective, yes, this is, I think, a super important project that there is now a quantum computer from IQM in Jülich. And I think benchmarking it is a very important part of the game.

Chris: We have covered a lot of ground from start-up worlds, academia, to Jülich, I think we are at a good point to finish, right? I don't know if you guys have important other things you want to discuss.

Mira: Yeah, after having now conversed with both of you, I feel like usually we have this idea that academia and industry are far apart, but it seems like they're going quite a lot hand in hand.

Chris: So thanks a lot for doing this, the both of you.

Jan: Thanks for having us.

Frank: Thanks for having us.