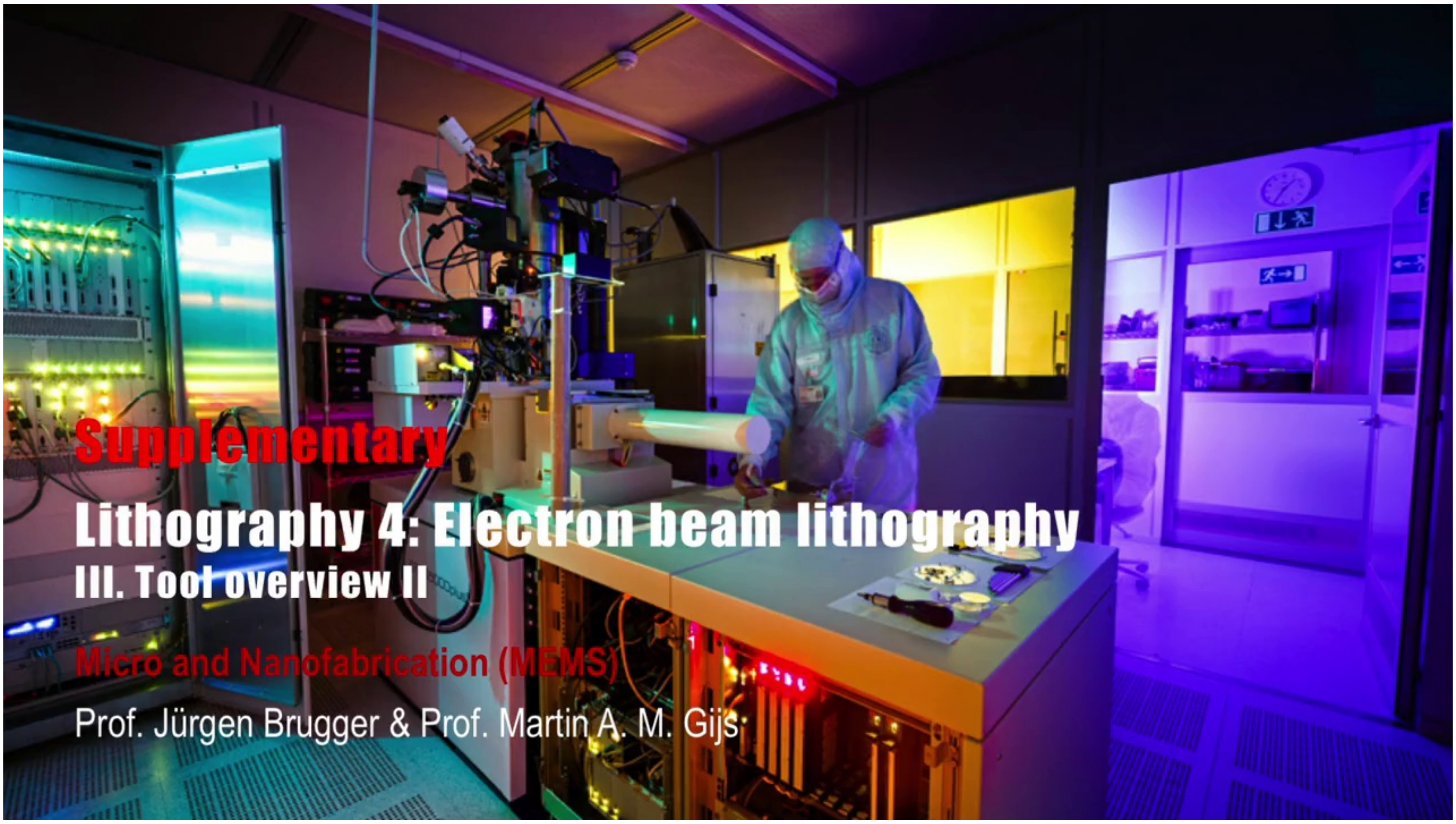

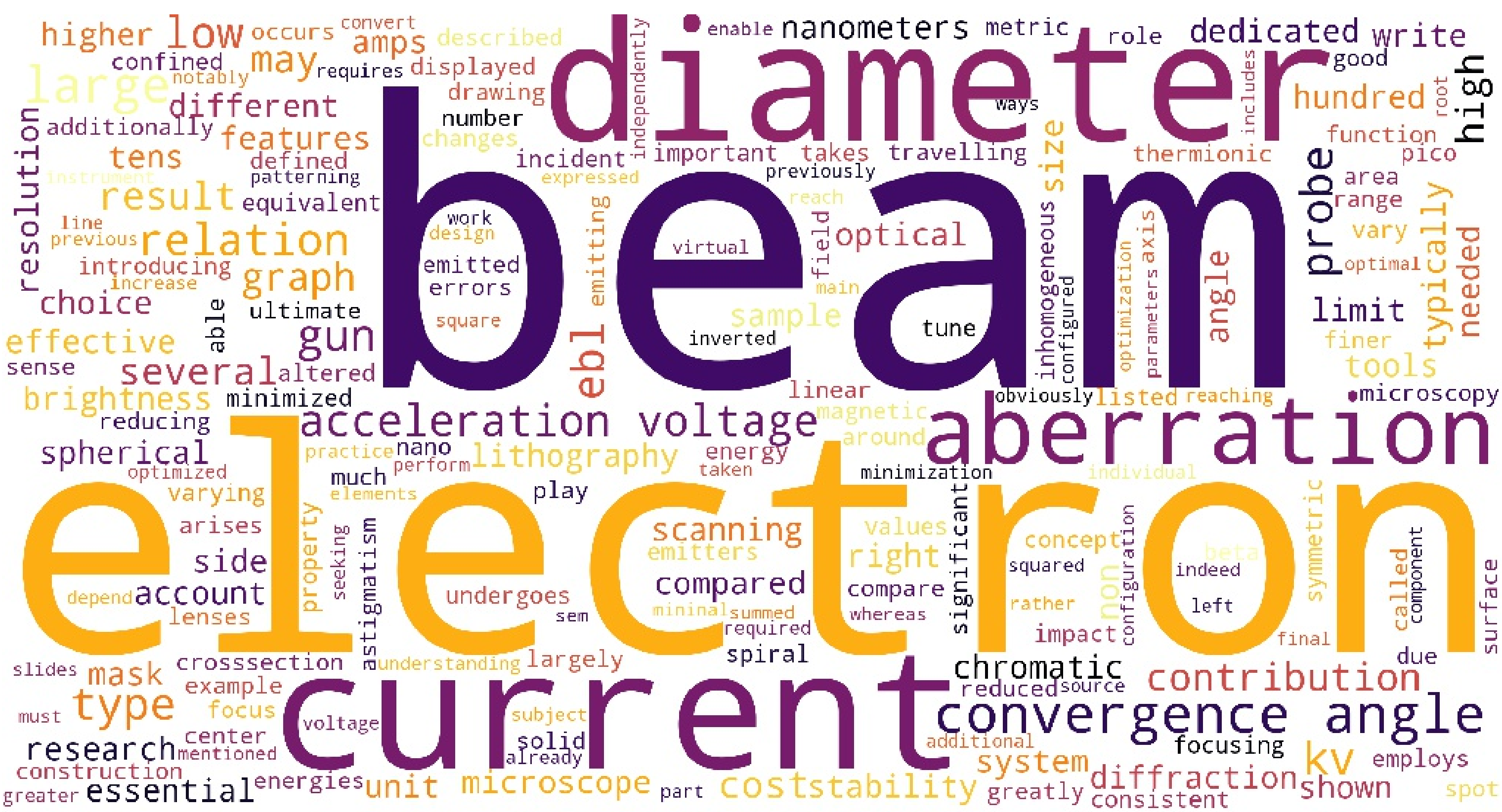

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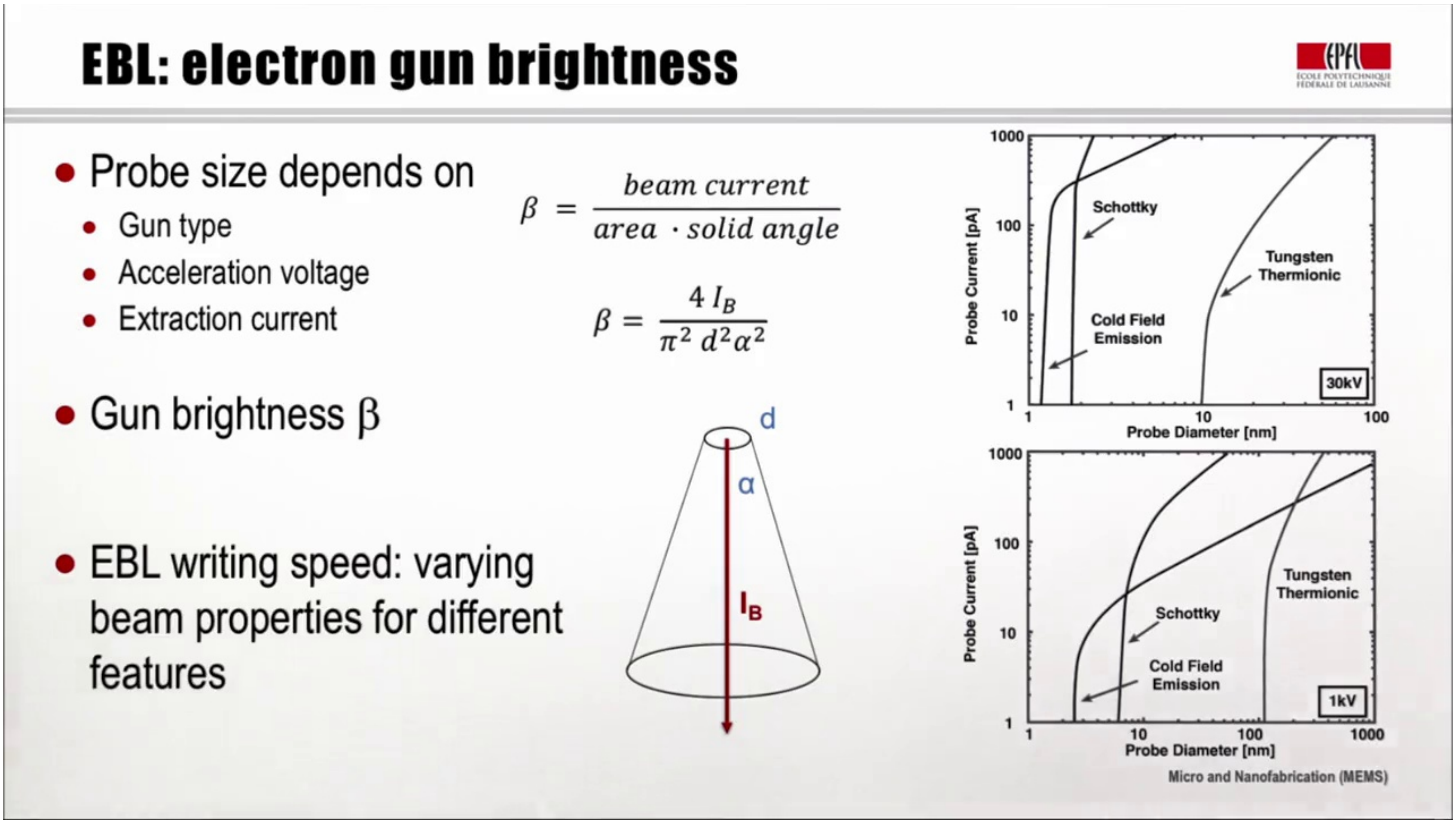
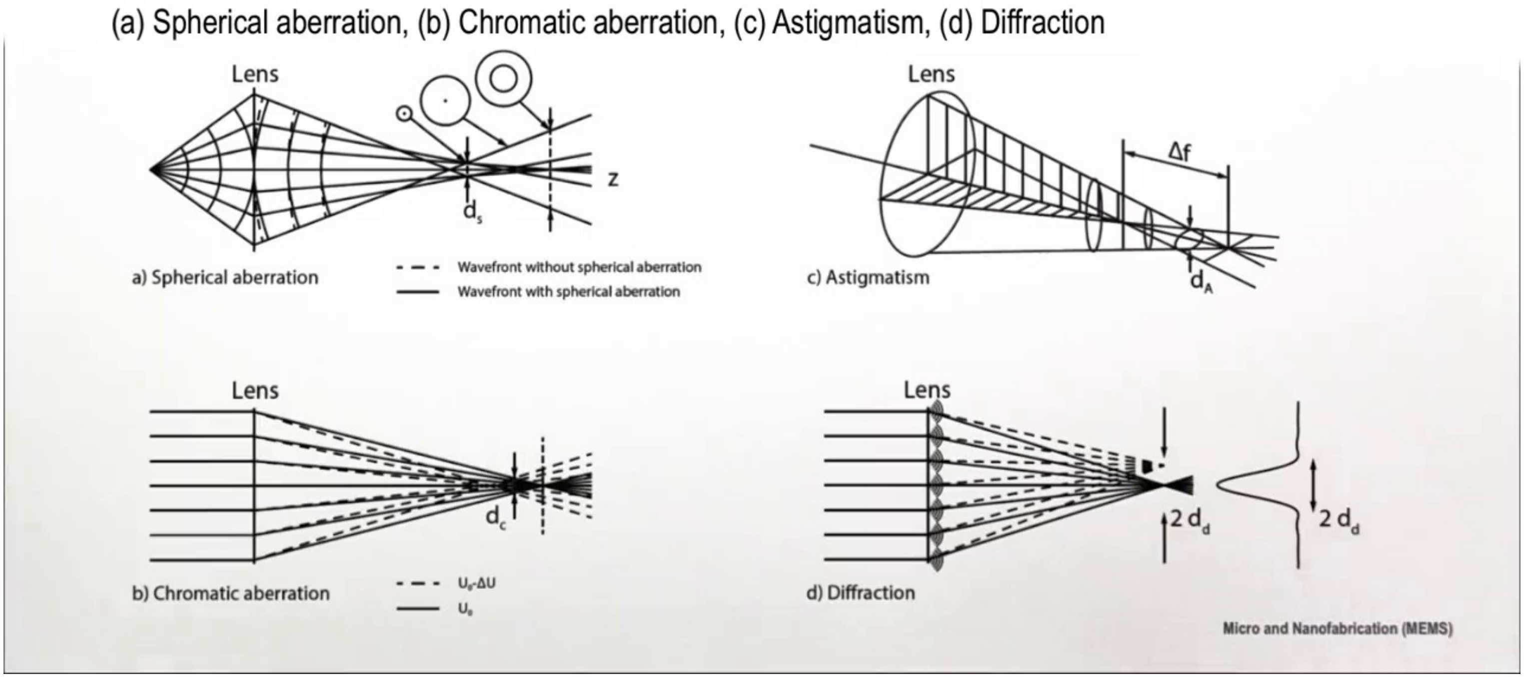
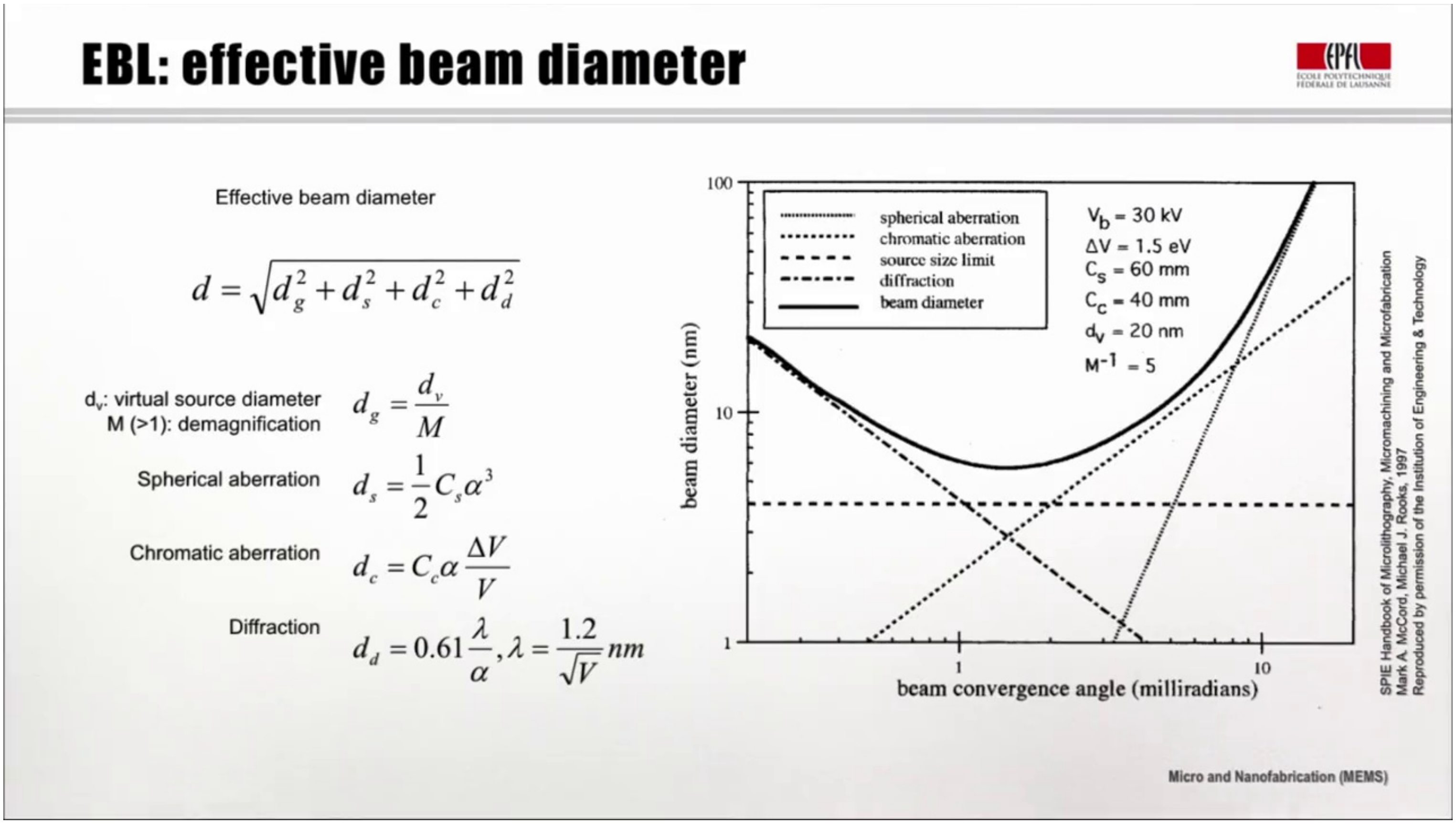


The electron gun choice has a large impact on the beam diameter. that is also called ”probe diameter”. As can be seen on the graphs here on the right, different gun types are compared where the probe current is displayed as a function of the probe diameter for two acceleration voltages, 30 kV here, and 1 kV down here. In EBL, one typically employs currents from a few hundred pico amps range, to several tens of hundreds of nano amps. As seen in the graphs, at these current values, the electron beam diameter undergoes large changes: from a few nanometers to several tens of nanometers. You can also see that these current diameter relations are not linear and they vary largely from one gun type to the other. Therefore, a good metric to compare gun types, is needed and introducing the concept of brightness or beta. It is defined as how much current is emitted per unit solid angle, per unit area of the emitting surface, described in this drawing here. This should be compared at equivalent acceleration voltages and takes into account beam current diameter and the incident angle on the sample. For example, thermionic emitters may have very high beam currents, shown here, but very low brightness, due to their large spot size. It is additionally important to be able to tune the electron beam so that one can write large features with a large beam and then use low currents to write the finer features.

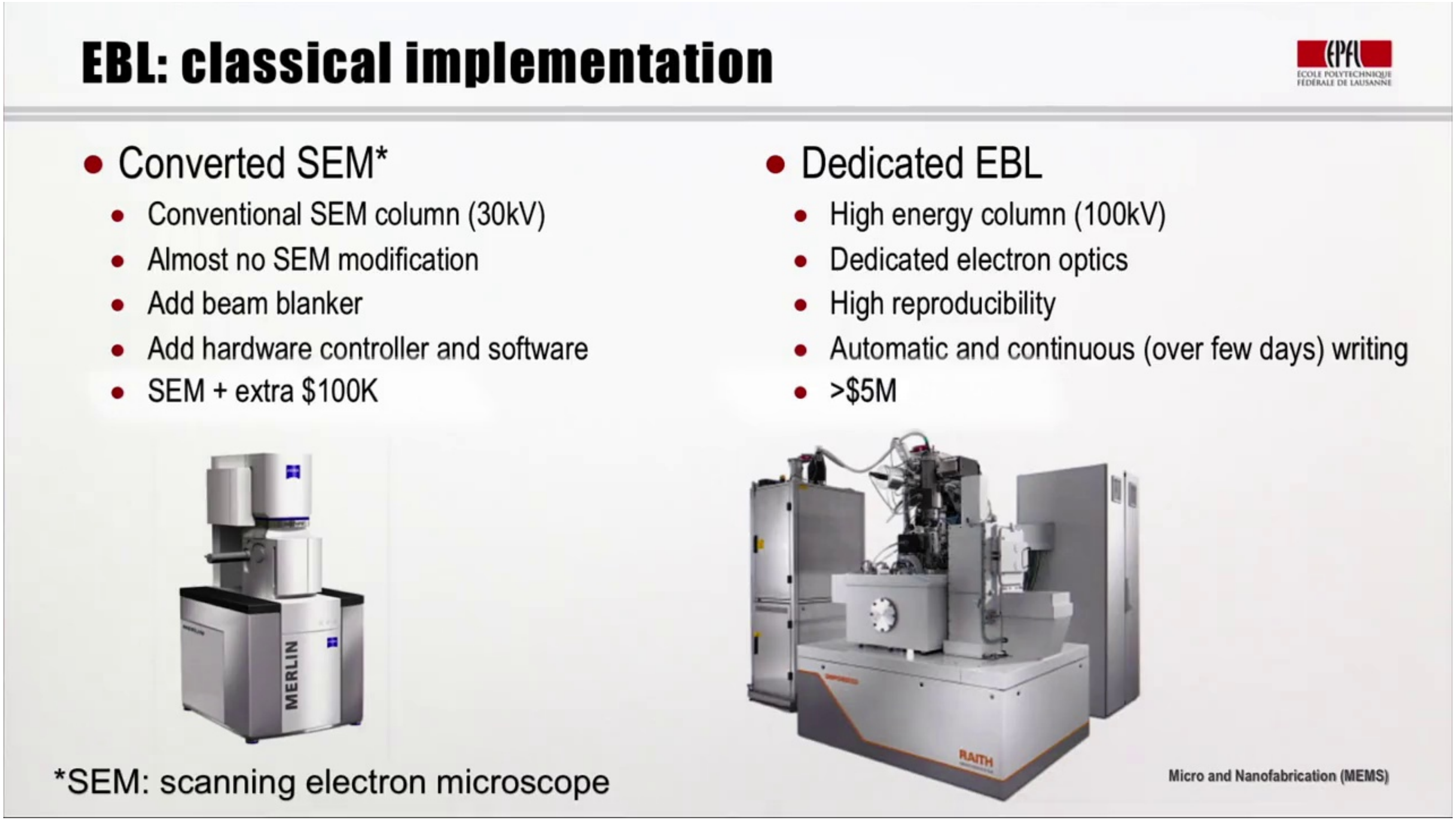
EBL: electron lens aberrations



Like in optical microscopy, a number of aberrations limit the ultimate resolution of the electron probe. There are 4 types of aberrations listed here from A to D. Spherical aberrations (a) are the result of an inhomogeneous focusing property, for electrons travelling on or off the axis. Chromatic aberrations (b) are the result of varying focus for electrons of different energy. Both of these aberrations can be minimized by reducing the convergence angle of the system so that electrons are confined to the center of the lenses, at the cost of greatly reduced beam current. Astigmatism (c) occurs when the electrons sense a non consistent magnetic field as they spiral around the optical x, which arises from construction errors. The result is a non symmetric beam cross-section. At low energies and with convergence angles, altered diffractions (d) may play a significant role, shown here.



The understanding of aberrations is essential to reach mininal effective beam diameters that enable high patterning resolutions. As you can see here on the graph on the right side, all the aberrations mentioned previously must be taken into account at once, also in relation with the beam convergence angle. In practice, the effective beam diameter is indeed expressed by the square root of each contribution squared and summed. Whereas the virtual source size limit does not depend on the beam convergence angle, this line here. Chromatic and spherical aberrations obviously increase with greater convergence angle. This relation is inverted for diffraction. Reaching an optimal work configuration requires the optimization of all contributions rather than seeking the individual minimization. Notably, and in relation to the previous slides, each aberration and contribution to the final beam diameter are subject to additional parameters other than the beam convergence angle and may be optimized in part independently by the instrument design or choice of acceleration voltage.



Electron beam lithography tools for research can be configured in 2 ways: one is to convert a scanning electron microscope SEM, here on the left side, as a scanning electron microscope already includes the main elements required to perform lithography. The only component that needs to be added is the pattern generator. It consists of a beam blanker to switch on and off the beam, as it raster scans the sample, as well as a computer control. These low cost EBL systems are typically using acceleration voltages of 30 kV and they do not benefit from the advantages of a dedicated EBL column in terms of speed and stability. So, dedicated EBL tools operate at a higher voltage, up to 100 kV, and allow for high throughput and stability. They have higher costs of several millions of euros - but they are essential and needed for mask writing in deep UV masks and nano-science research.