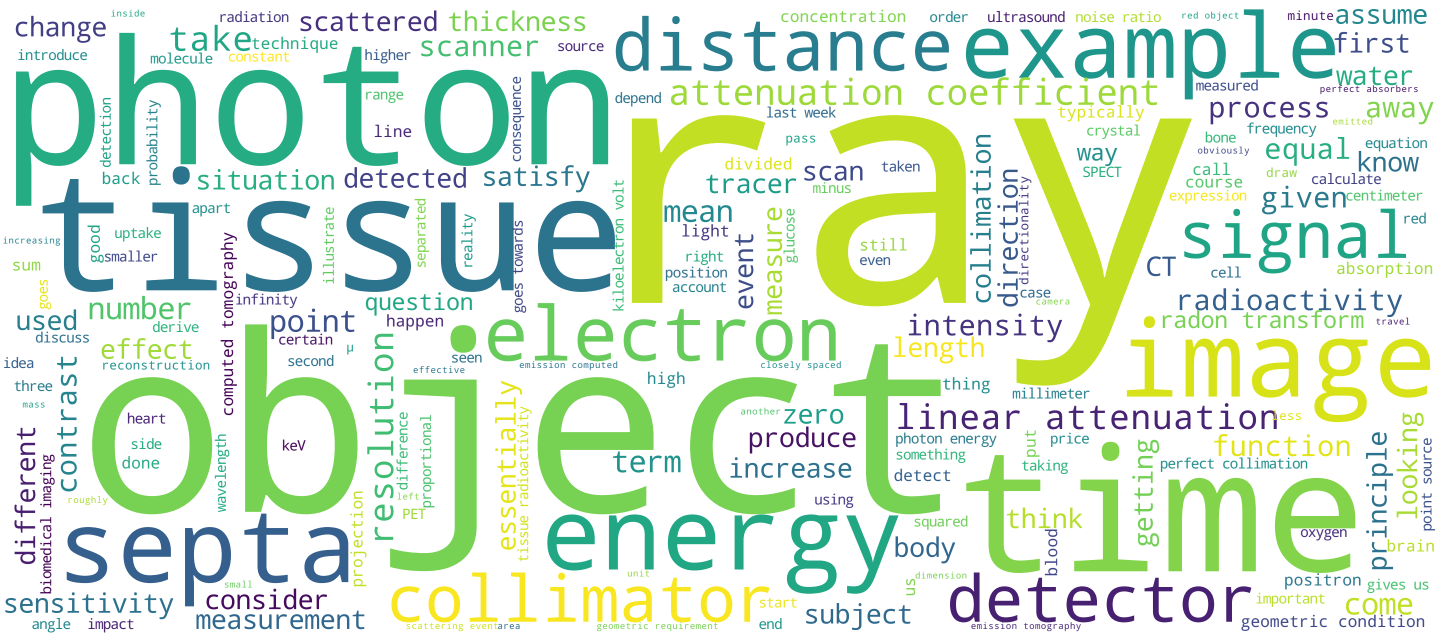
# 5.2 Collimation of emitted x-rays

## Fundamentals of Biomedical Imaging

Prof. Rolf Gruetter

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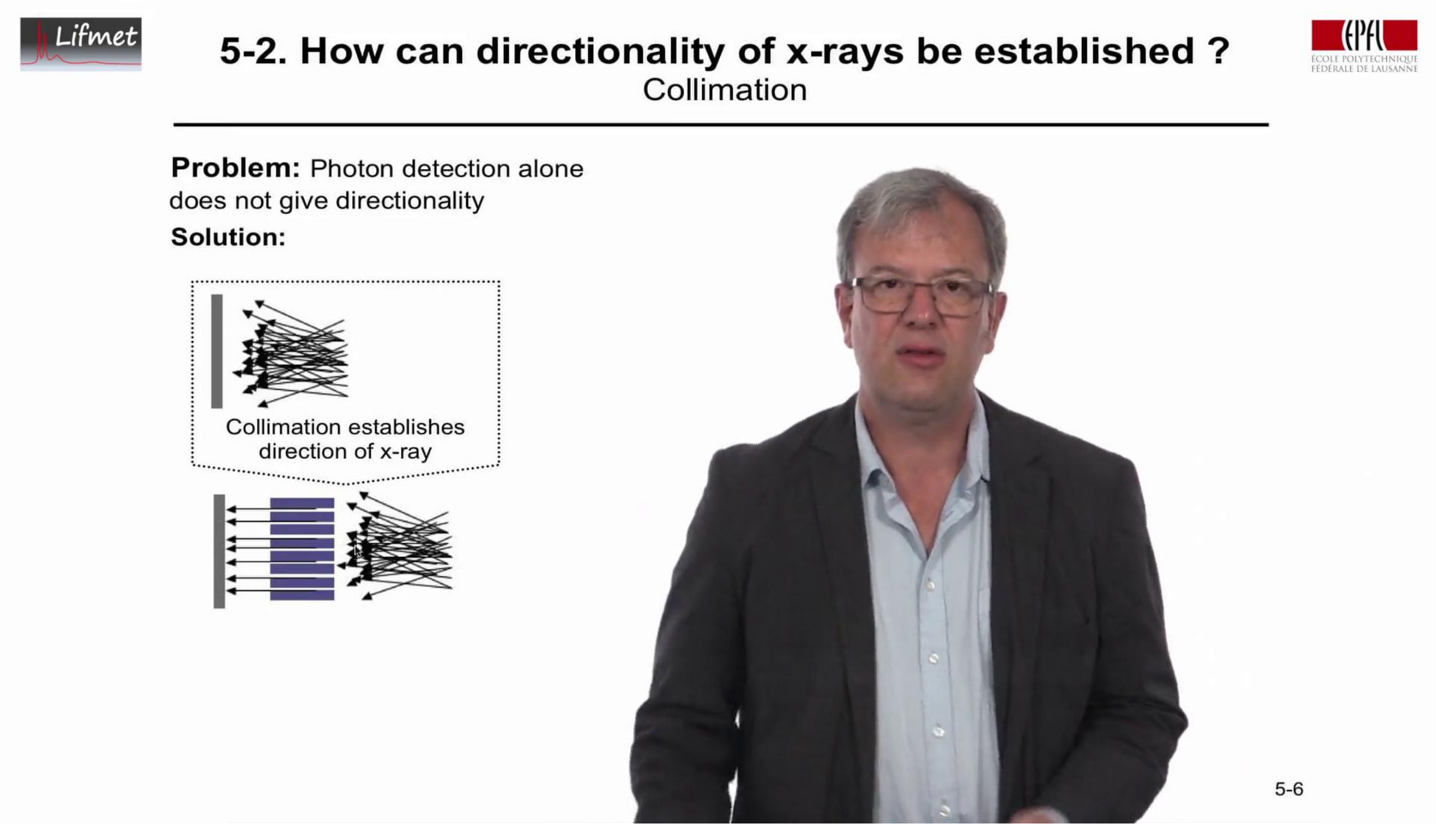
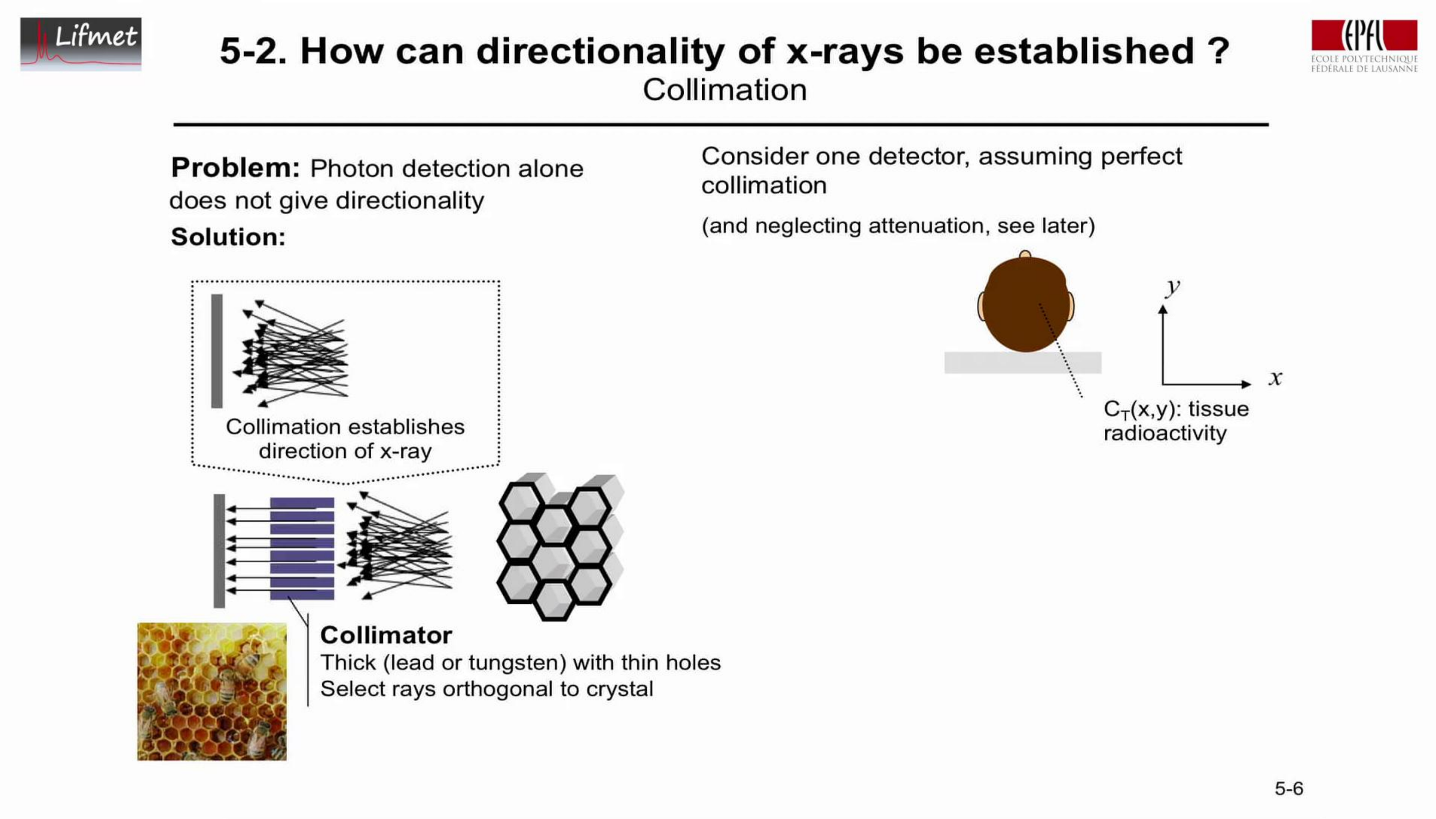



So, I mentioned that photon detection does not give us the option to determine the directionality of the photon. The question here is, how can we establish the directionality of the photon? How do we know where it came from? So, here's the situation: we have a bunch of x-rays that come from the body. This is the x-rays, they go in all sorts of directions and here would be our detector, our camera. This is not a very useful situation. So, what we can do, and we've already dealt with this two weeks ago when we talked about x-ray imaging--I'm sorry, last week, about CT, that we can use a anti scatter grid to eliminate photons that don't have the right directionality. So, we can do the same thing here. We'll introduce this collimator, which is essentially the same thing as a anti scatter grid, and of the x-rays, we will only allow to pass the x-rays that satisfy the geometrical condition of collinearity with the slates that are in the collimator. Now, this is an extreme simplification, but it serves to illustrate the principle that we put in the collimator and only x-rays that satisfy the collinearity of going from left to right, in this direction, are being passed through in an idealized way.

Notes

Summary

0m 04s

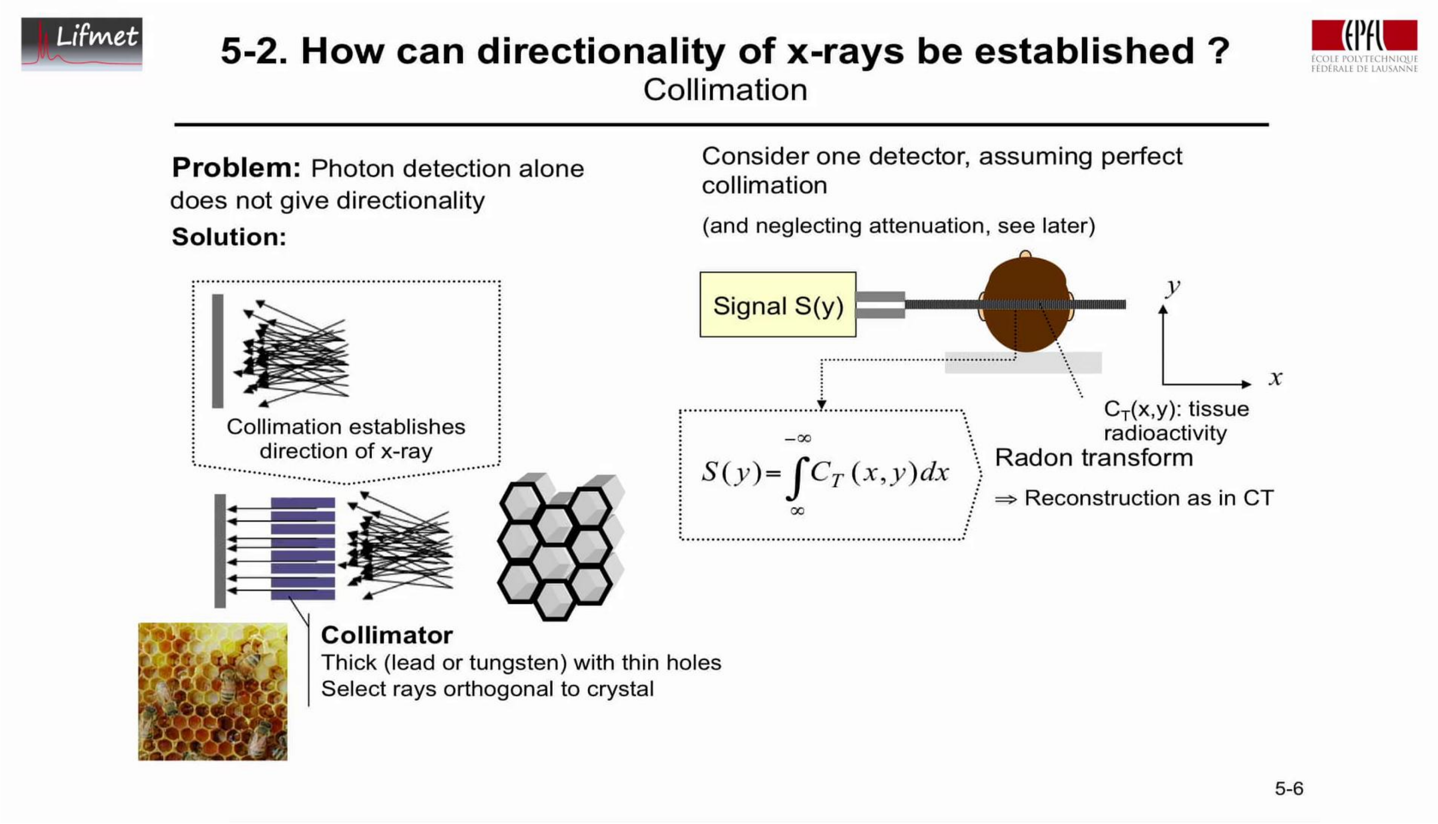



The collimator typically is fairly thick material. It is lead or tungsten, so it has high Z, it has thin holes and this basically establishes that the rays only orthogonal to the crystal pass into the crystal. What does a collimator look like? It is hexagonal in structure, so these are the collimator material, thick material here, and fairly long here, similar to the hexagonal structure of a beehive. So, now let's look at the scan here. We have a subject and we'll now assume we just have one single detector, and we'll assume perfect collimation, so we'll assume that we have done everything so that only x-rays that satisfy this geometric condition of being perpendicular to the detector are being detected. And for the sake of simplicity for now, we will neglect the effect of attenuation. We'll assume that the x-rays that are in the subject are passing through perfectly. I'll establish here the frame of reference. X is to the right and Y above. So here, X to the right and Y above. And now we'll consider here one point in this subject's head. This point is indicated by the coordinates X, Y. We'll call the tissue activity here CT, so CT typically stands for radioactivity, T for tissue, so that's tissue radioactivity at this point, X and Y.

Notes

Summary

1m 30s

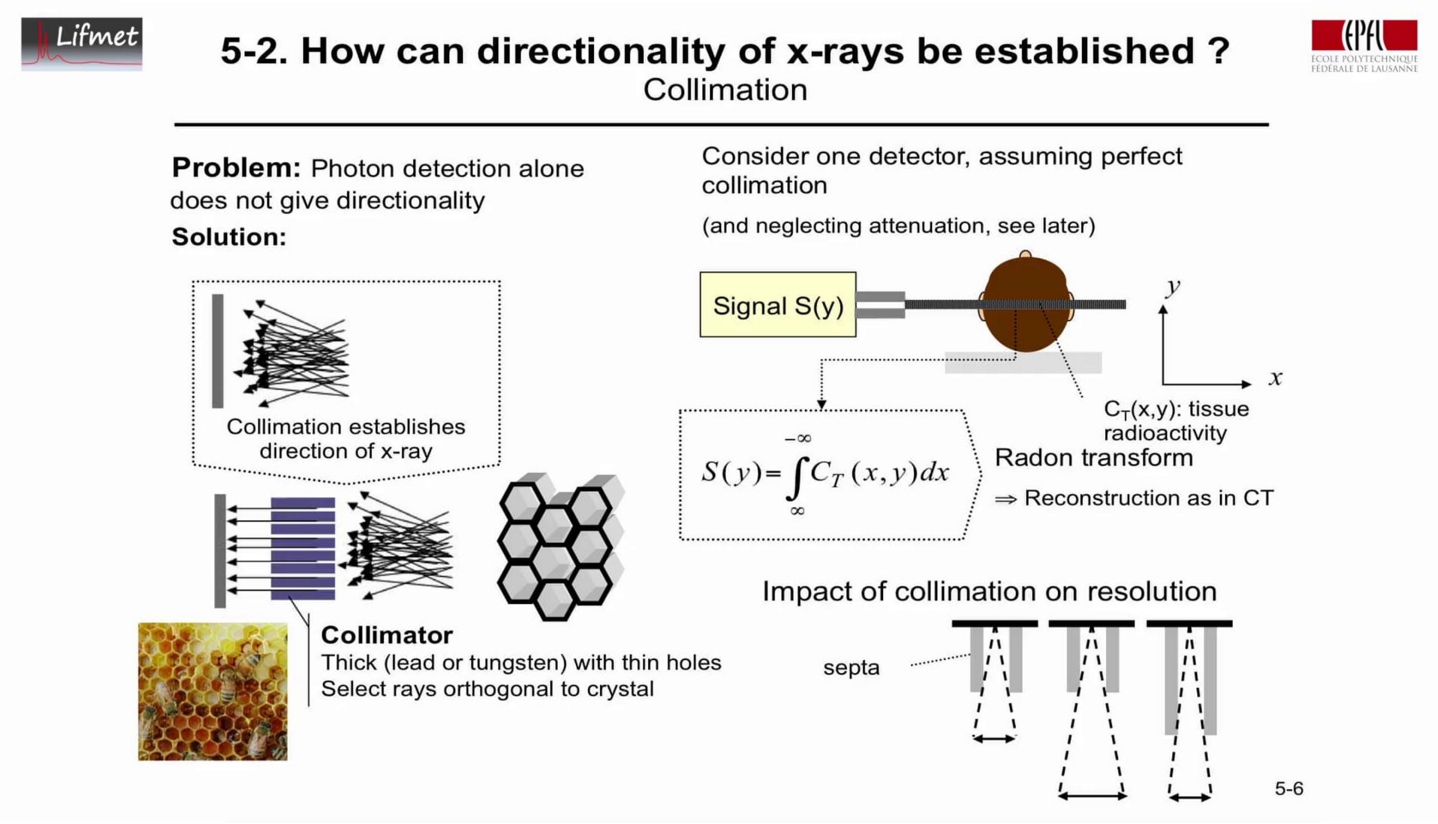



And now we will have here our single detector with the collimator, and we'll pretend here it only selects photons that satisfy this geometric condition set forth by the collimator. So this is the signal that we now detect in this situation. We not only have the radioactivity of this point that contributes to the signal, we also have radioactivity that's here, radioactivity that's here, radioactivity that's here, so we have to sum over the entire range where there is radioactivity, or, in other words, we will sum over the entire range of distance here because we don't know whether the x-ray comes from here or from here. It is being detected. We'll sum all the x-rays that are satisfying this geometric condition, and when we sum so, then we get this integral here. So we have the tissue radioactivity along X for this given position along Y summed from infinity -- minus infinity to infinity. Do you recognize this function? Have we already dealt with a function like this? Well, you might have guessed it. This is a radon transform. So we can actually write our signal as a radon transform. That's actually the process of how we do it.

Notes

Summary

3m 03s

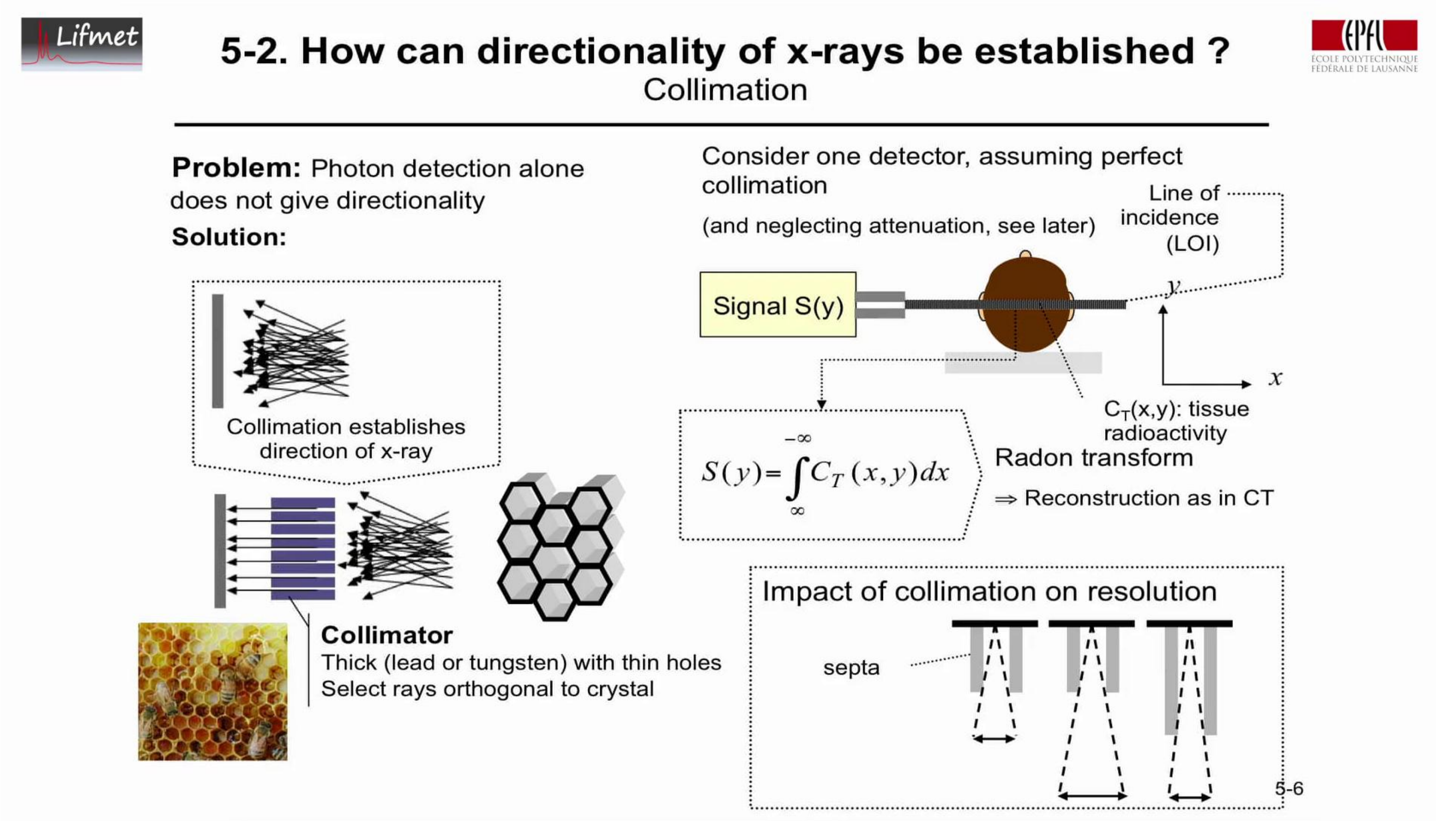



The good news is, if we know the signal is described by a radon transform, we've already established last week the process by which an image can be reconstructed once we have it collected as radon transforms, and that is back projection so the reconstruction is done exactly-- can be done exactly as in computed tomography. So for us, there is no need to introduce a new algorithm for image reconstruction in emission-computed tomography. Now, let's look at collimation. So, what we said with collimation we're using-- this is a way to establish directionality of x-rays, and we have assumed here we have perfect collimation. So only the x-rays along this line here are being observed. If we look at the real situation here, we have the septa and the separation of objects, so these two objects are separated by this distance can still give a rise to detection here at this point. If my object is further away, then by these geometric requirements, these are the same septa here, same length, the objects are further apart, so the resolution goes down. If we make the septa length longer, then the objects that can contribute here to the radioactivity detected, they are closer together, so the resolution goes up.

Notes

Summary

4m 19s

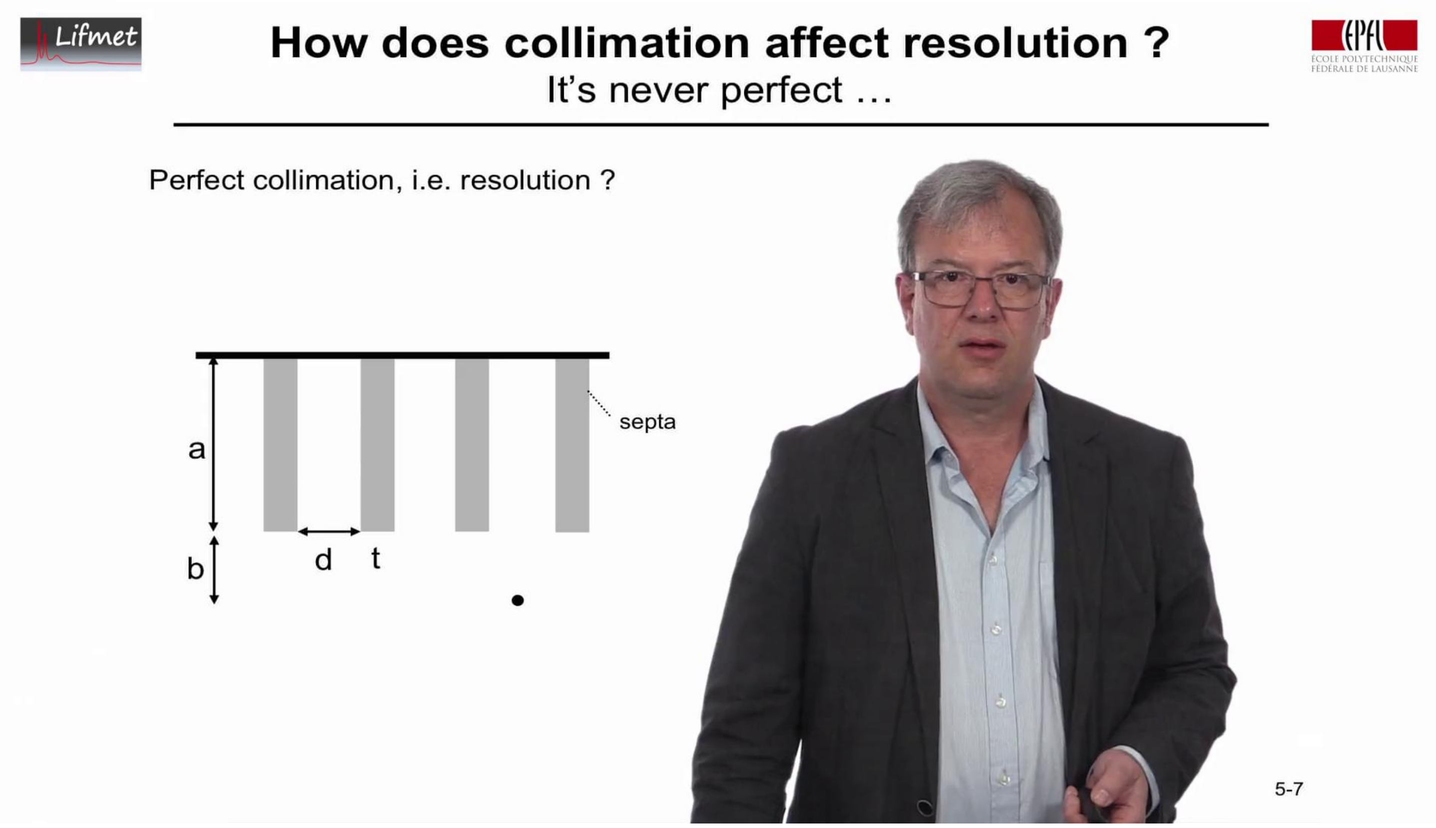



So this is a brief introduction that the collimation has an impact on the resolution. I want to briefly mention here one term and that is this line here, we call that the line of incidence. So, collimation has an impact on the resolution. Does it have another impact? Let's think about this. What do we do with collimation? With collimation, we are establishing directionality of the x-rays by eliminating the x-rays that don't satisfy the geometric condition. So this means that we are eliminating x-rays so principally and fundamentally, we are reducing the sensitivity of the scanner. It's a brute force way of establishing directionality of the x-rays.

Notes

Summary

5m 47s

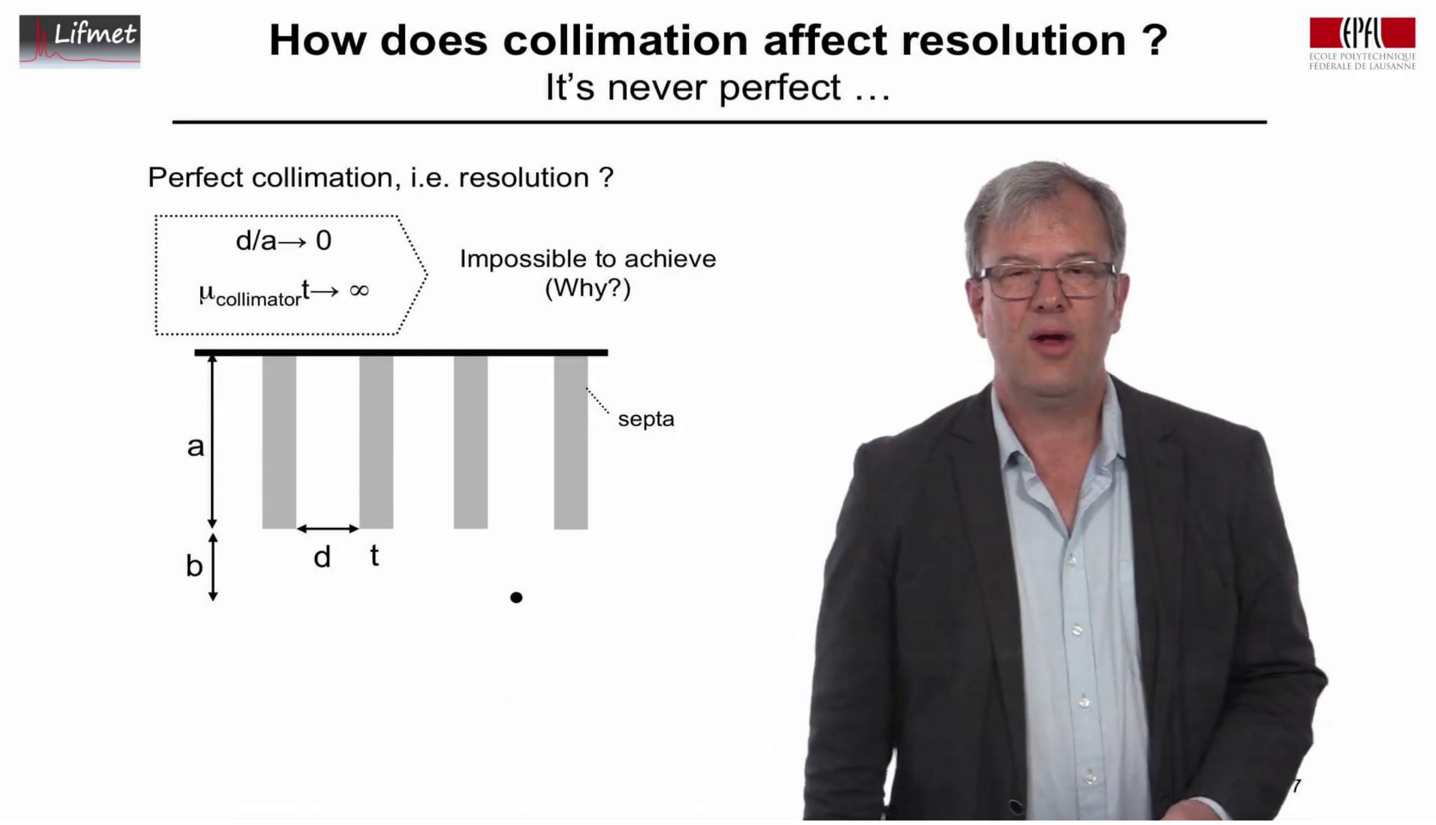



So, while good collimation improves the resolution, it does at the same time, and we can see that here, it does at the same time eliminate more x-rays and therefore reduce the sensitivity, and we are back to being sandwiched between the needs for sensitivity and the needs for resolution, and those two are two principles that go against each other. How does collimation affect resolution? I want to spend some minutes on discussing how collimation can impact the resolution of the scanner. Let's consider first what would be the conditions for perfect collimation, perfect resolution. I'll draw here on the X axis the detector, and then we have one septa here, so that's a septa here. We'll draw a second one. and a third one, and a fourth one, and a fifth one-- no, the fifth one will not come here. And we'll say that the septa have a length of *a*, "a" being a certain distance in centimeters. They are separated by a distance *d*, typically millimeters. They have thickness of *t*, typically also millimeters. And we'll now introduce a point source of radioactivity that is at a certain distance *b* away from the end of the septa. What would give us perfect collimation?

Notes

Summary

6m 35s

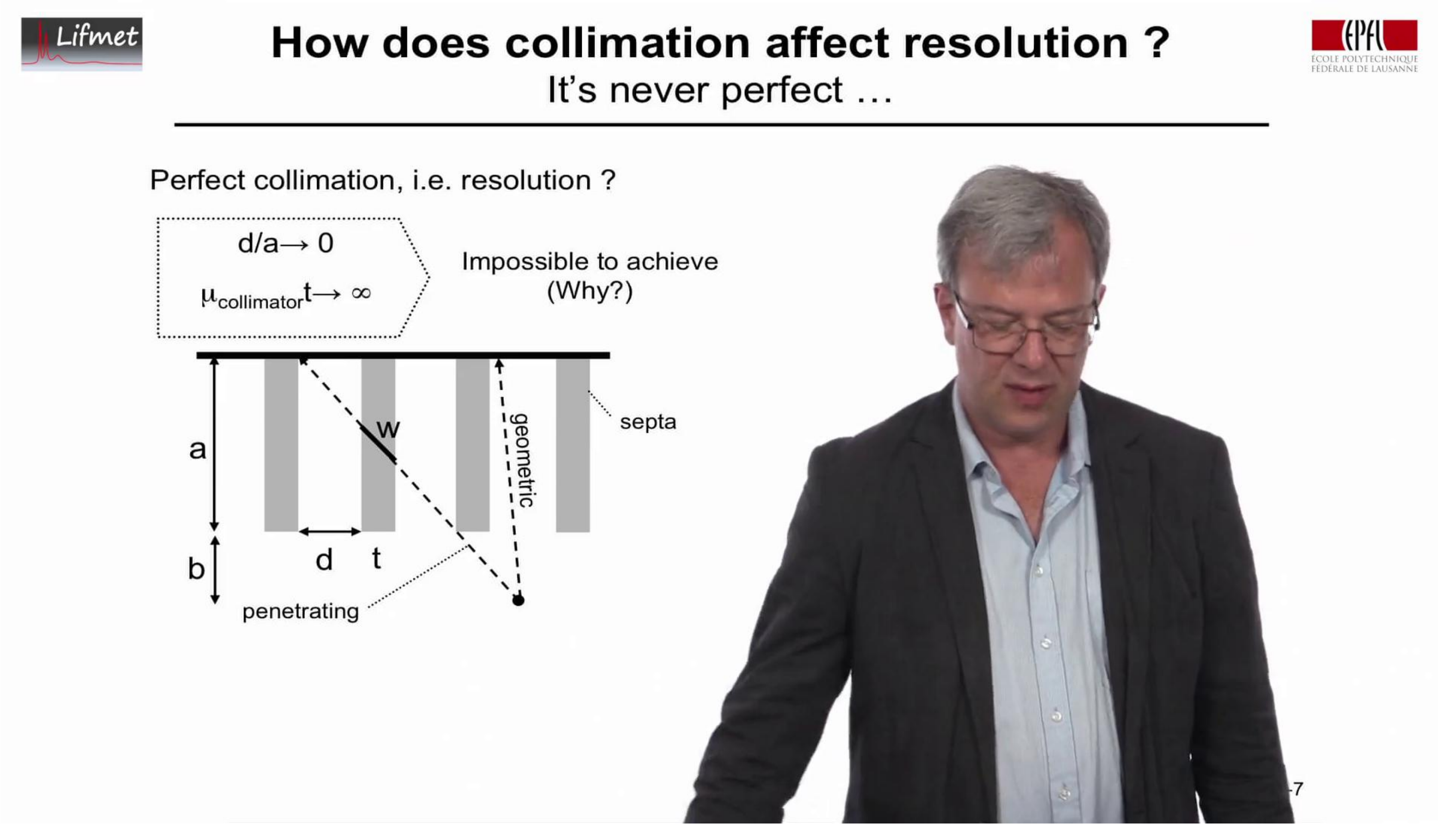



Number one, perfect collimation, we would want to have x-rays that are perfectly perpendicular to the detector here. This we can achieve by making sure that *d / a* goes to zero. So we have either very long septa, that's *a* going very long, or they are very closely spaced. So, closely-spaced, very long septa that will provide us with, essentially, only x-rays that are very perfectly perpendicular to the scanner camera. The second condition is that the linear attenuation coefficient of the collimator that times its thickness goes towards infinity. Where does that come from? Where does this condition come from? We have to consider that the collimator, we have so far assumed that the septa are perfect absorbers. They're only perfect absorbers of the x-ray if the distance through which the x-ray travels in the septa times the linear attenuation coefficient is such that very few x-rays pass through the septa. So, this is the condition that they are perfect absorbers. Can we achieve this in practice? No. The answer is no. Why not? Well, theoretically, we could generate a collimator that has *d* to *a* that goes towards zero, so very long collimators that are very closely spaced.

Notes

Summary

8m 14s

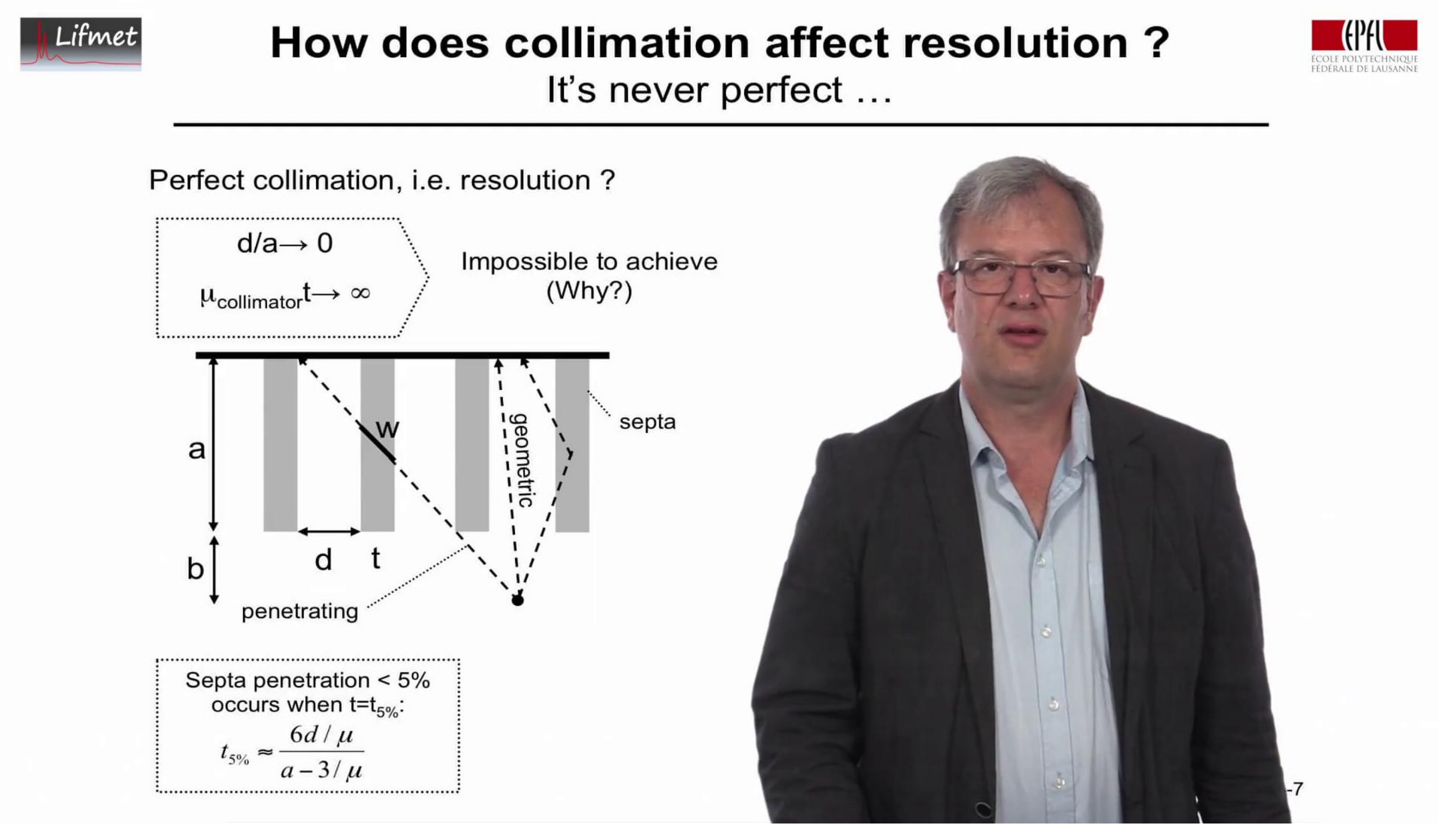



We would lose a lot of sensitivity doing that, but from a manufacturing standpoint, we could imagine that we are building separations on the order of microns and collimator length on the order of millimeters and then this goes towards zero. But even with the heaviest, high Z materials that we can think of, and that we have available in nature, we will not be able to get the thickness times the collimator go to infinity, so we have imperfect absorption of the x-rays. And *d* to *a*, letting that go to zero, that would essentially mean we're detecting perfect collimated x-rays but very few of them, so that's not very efficient for the image-generating process in terms of sensitivity. Now I'll draw here an x-ray that's a properly-detected x-ray. It's what we call the geometric event. This is the one that we've selected according to our geometry, this is a good x-ray that satisfies our geometric conditions, that's a good detection. Now we have another event. This is a x-ray that does not satisfy the geometric condition but is still being detected because it's one of those x-rays that has not been absorbed by the septa. It's passed the distance W through the septa here and the absorption has not been perfect.

Notes

Summary

9m 49s

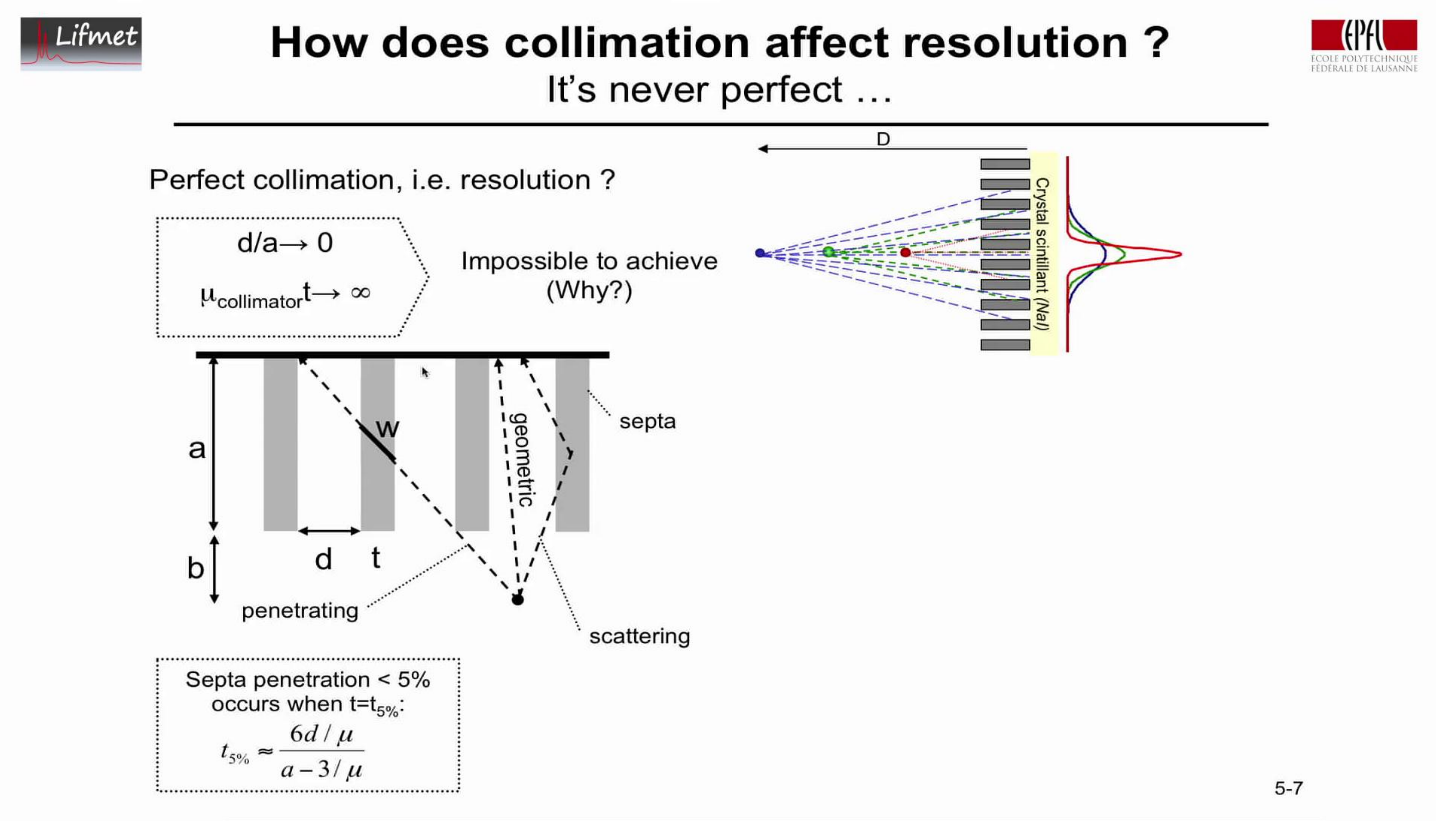



This is because this is not infinity, and so it's still being detected. That's a so-called penetrating event. Now, I'll give you a formula. I won't derive it here, and we'll consider here a penetration of the septa that is less than 5%. And this is given if the thickness is equal to the thickness at 5%. Now, this is an emprical formula I've taken from the literature here. It says that this thickness is roughly proportional to the distance between the septa divided by the linear attenuation coefficient--that makes sense. This thickness becomes thinner the higher the linear attenuation coefficient, and it is inversely proportional to the length of the septa here, the length *a* minus a correction term that involves the linear attenuation coefficient. So, if the linear attenuation coefficient is not perfect, this length here becomes longer-- shorter and this term in the bottom becomes shorter and so this thickness has to be thicker to take into account for imperfect penetration. We have another effect and that is scatter. So the x-ray from our point source can also interact in the septa by Compton scattering and be scattered into this event here.

Notes

Summary

11m 13s

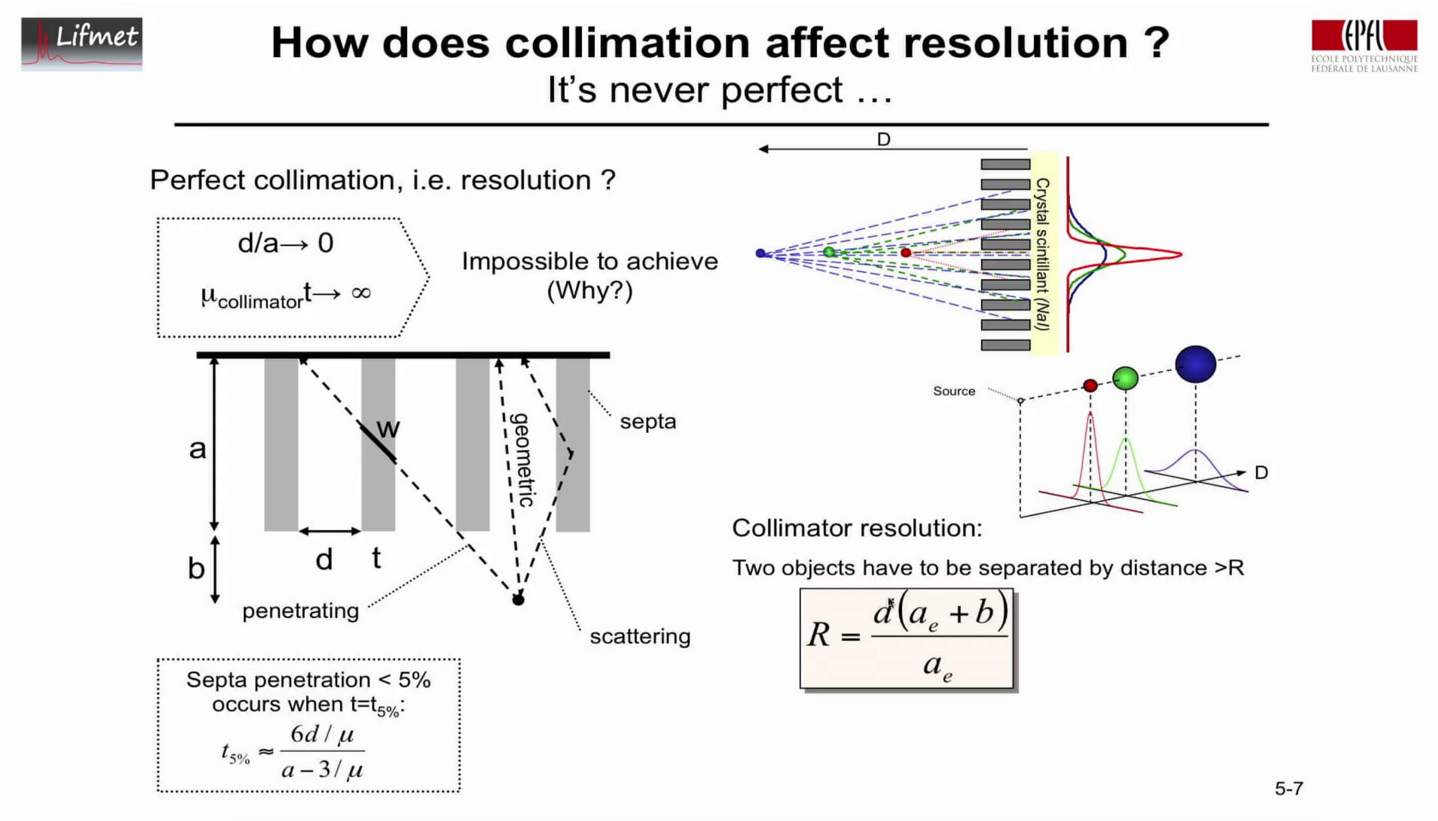



So we're getting a scattered event, a scattering event at this point. So, what does this mean? We are essentially trying to select only the geometric events, we are getting penetrating events, and we're getting scattering events here. The scattering event is good but it could also be that this is being here and scattered there or it goes here, scattered here, et cetera. So, what does this mean if we look at our object? We have an object, a red object here, and it's relatively close to the collimator here, we're plotting the distance *d* here, we're getting in our detector a distribution of the measurement here with a certain distribution, even though we're saying here the red object is a point-wise source. If we're going further away then our point-wise source, still the same, it's just further away. In green here, now we're getting a wider distribution because the geometric requirement is relaxed. We're further away so we're increasing the probability that some x-rays will actually pass into the next bin here, on the side. And finally, for the blue object, we are even further away, so its distribution, its width as the way it's being detected, increases.

Notes

Summary

12m 41s

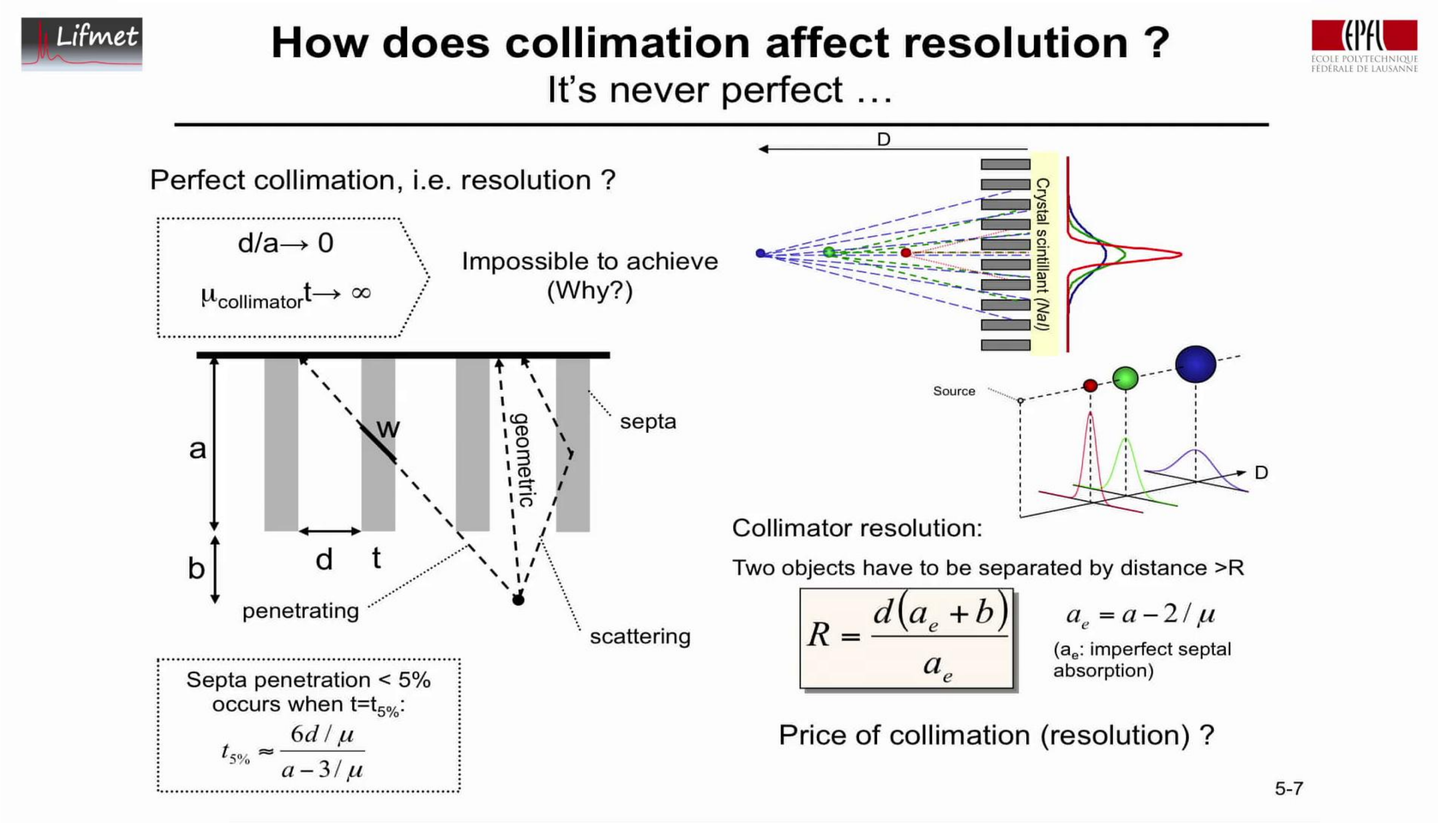



That's another way of saying that the resolution decreases because the object is no longer represented by a point object. So, our source, that is in truth and reality a point source, at the distance indicated by the red object is becoming a red circle. At the distance indicated by the green object it is increasing. And even further away, the blue representation here gives us the furthest distance, the object becomes blurrier and blurrier. So, we can put an emprical equation to describe collimator resolution, and this is, again, from the literature here, I won't derive it. You have an exercise where you can derive it with slightly different geometrical conditions. So, we can say here in a loose way, the objects are resolved if they are separated by a distance, *R*. This distance *R* is given by the distance, is proportional to the distance of separation of the septa. That makes sense, the further apart they are, the bigger is the angle with which I can see the object, times the total distance from the detector to the object, *a* plus *b*, although here the *a* is not the real geometric *a*, it's an effective *a*, and I'll come to that in a second, divided by the collimator length *a*.

Notes

Summary

14m 02s

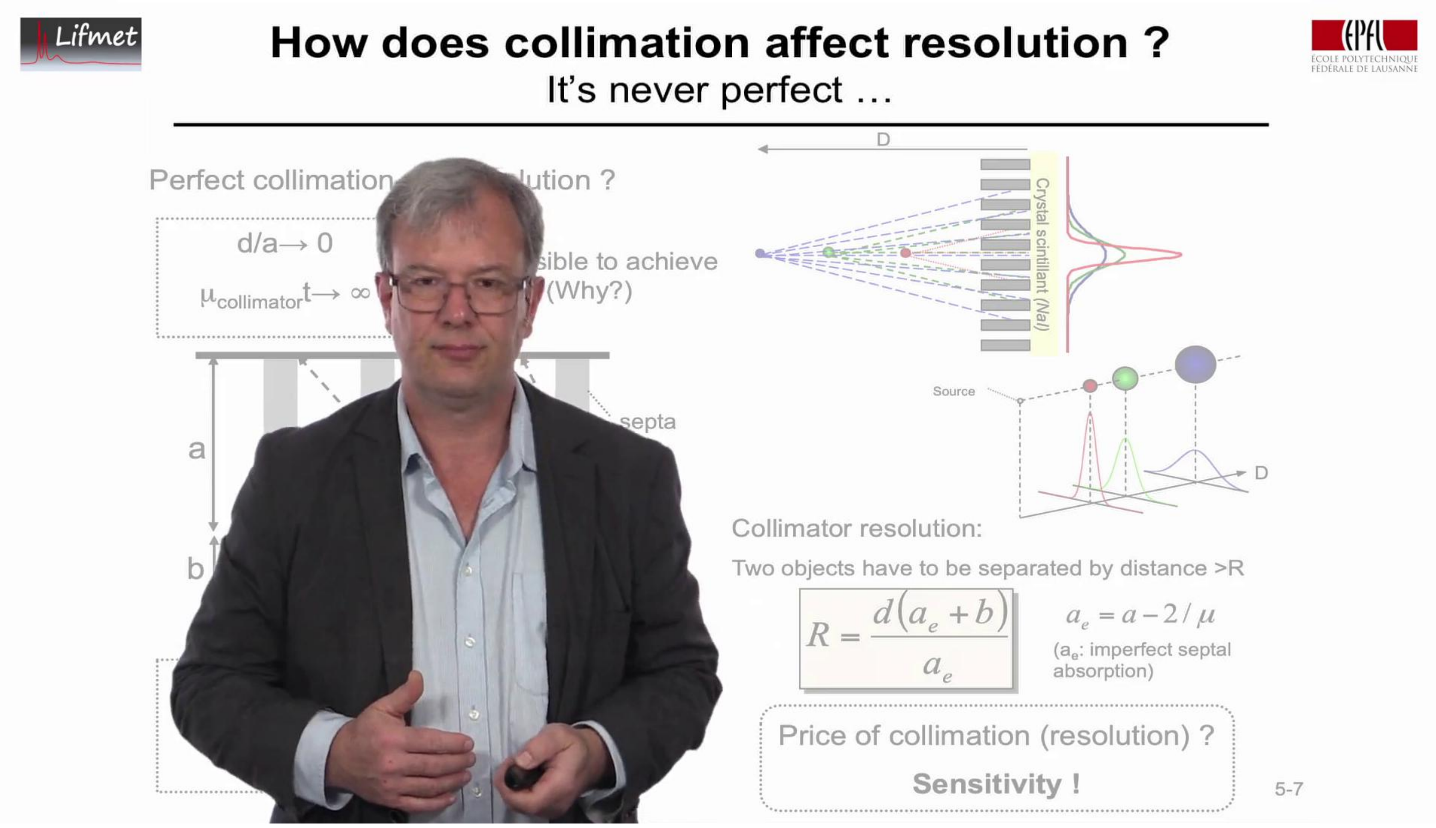



So, does this make sense? The further the collimators are apart, the bigger is *R* so the poorer is the resolution. The longer the septa are, the longer is *a*, the smaller is *R*, so the better is the resolution, and finally, the closer the object is to the septa, to the collimator, the smaller is *b*, the smaller is also *R*, and the better is the resolution. Now, what is this story about the *a_e*? Why do we not just put the *a*, the length of the collimator? Well, *a_e* is the length of the collimator corrected for the fact that the collimator, the septa, will not perfectly absorb the x-rays so it is an effective length, it's the geometric length, the true physical length here, minus 2 over the linear attenuation coefficient, *μ*. Basically means if the linear attenuation coefficient, we pretend it goes towards infinity then this is indeed the geometrical length of the septa, but in reality it's a bit shorter than that. And this expression takes into account that the septal separation-- septal absorption, I'm sorry, septal absorption is not perfect. That's what is going into the equation here. So, what is the price of collimation? We have seen that good collimation, we have expressions here, can give us good resolution.

Notes

Summary

15m 32s



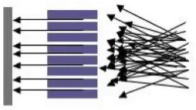

What are the consequences of wanting to go to very good resolution? I've already hinted at this a bit. The price is sensitivity. Remember, collimation is the elimination of unwanted x-rays that do not satisfy our geometric requirement of the x-ray being perpendicular to the scanner, to the detector, and we're doing that by brute force, eliminating the x-rays, by basically trying to prevent them to come to the detector. So we're taking out events, we're taking out radioactivity that passes through the subject's body from arriving at the detector. And so, we are, again, paying the price of resolution with sensitivity, coming back to these two effects, that in biomedical imaging, consistently counterbalance each other, or counteract each other.

Notes

Summary

17m 04s

# Credits



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Notes

Summary

17m 59s