



Mastering AVI

Part2: Introduction to technical principles of automated inspection machines

- Camera systems / light / motion
- Image processing and database system
- Interlinkage of parameters:
 - Speed, Rotation speed, Inspection parameters,
 - Detection probability, False reject rate
- Properties, capabilities and limitations of automated inspection systems
- Scope of Automated Visual Inspection
 - Critical design elements

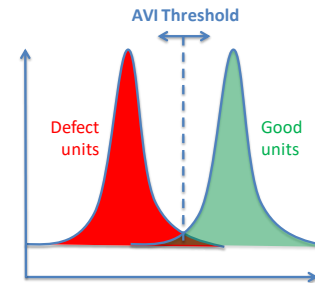


Instructor Lead: Romain Veillon / Fernand Koert / Sébastien Koch

Mastering Automated Visual Inspection

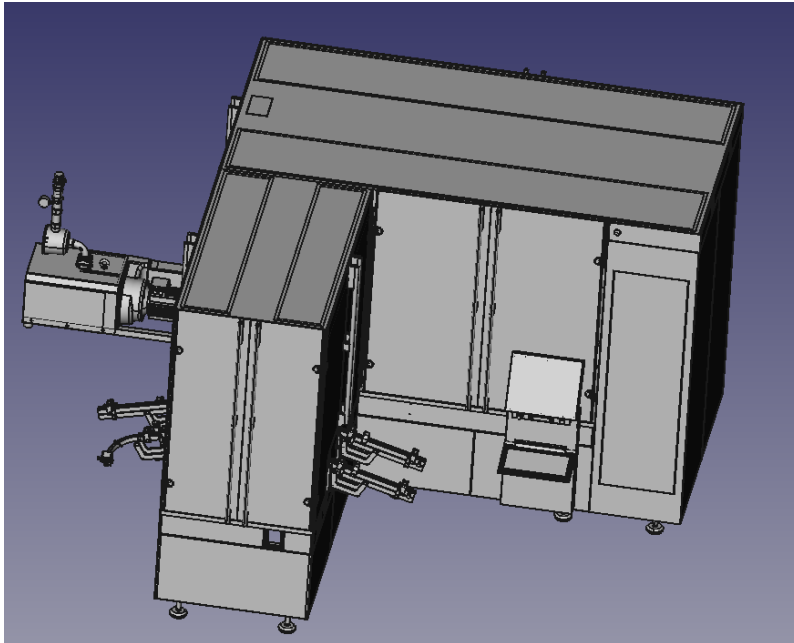
Part 2: Introduction to technical principles of automated inspection machines

- Process / People to master AVI
- Functionality of automated inspection machines
- Camera systems / light / motion
- Image processing and database system
- Interlink age of parameters
 - Speed
 - Rotation speed
 - Inspection parameters
 - Detection probability
 - False reject rate
- Properties, capabilities and limitations of automated inspection systems
- Scope of Automated Visual Inspection

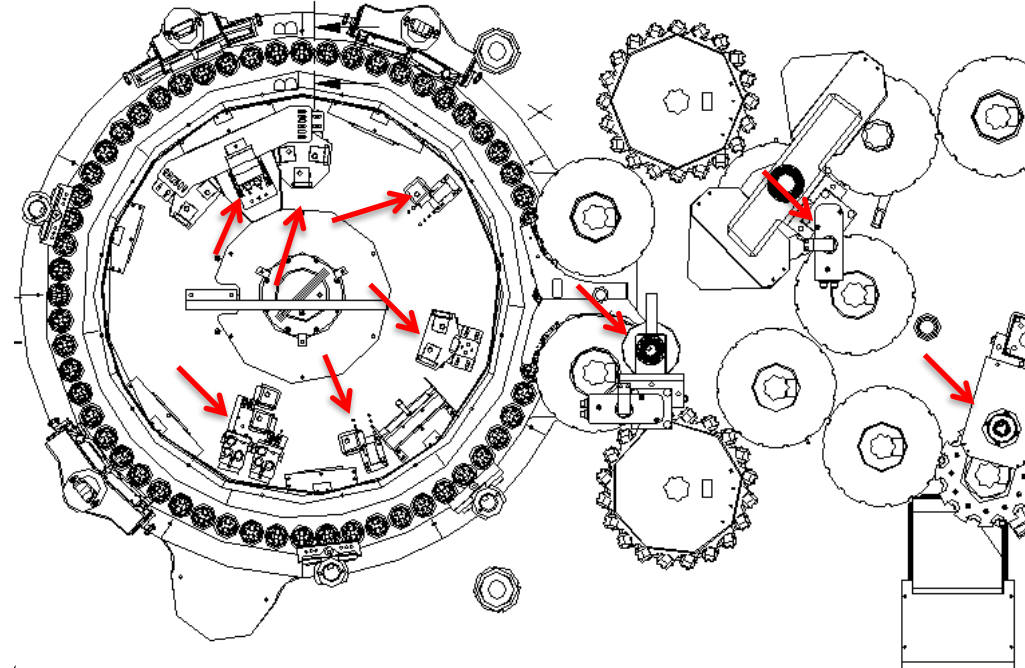


General intro

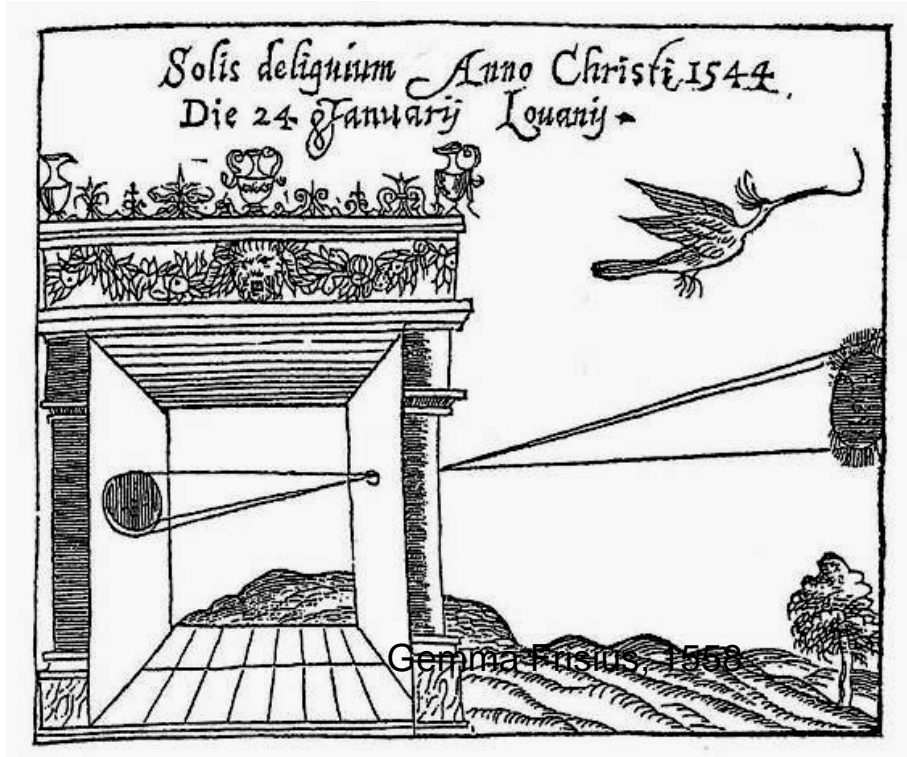
Is it just a black box ? Need for transparency / explain ability



Certainly, no more!!



inspection machines Some milestones



“...and we call invisible, either what is absolutely – as we consider impossible in other cases -, Or what is visible by its inherent nature, but in fact it may only be hardly visible or invisible »

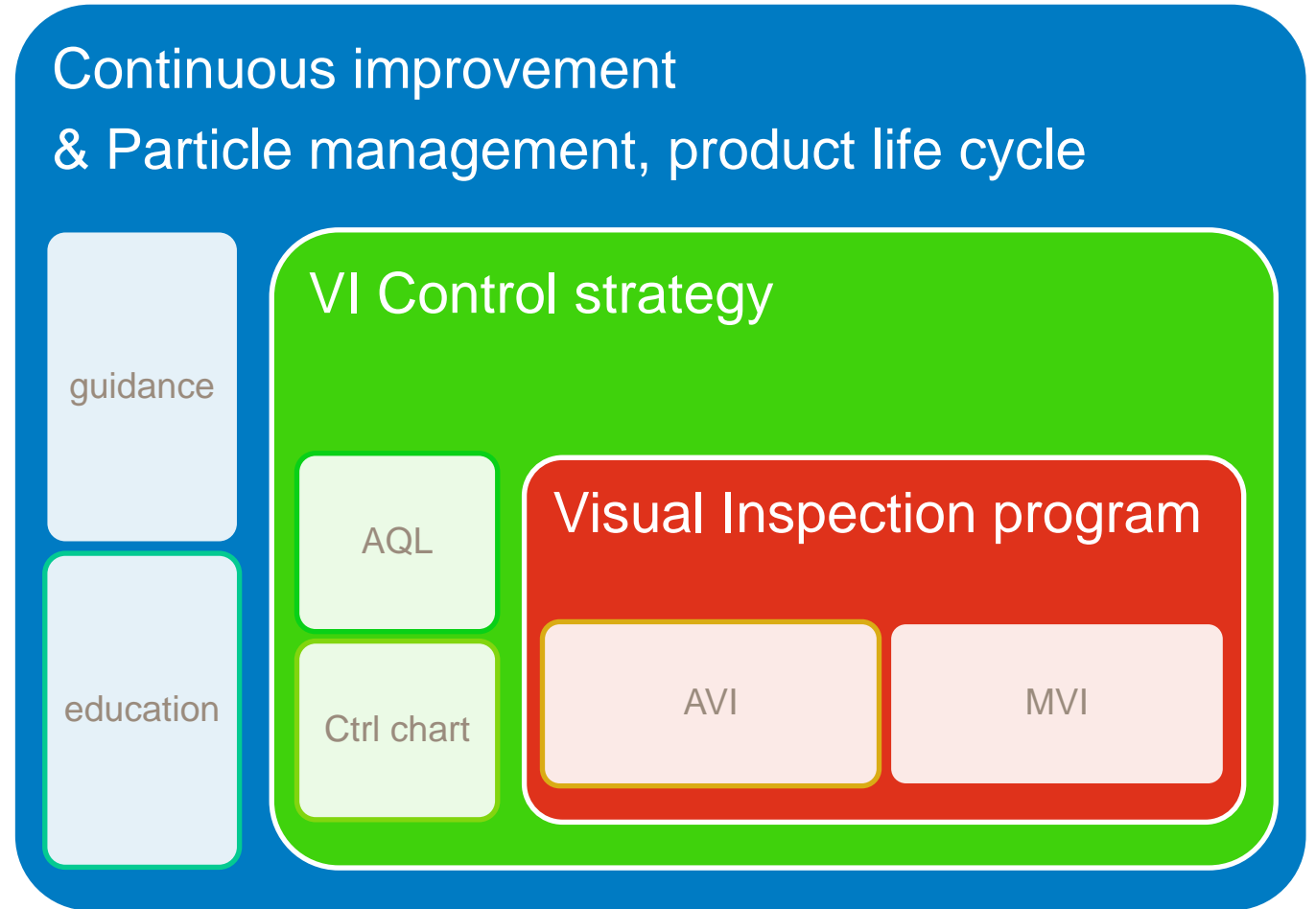
Aristotle, De Anima, Book 2, 10

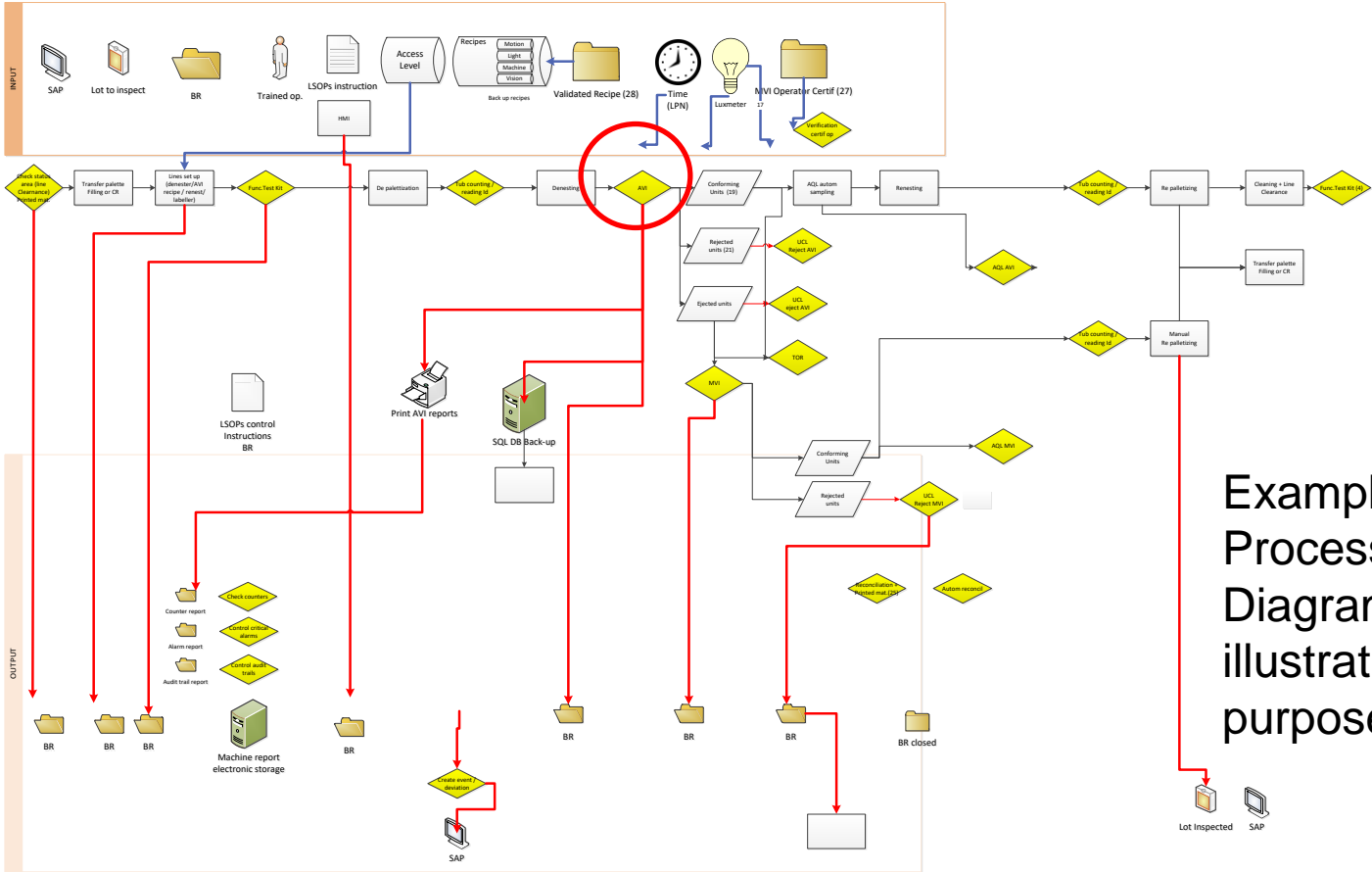
Camera Obscura

- Basic principle Aristotle (384-322 BCE)
- Drawing aid for artists: described by Leonardo da Vinci (1452-1519)
-first industrial CCD camera 1975
- 2022 AVI

Visual inspection program in 3 layers:

- ❑ -The Core is AVI/MVI program, with strategy for DML / standard work / certification / validation
- ❑ -The control strategy with ctrl chart and AQL guarantees that VI is kept under control
- ❑ -Continuous improvement is the goal of all VI activities with CAPA management. The Particle management guidance is a key to success with particle control and associated WOW & education, product life cycle approach





Example of a Process Flow Diagram for illustration purpose

For AVI masteryPeople mgnt is a key ! Need to have landing conditions for equipment / Process

Best in class organization for VI (People mgnt)

Transformation is not only buying a machine, but build a team/organization for VI

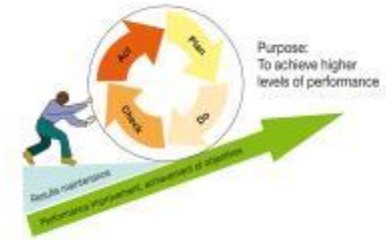
- develop operators / supervisors
- develop maintenance (calib./mech./vision)
- develop automation support
- opportunity to develop vision experts / Ext.
- develop a team to supply kits or externalize
- develop AQL quality team
- develop control chart tools & SPC team
- develop defect id. / externalize



CAPABILITY MNGT IS KEY

And change mindset by generating a feedback loop and involve the filling & Quality department

Loop with USP<1790> ultimate goal of VI
is continuous improvement



Let's reflect of Quality attributes ?



- what are your CQAs / CPPs for VI process ?

Some CQAs may be proposed:

Can you list some of them ?

- CQAs: Critical quality attributes
=> think about USP<1790>....
- CPPs: Critical process parameters
- CDEs: Critical Design elements
- PA Performance Attribute

Attributes						
CQA	CQA	CQA	CQA	CQA	CQA	PA
Identity	Essentially free of glass Defect/Particles/Stopper defect/Closure defec. fill level/Empty/Lyo defect	Leak absence	Container Integrity	Stength, Potency	Potency (sheer stress)	Equipment Performance

Core parts of AVI



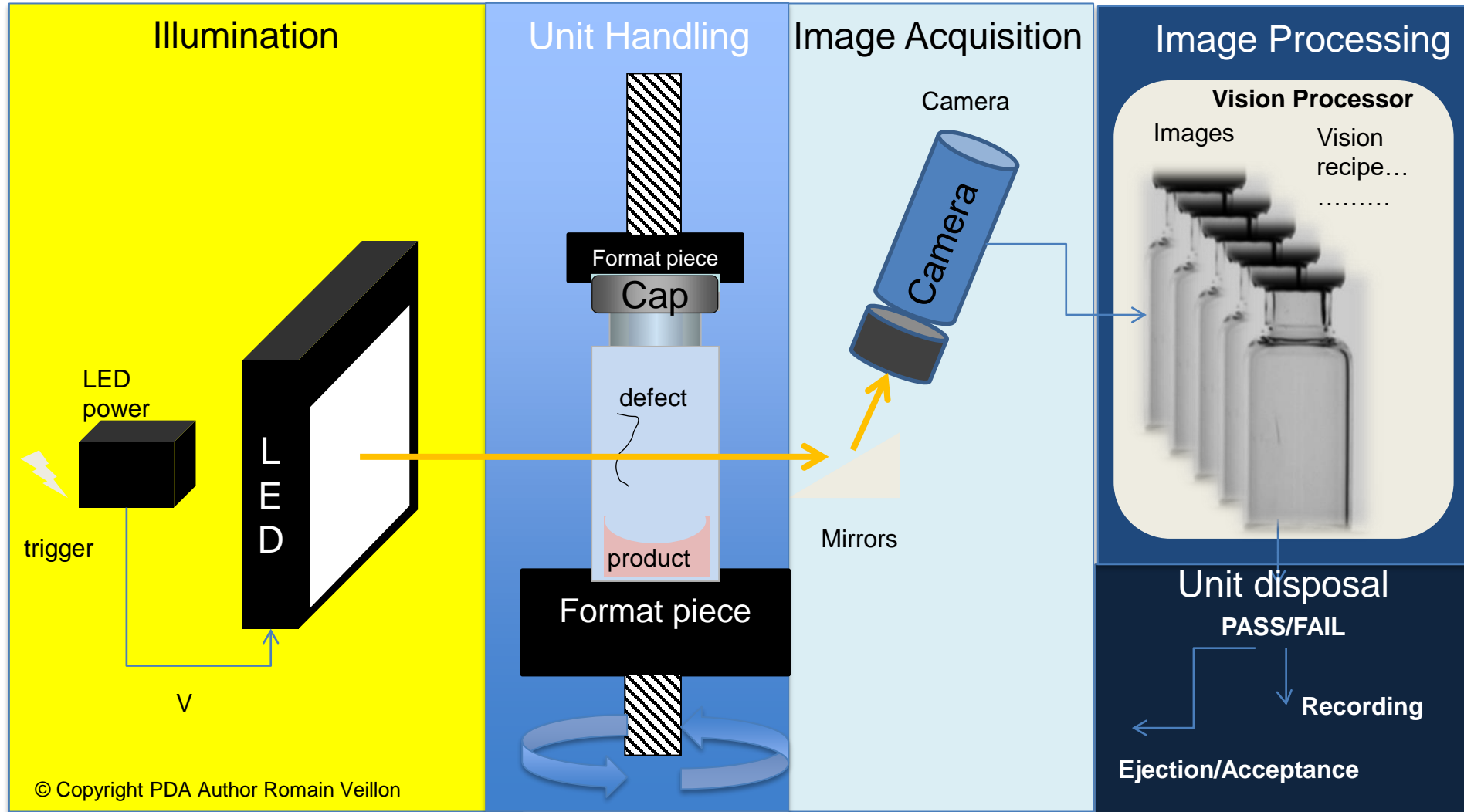
Motion of units



Light illumination

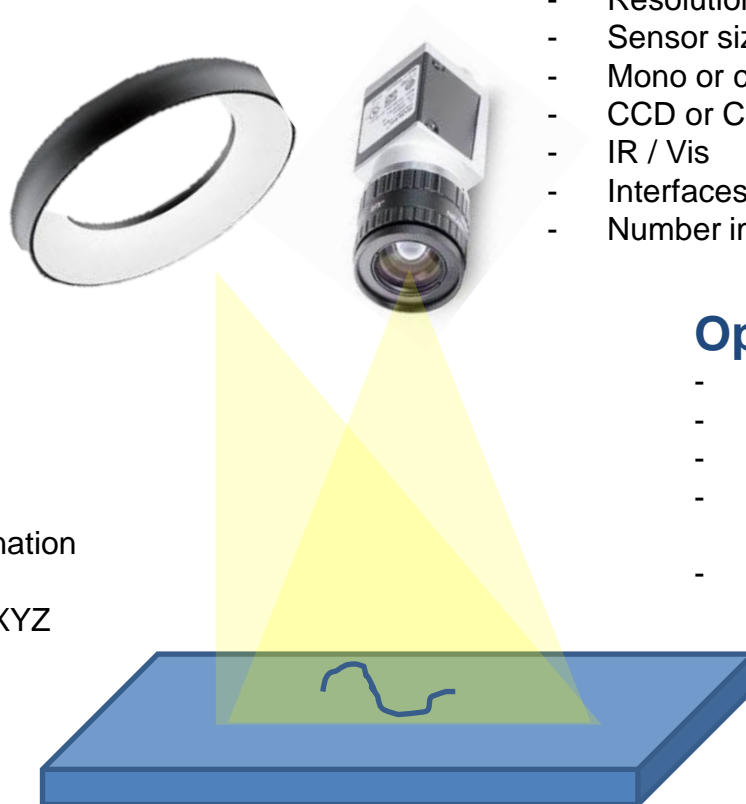


Digital image processing



Lightning

- Shape
- Distance
- Color
- Type illumination
- Intensity
- Alignment XYZ



Camera Sensor

- Resolution
- Sensor size
- Mono or color
- CCD or CMOS
- IR / Vis
- Interfaces
- Number image

Optics

- Focus
- Focal length
- Field of view
- Chromatic aberration
- Stability of tuning

Machine vision

- Digital image processing
- Speed
- Software
- Vision processing
- Learning type
- Access level
- Image archiving

AVI machine

- Automation
- Fail safe design
- Environment (dust, temperature....)
- Holding time
- Vials/syringe
- Closure design
- Glass suppliers

Object to inspect

- Size
- Geometry
- Surface
- Material
- Color / transparency
- rheology

1. Unit presentation to camera by mechanical handling
2. Unit presentation to camera with product rotation
3. Unit presentation to camera with glass & product dependent parameters
4. Refeed transport mode
5. Lightning to camera
6. Image acquisition
7. Digital Image Processing
8. Result transfer to shift register
9. Physical unit ejection
10. Inspection result archiving (ex SQL)
11. Batch closure and local report creation
12. Central reporting & archiving

Object presentation to camera

Different ways of conveying:

Intermittent rotary CMP : <https://www.youtube.com/watch?v=H55CQj1JsNI>

Linear Continuous Heuft: <https://www.youtube.com/watch?v=5BCChqQZFac>

Bottom gripper Rotary continuous: <https://www.youtube.com/watch?v=xC2ed0Tu2NU>

handling syringes: <https://www.youtube.com/watch?v=GlojLwZeX0o>

Side clip conveyor Innoscan: <https://www.youtube.com/watch?v=5oueC3ilxY>

Top gripper ATS Lyo : <https://www.youtube.com/watch?v=opscAQFk1sM>

Brevetti Continuous mvt + up and go moving arm: <https://www.youtube.com/watch?v=XkiKzSL-bfw>

Innoscan continuous mvt + fixed VI + oscillating mirror piezo:

<https://www.youtube.com/watch?v=mw3UU9wPwKo>

Vacuum wheels suckers Seideander: <https://www.youtube.com/watch?v=2g4RABopl1k>

Pre Spin turret Syntegon: <https://www.youtube.com/watch?v=s31mC8rFwZk>

Wilco mechanical conveyor: <https://www.youtube.com/watch?v=7MiQVALsRCo>

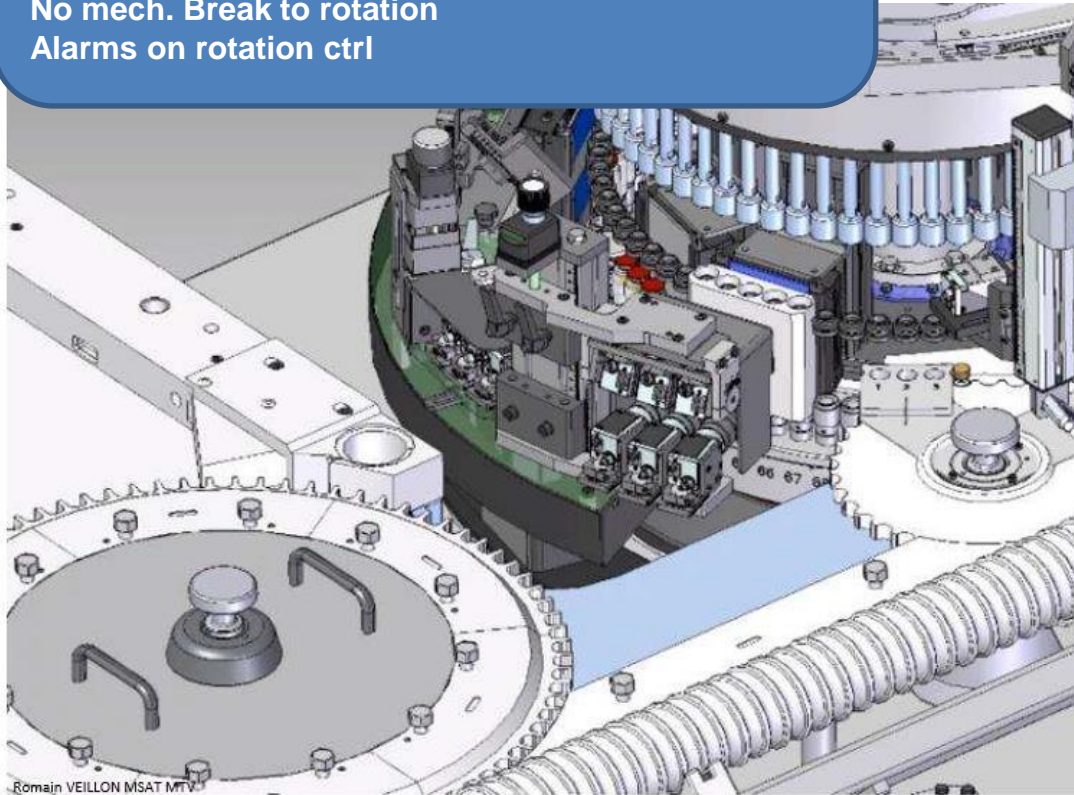
Base holder / Gripper / sucker

Those are pieces with ageing / regular checks / changes

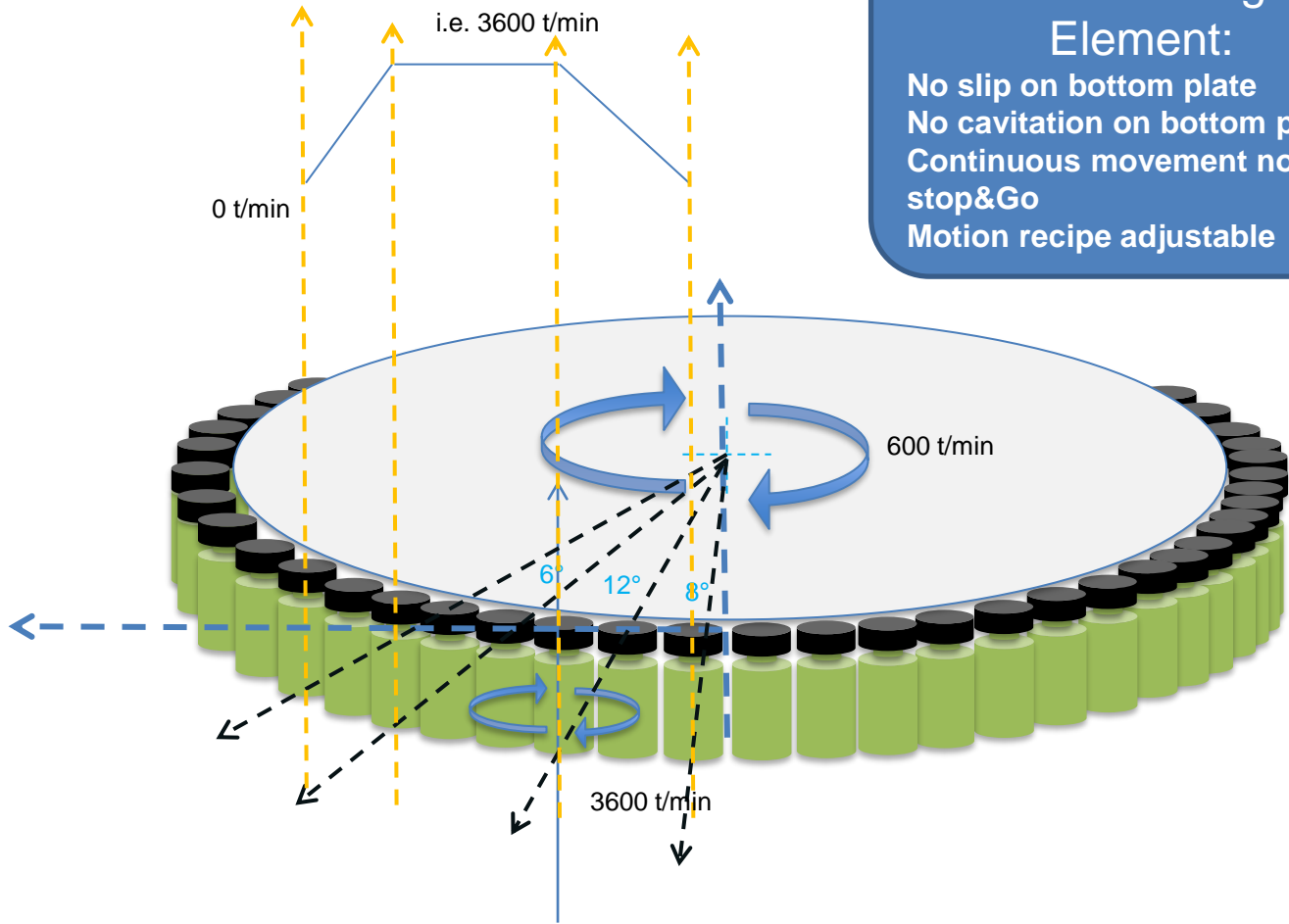
Critical Design
Element:

Mechanical stability of AVI
Axial Rotation no cavitation
Aging parts maintenance

Critical Design Element:
Bottom and top carousel aligned
Pressure top caroussel
Mechanical fitting bottom ring
No loose in X Y
No mech. Break to rotation
Alarms on rotation ctrl

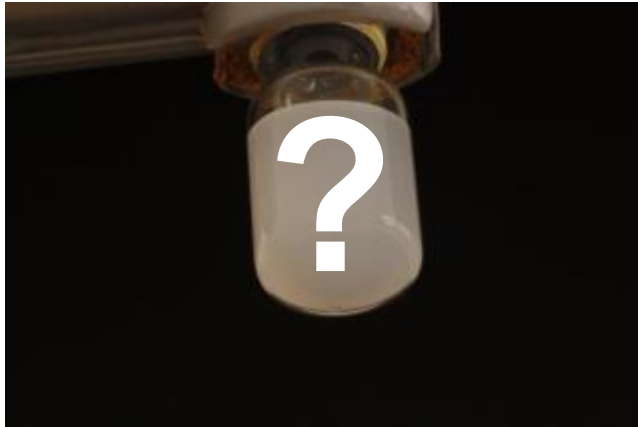


Critical Design Element:
 No slip on bottom plate
 No cavitation on bottom plate
 Continuous movement no stop&Go
 Motion recipe adjustable



Key learning: Modern AVI machine is very complex in term of unit motion;
Double motion main
 - carousel rotation
 - each unit individual fast rotation
 + all synchronized to image acquisition every few ms





How to inspect Automatically a suspension that has a high optical density + scattering?

= Fast rotation To present liquid in thin layer

- ⇒ Lower optical path (density beer lambert)
- ⇒ Minimized scattering effect



0 t/min



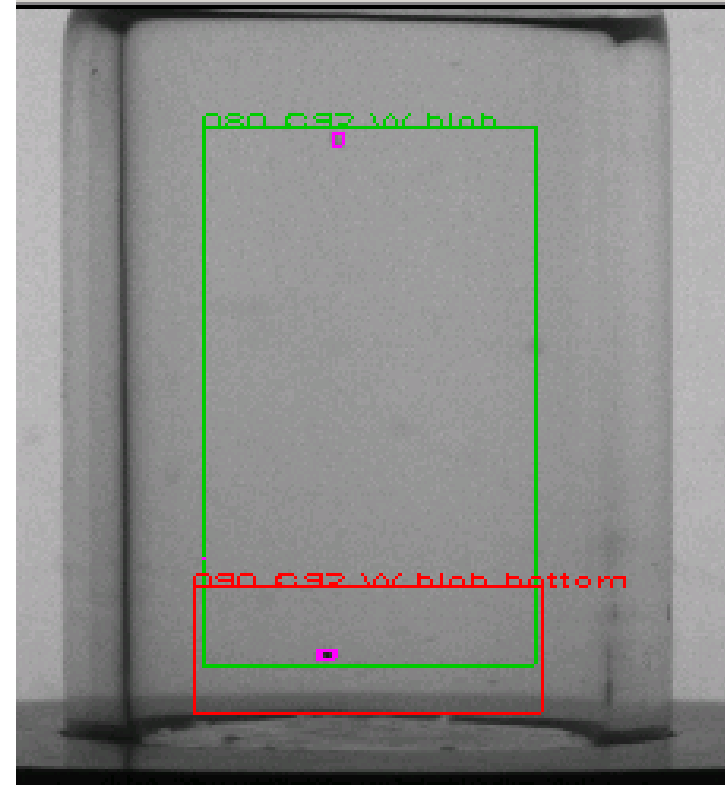
600 t/min



1800 t/min



3600 t/min



1000 images Conform overlaid



Conform images are clearly shifted to the left and more shaky

1000 Crack image overlaid



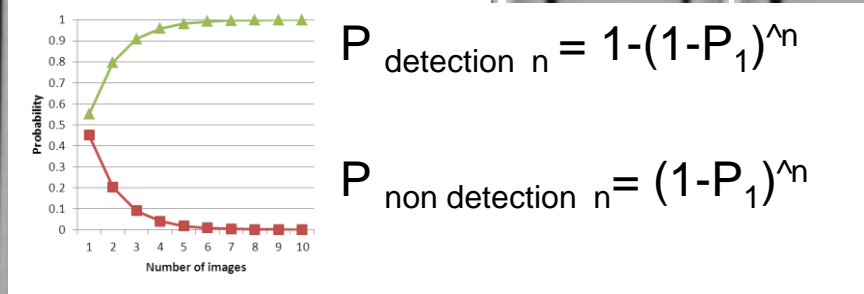
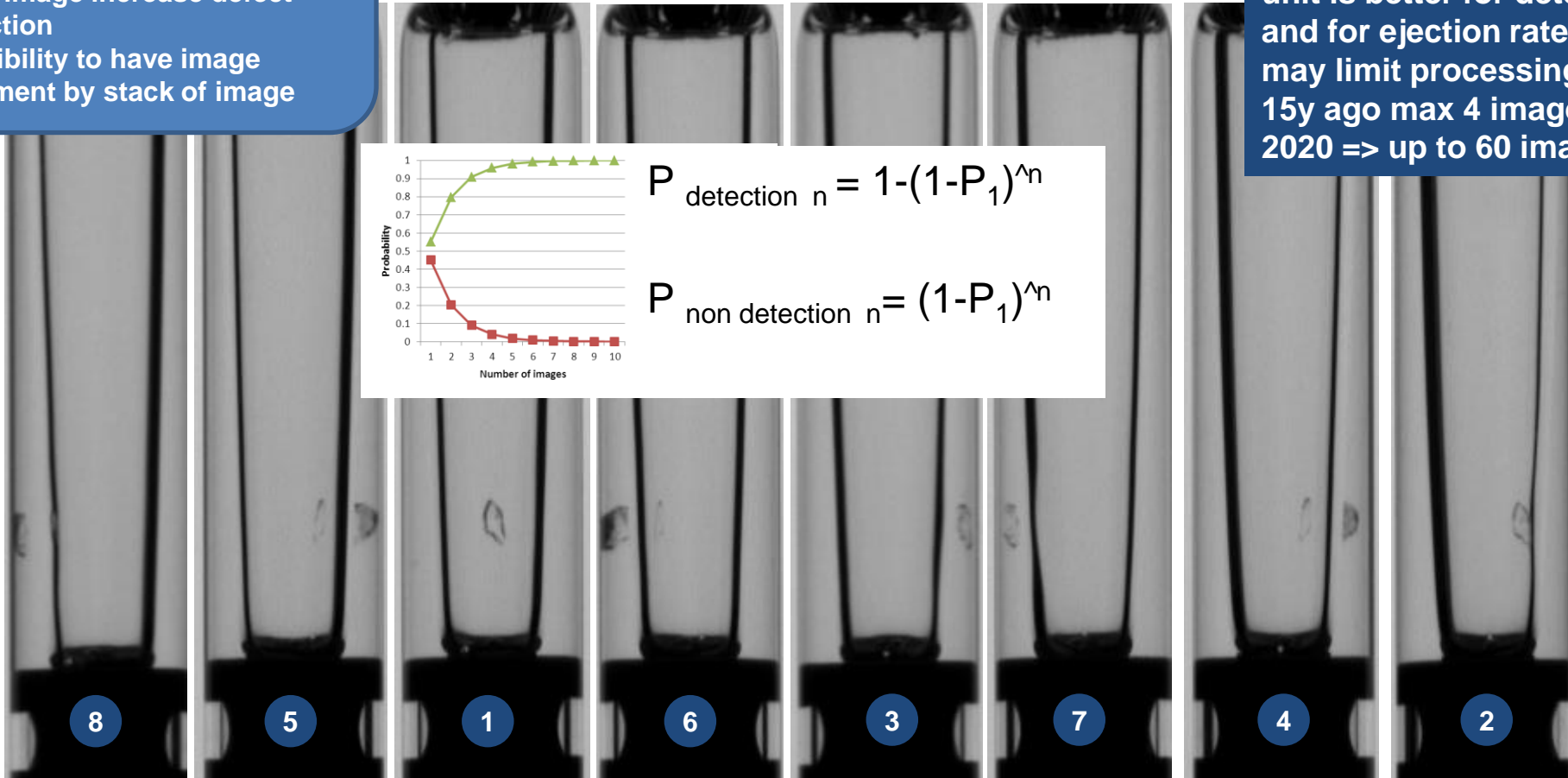
Crack images are more stable

Critical Design Element:
Fast spin requires strict mechanical alignment
Need to have some periodic control of axial rotation with no cavitation

Critical Design Element:

More image increase defect detection
Possibility to have image treatment by stack of image

Key learning: more images per unit is better for detection rate and for ejection rate, but this may limit processing time
15y ago max 4 images
2020 => up to 60 images/unit



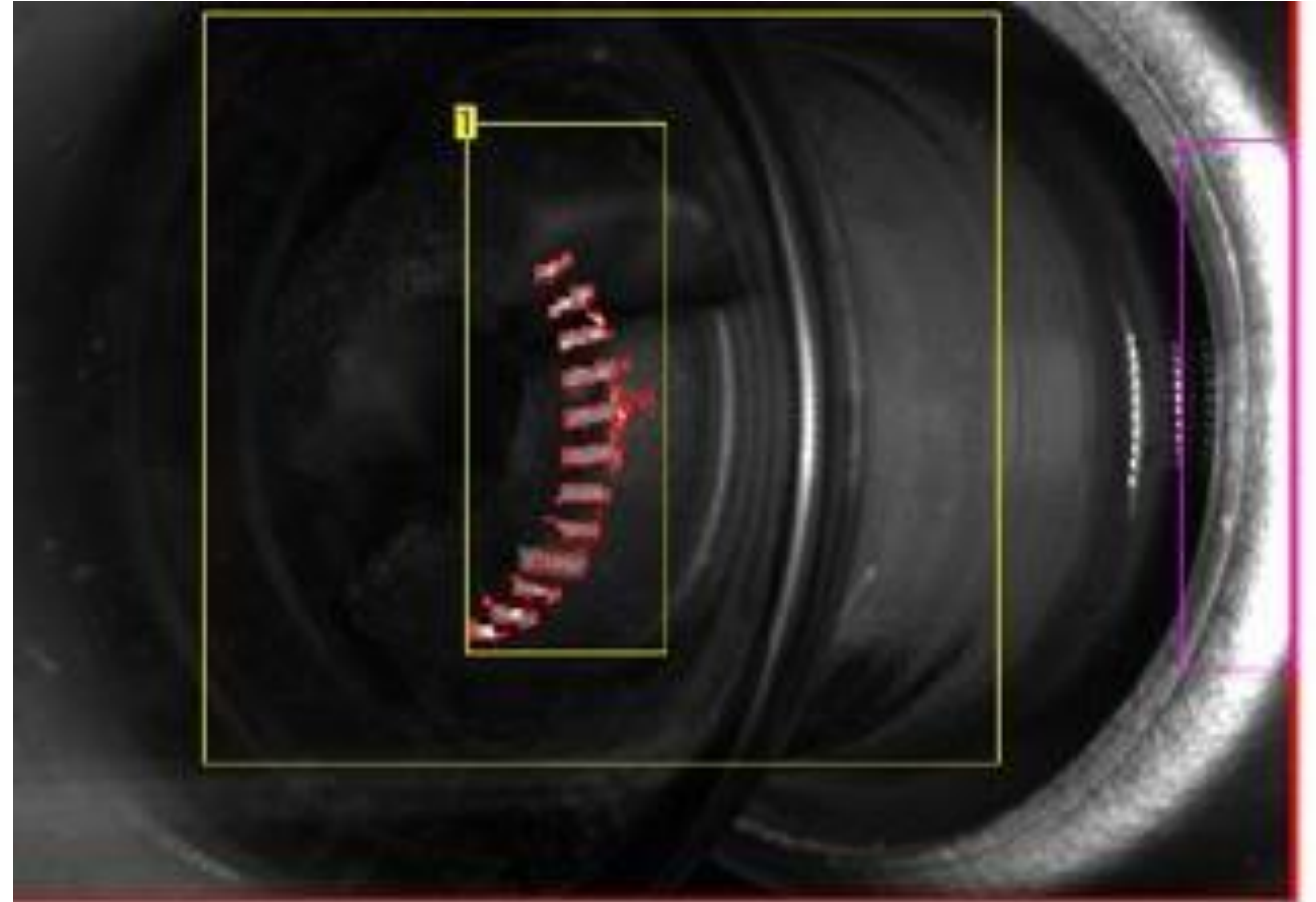
$$P_{\text{detection } n} = 1 - (1 - P_1)^n$$

$$P_{\text{non detection } n} = (1 - P_1)^n$$

Critical Design Element:

More image increase defect detection and lower false reject

Possibility to have image treatment by stack of image



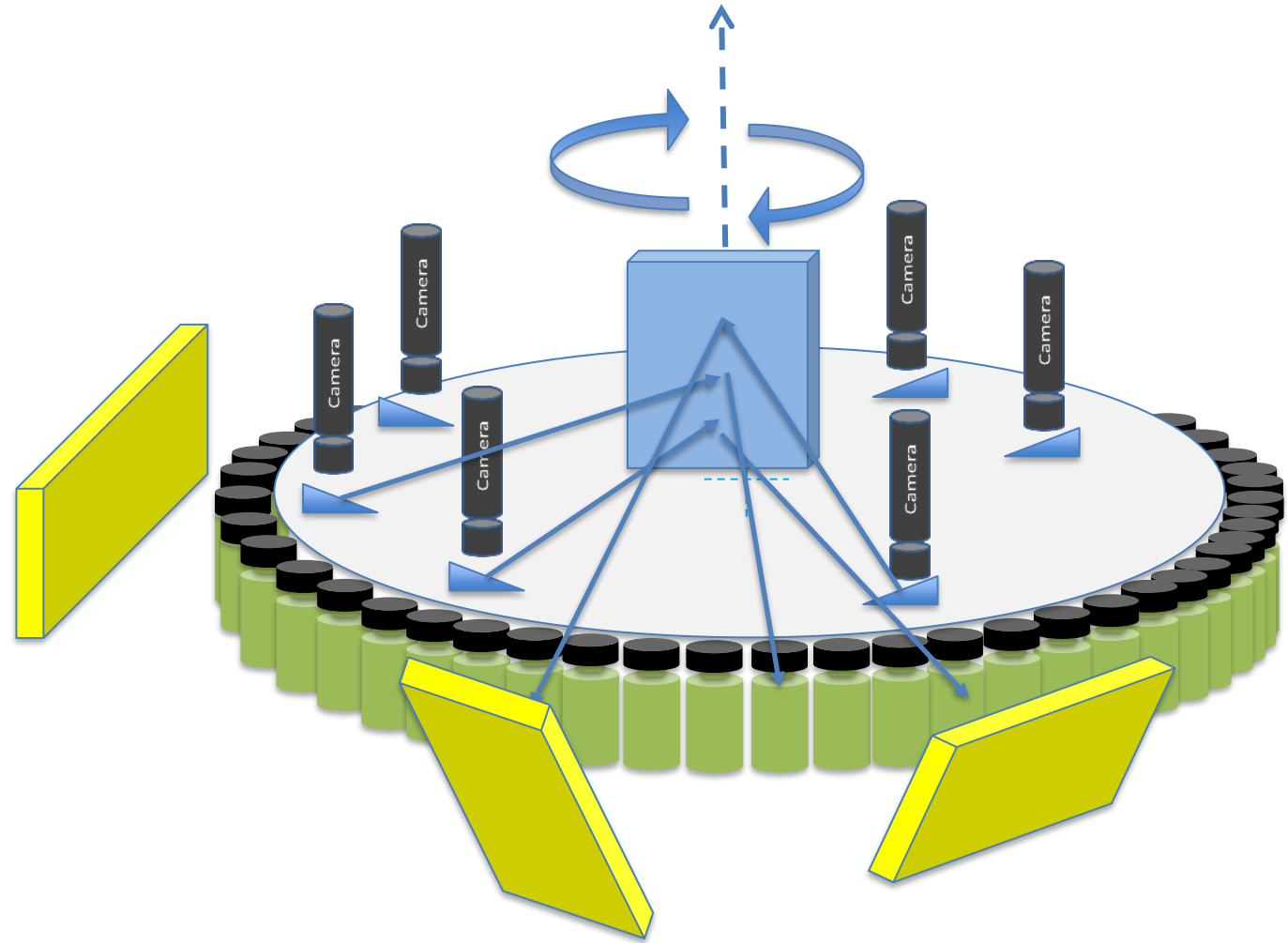
1 Central moving
Mirror

1 torque moving arm
for LED / cameras

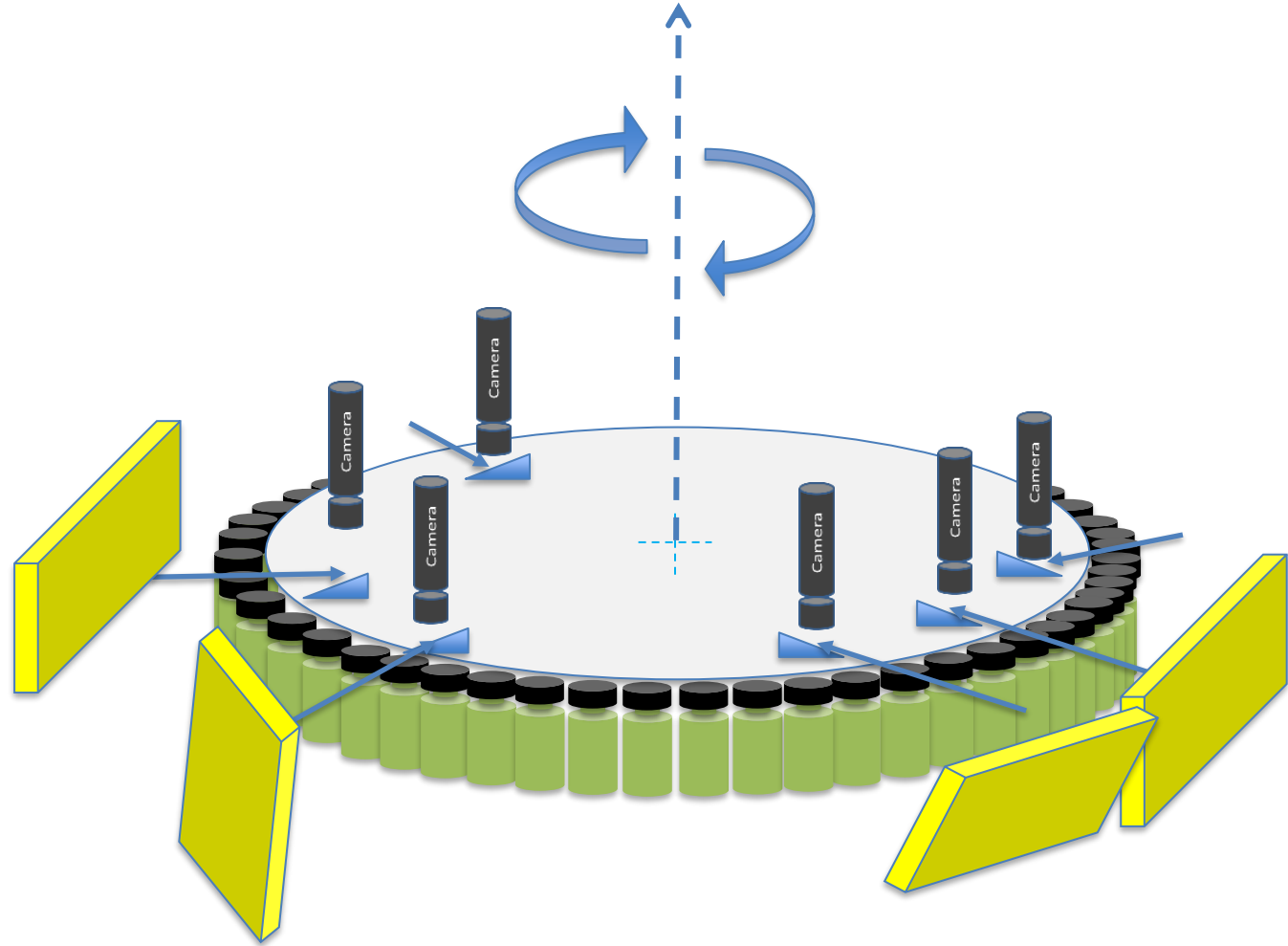
1 piezo oscillating
mirror on each
camera station

Fixed camera larger
field of view

1 Central moving
Mirror



1 torque moving arm
for LED / cameras



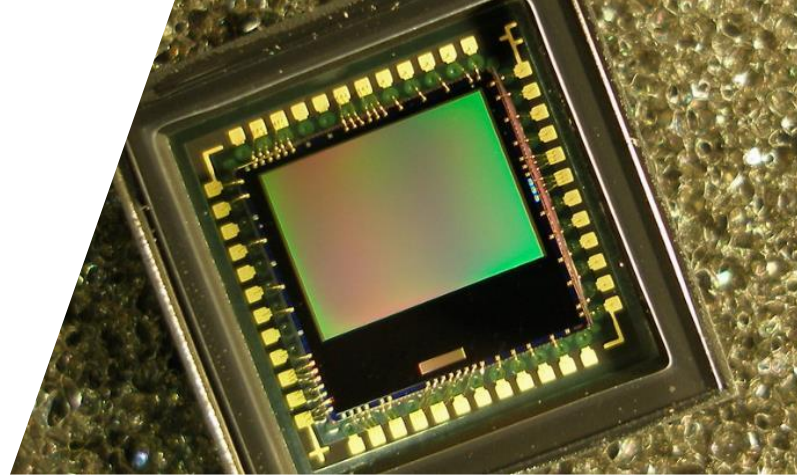
Camera and image acquisition



- Integration
- Transfert
- Amplification

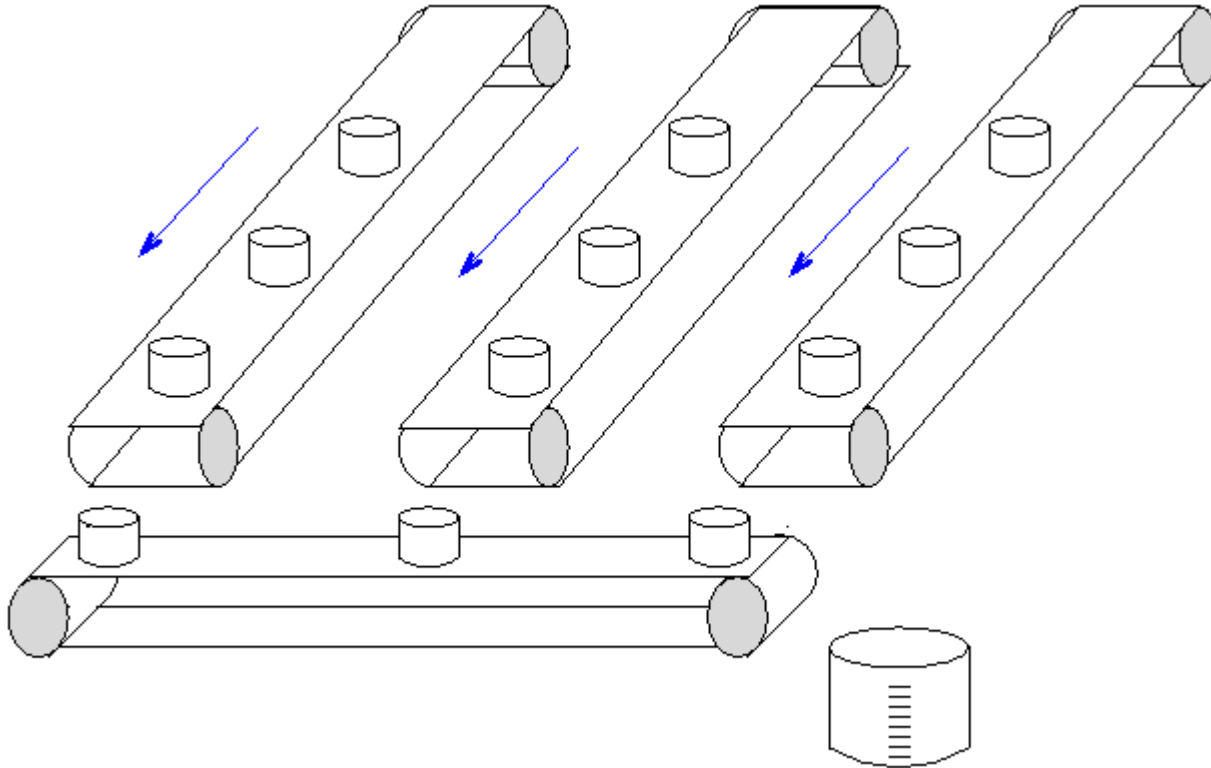
[Further Deep Dive:
https://www.baslerweb.com/en/vision-campus/](https://www.baslerweb.com/en/vision-campus/)

- **Matrixial Sensor : X and Y image**



- **Linear Sensor = Line Scan**



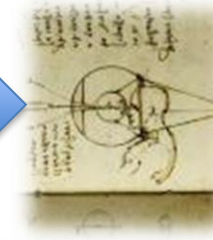


https://youtu.be/ZwN0DT_4FhY

MVI

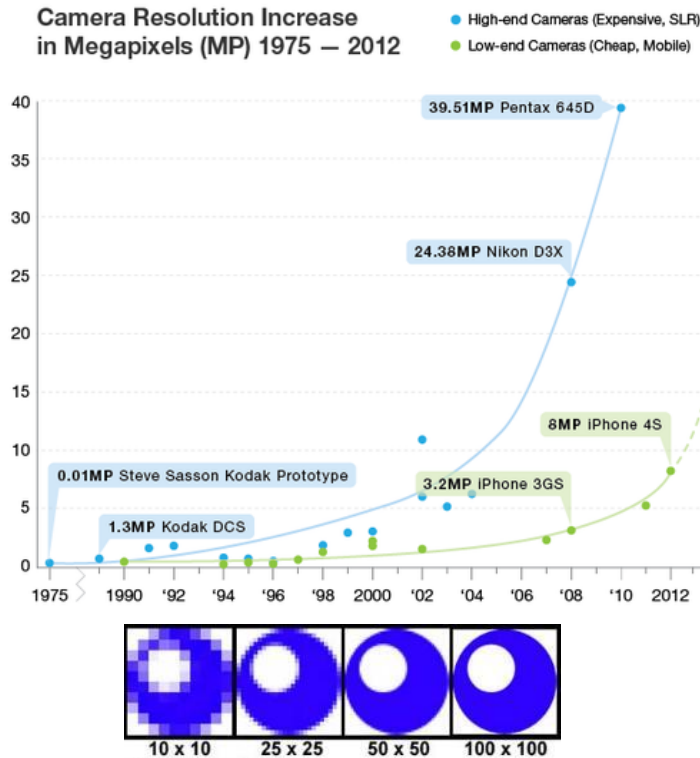


11µm per cone/6^{E6} Cones/ LOD 50-150µm particle

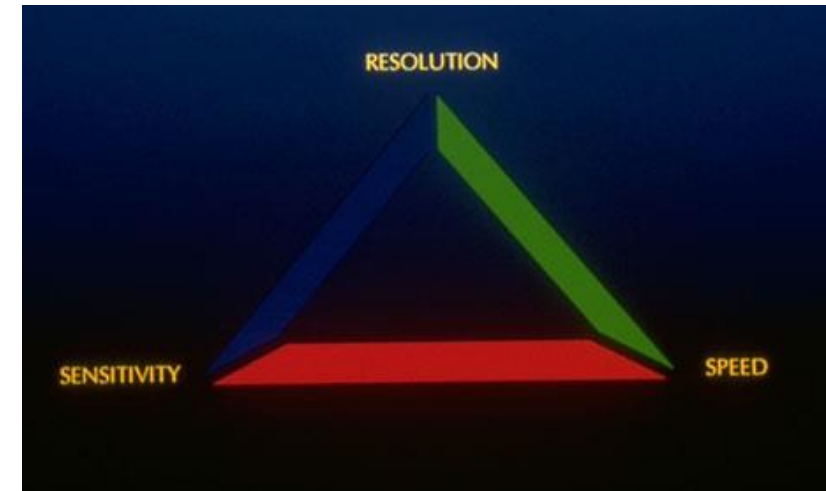


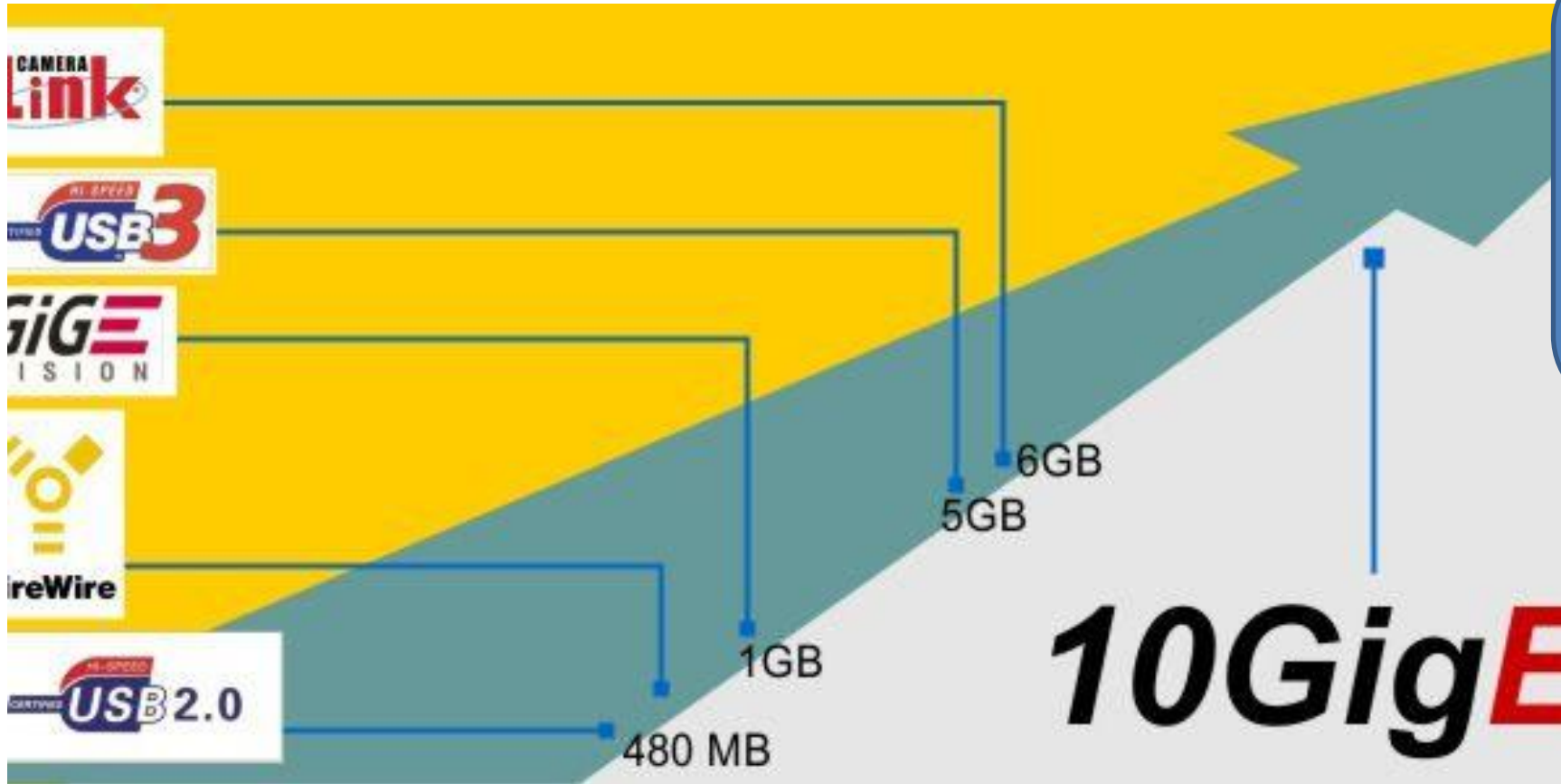
2022
2-5 MP
6µm / pixel
48 images
/unit
128FPS

AVI



Critical Design Element:
 Today compromise between performance / speed
 Availability on the market
 sustainability





Critical Design Element:
1 GigE bus on a vision computer is limiting for 3 or 4 camera
The design of com card is critical to handle a fast transfer mode
Some camera have now more than 100 FPS

The screenshot displays the pylon Viewer 64-Bit software interface. On the left, the 'Devices' panel shows two GigE cameras: 'Basler acA2500-20gm (21694230)' and 'Basler acA4024-29uc (22223214)'. The 'Features' panel for the selected camera shows various settings like Noise Reduction (2,0), Sharpness Enhancement (3,98438), Hue (0), and Saturation (1,0). The main view shows two camera feeds: the top one displays a grayscale image with a crosshair, and the bottom one shows a color image with a grid. A histogram on the right shows the distribution of gray values. The bottom panel is a 'Message Log' with the following entries:

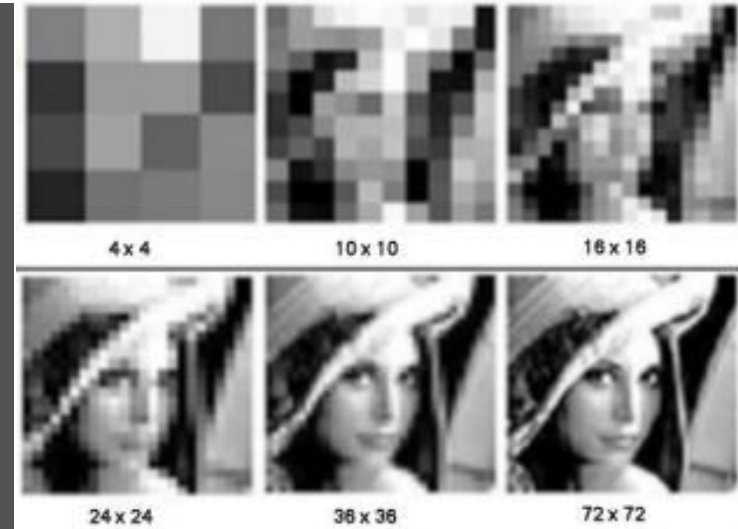
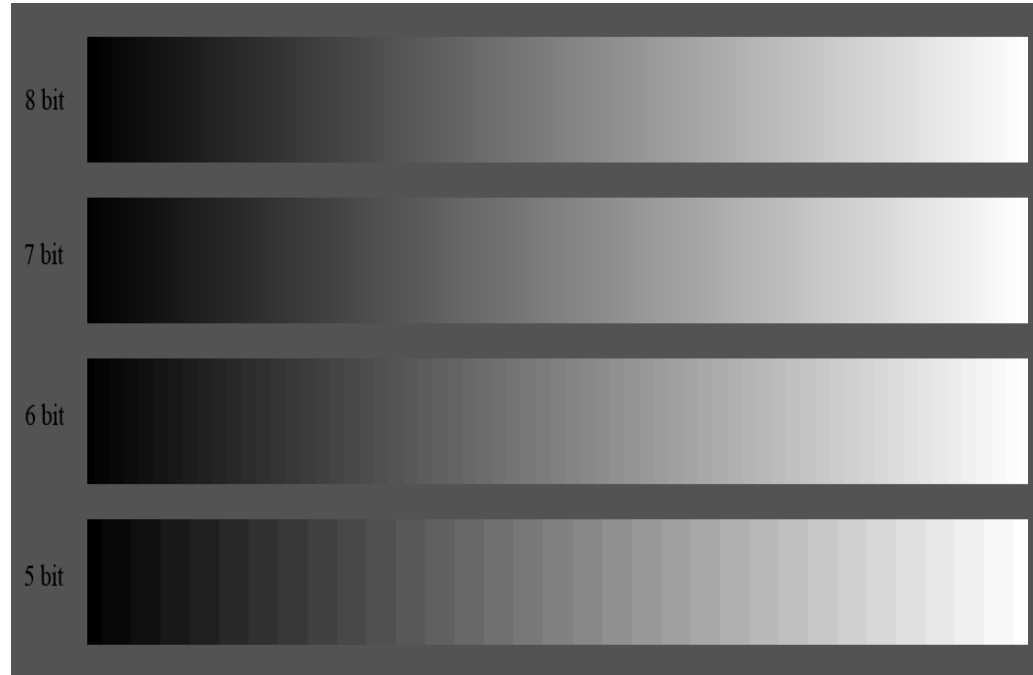
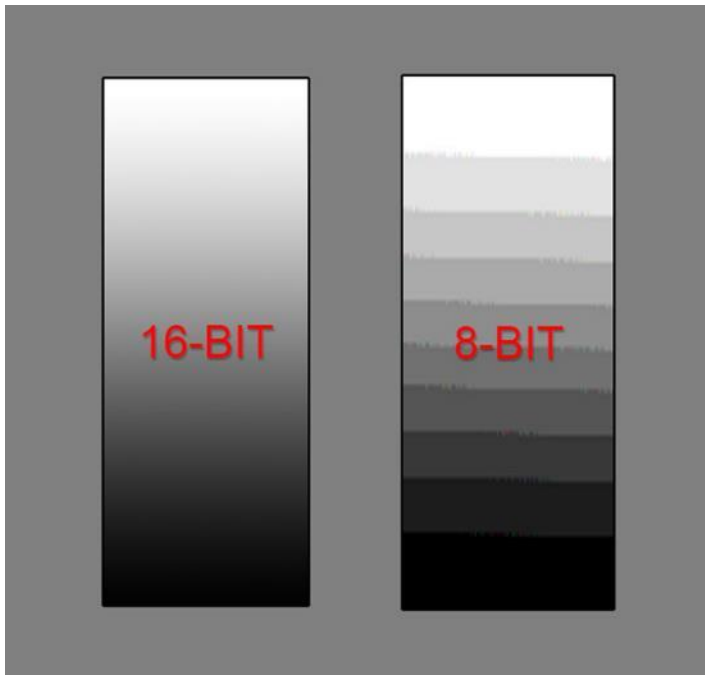
Level	Time	Source	Message
Information	2018-08-06 16:4...	Basler Emulation ...	"Basler Emulation (0815-0000)" has been detected.
Information	2018-08-06 16:4...	Basler acA2500-2...	"Basler acA2500-20gm (21694230)" has been detected.
Information	2018-08-06 16:4...	Basler acA4024-2...	"Basler acA4024-29uc (22223214)" has been detected.
Information	2018-08-06 16:4...	pylon Viewer	pylon Viewer 5.1.0.12636 64-Bit has been started.

Critical Design Element:
GigE camera have tones of parameters....
Need to control those parameters with access ctrl

Key learning:
Tonal resolution in bit
Spatial resolution in pixel

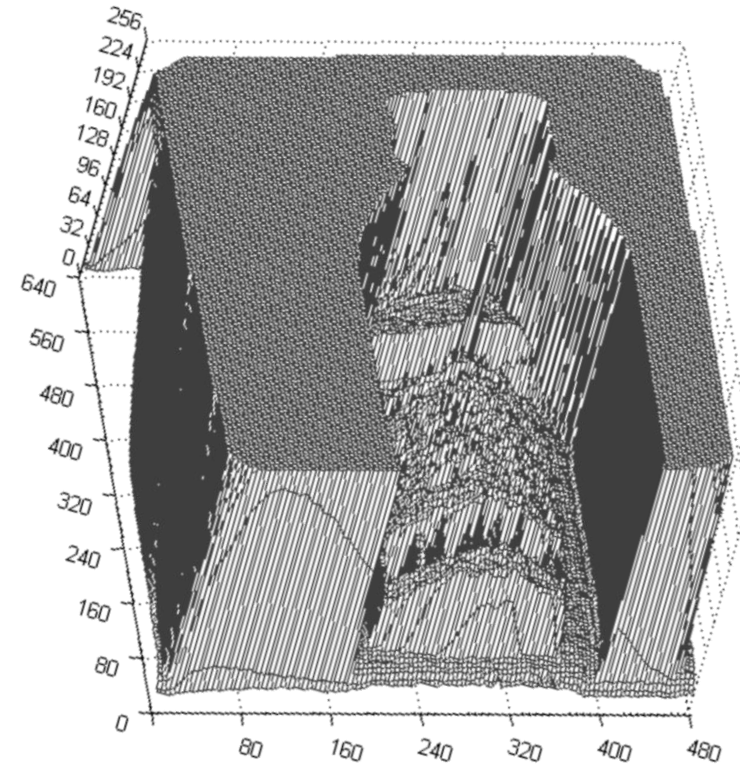
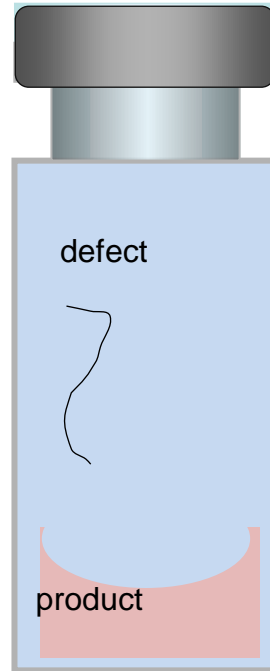
tonal resolution in bit

Spatial resolution



Variable:

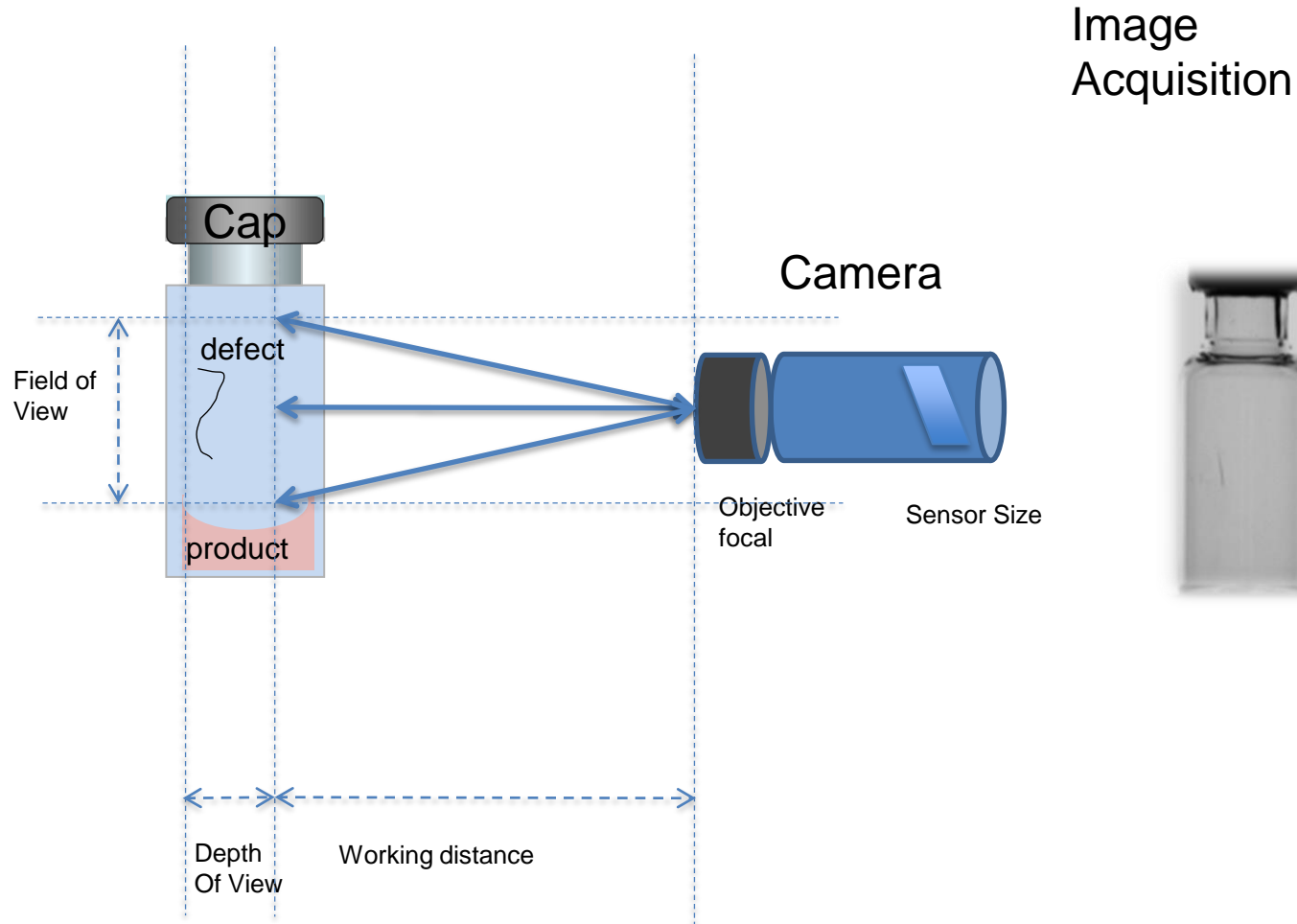
- discrete spatially
- discrete quantitatively



Key learning: AVI sees only a matrices of discrete information in X Y and Z for grey levels

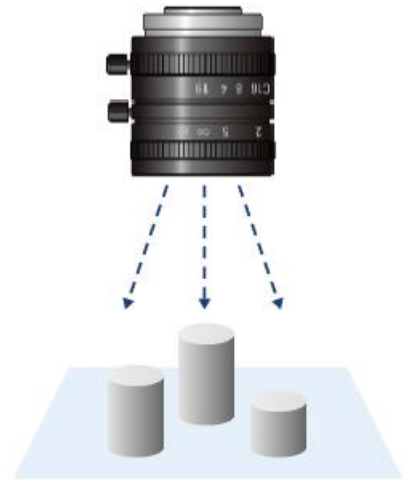
Optic Fundamentals

Image Acquisition => optic parameters



Critical Design Element:
Optical setup must be masked and locked
In case of change possible to come back to pre existing image before validation

Ordinary lens

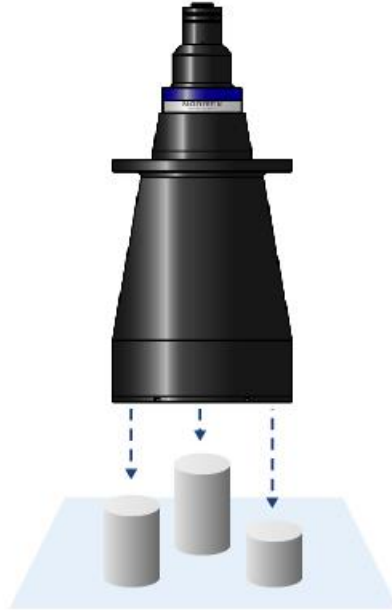


Part of the object's surface may be hidden by surface unevenness

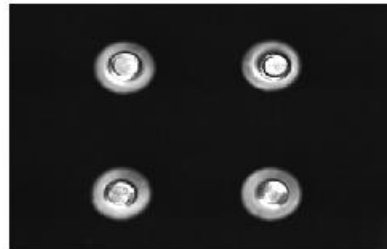


Size of the image changes

Telecentric lens



The entire surface of the object is visible

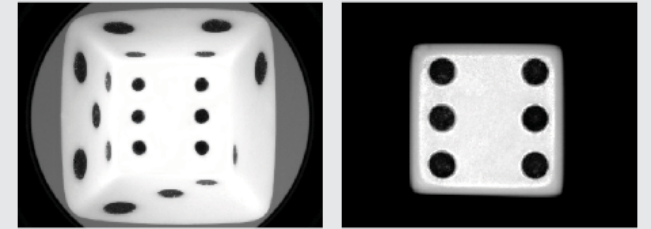


Size of the image remains the same

macro



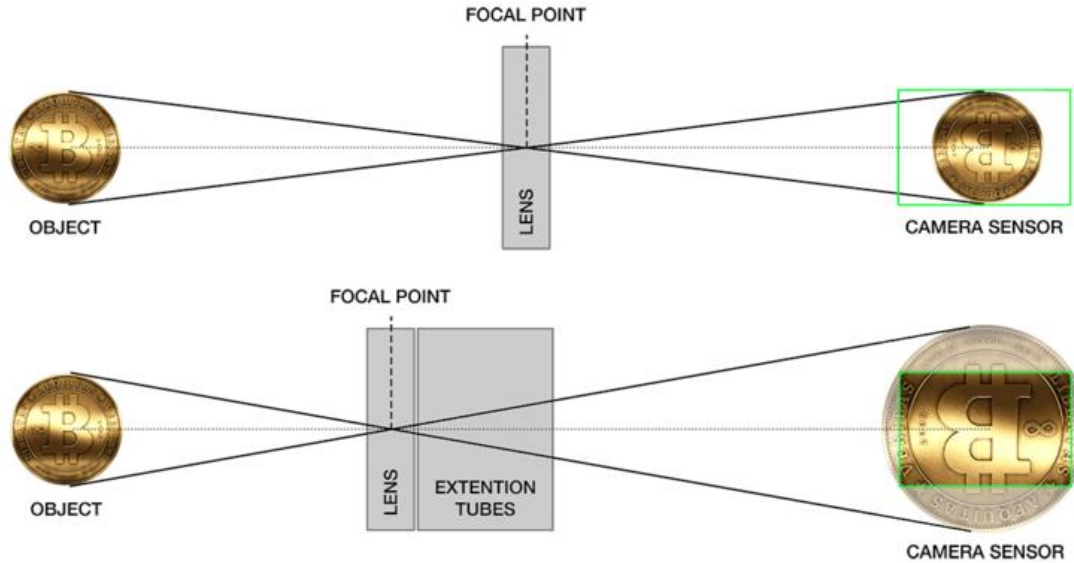
hyper centric



Images of dice using a Hypercentric Lens (left) and a Fixed Focal Length Lens (right)

Critical Design Element:

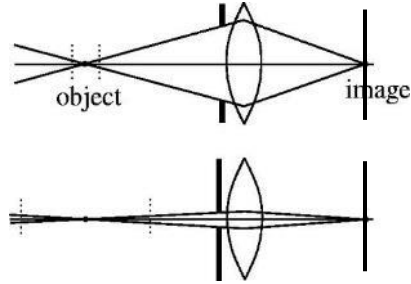
Innovation in optic goes with larger size optics that are difficult to integrate in some AVI design



Critical Design Element:

Extension tubes and mirrors are used to cope with lack of space to shorten focal distance
But the depth of view is deeply impacted in some case, to be discussed during design review with suppliers

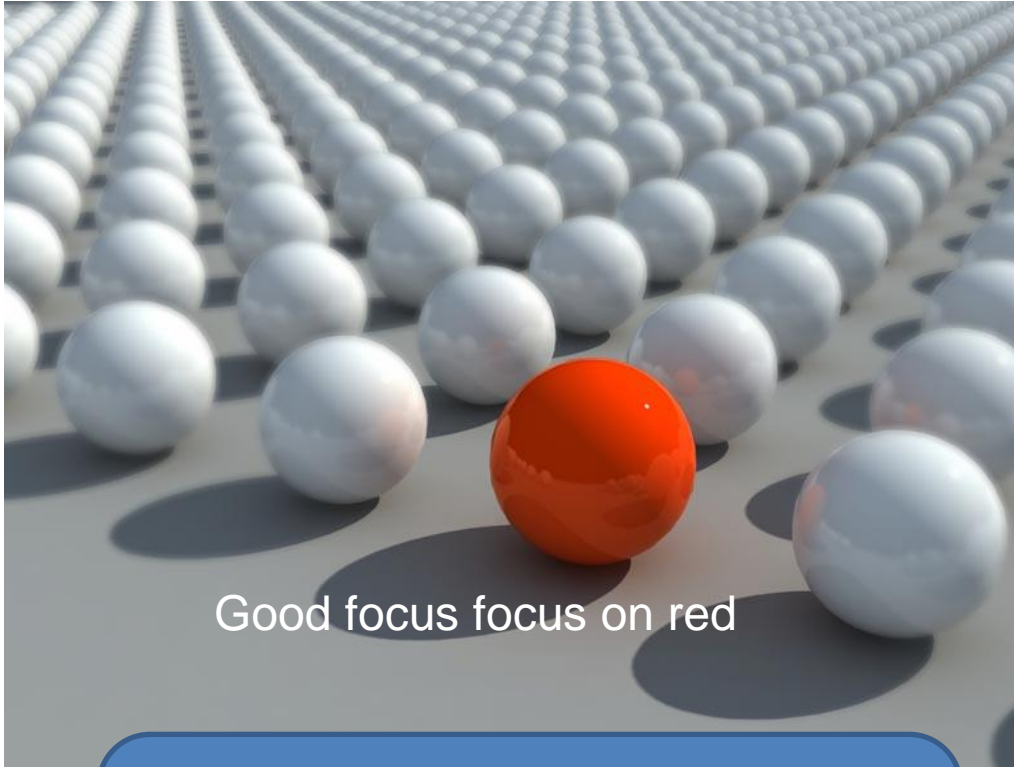




Critical Design Element:
 High Depth of field can allow to see defect from front and back of unit at same time.
 To do so we close objective aperture but image are darker

Macro objective can allow large field of view like on the lyo cake below:





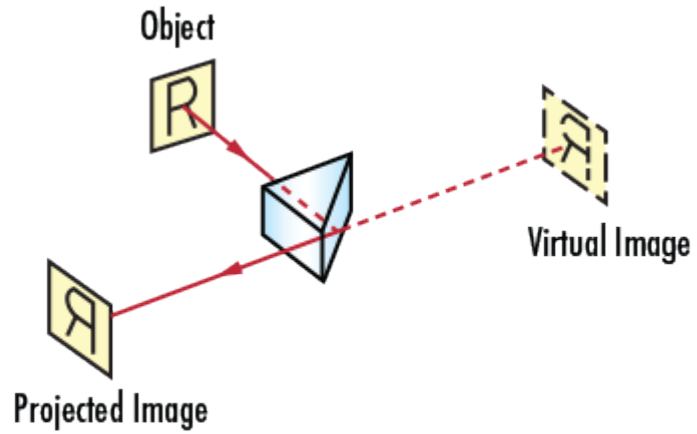
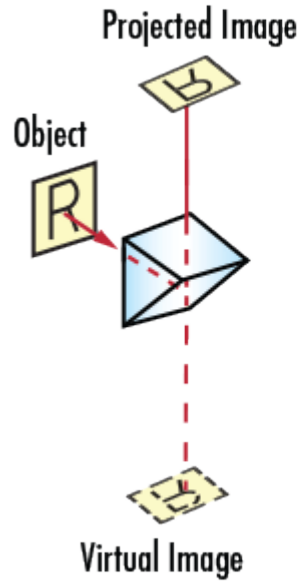
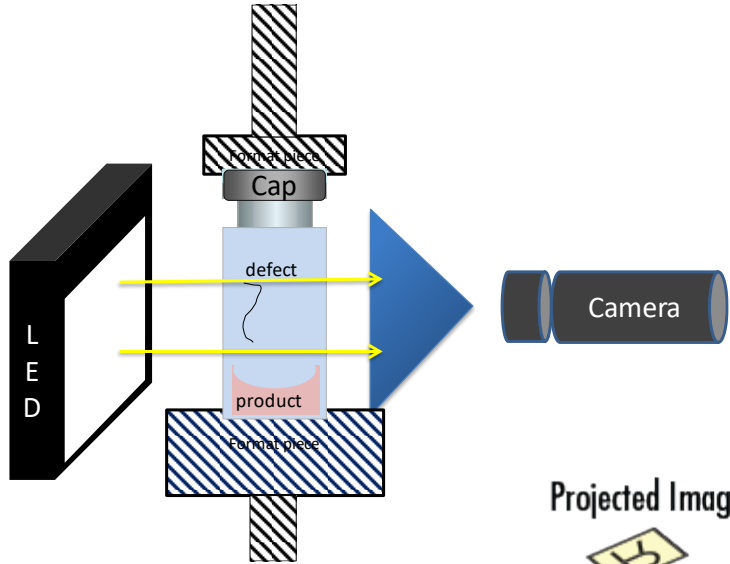
Good focus focus on red

Critical Design Element:

It is critical to have a good focus on the field of view, focus must be locked and graved to be able to come back to pre existing focus



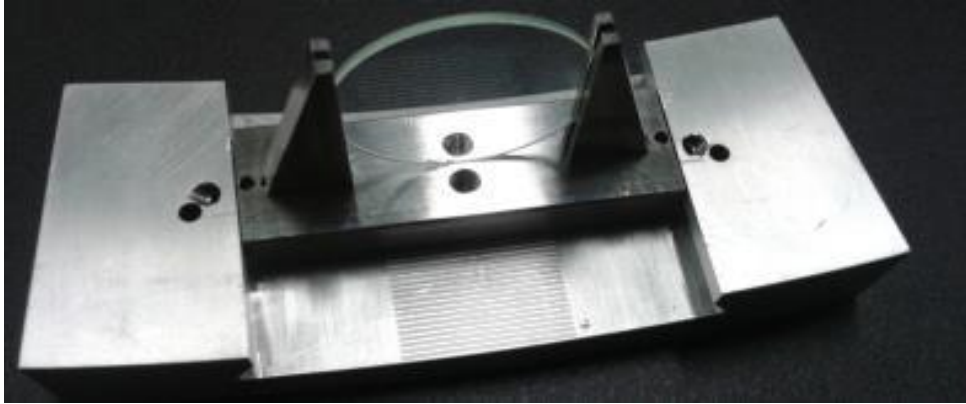
Bad focus
=> poor specificity
=> hard to detect
crack vs
dust/scratch



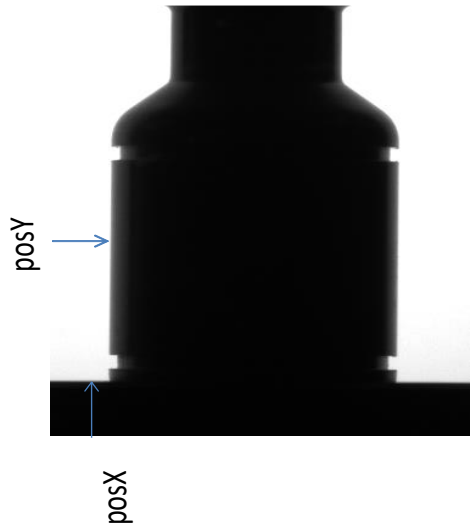
Critical Design Element:
Prism or mirror position and dust may impact image, do periodic check
Can allow to have 2 views with 1 camera

Image Focus control

Control focus with reticles



Control focus gauge

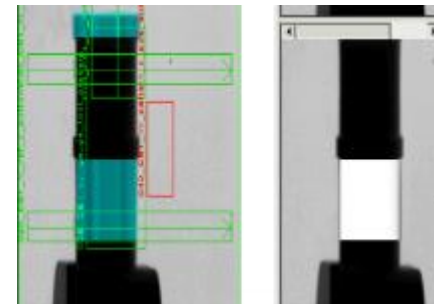
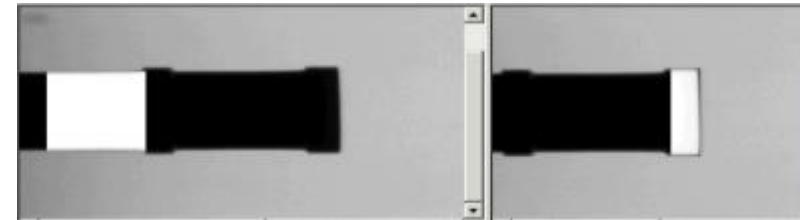


Dummy vial

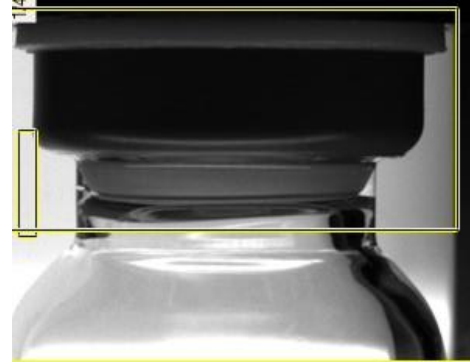
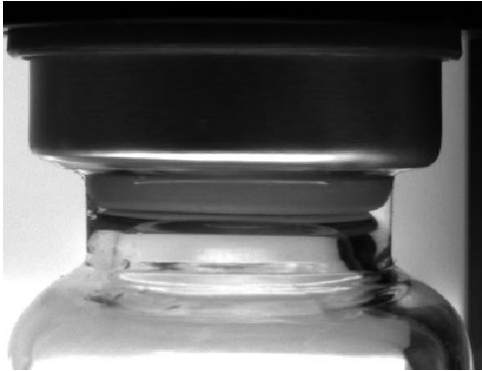


Dummy syringe

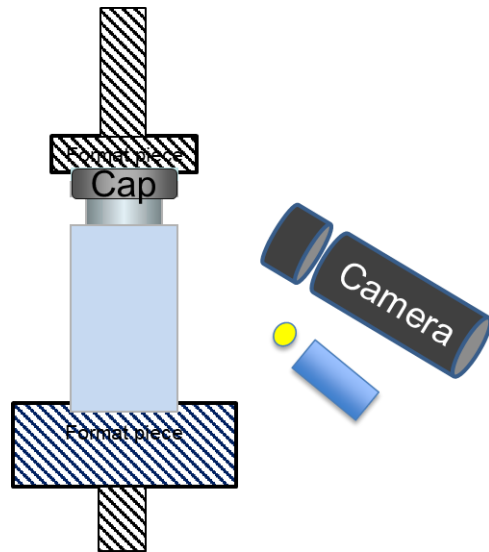
Critical Design Element:
 There should be tools to control vision alignment to document that vision tools remains within range from initial baseline corresponding to initial PQ
 Special gauges and vision setup



Adjustment recipe

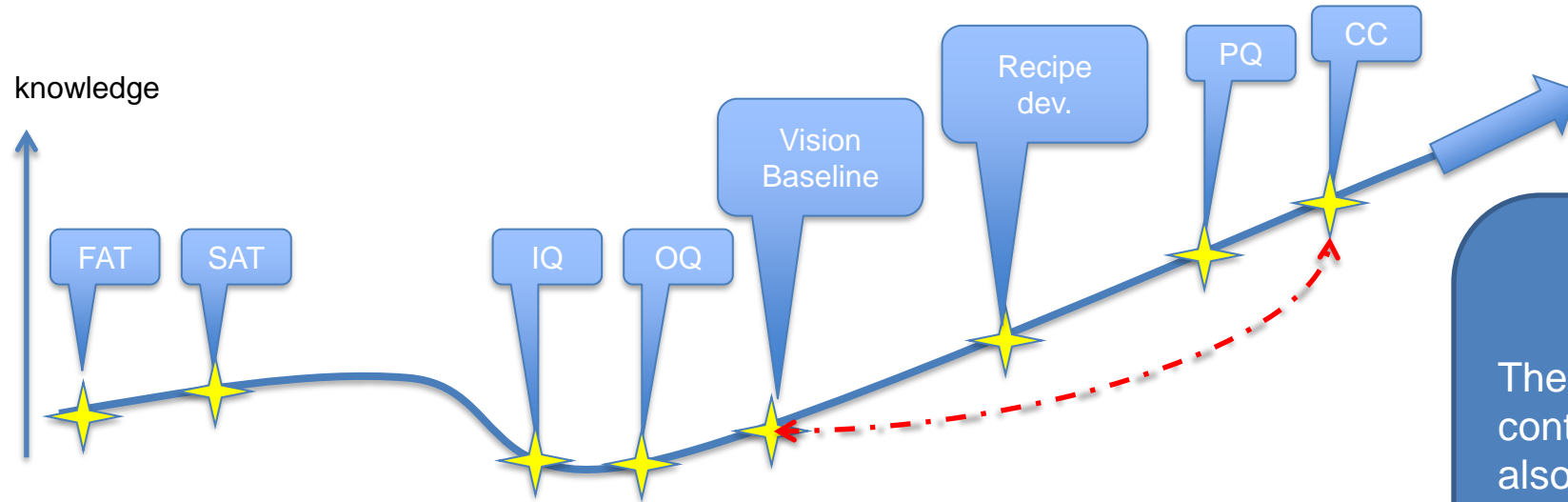


Critical Design Element:
There should be tools to control vision alignment to document that vision tools remains within range from initial baseline corresponding to initial PQ
Special gauges and vision setup



Most common light sources are back- and front light.

- The position of Backlight is not that critical, but the light intensity is. This is often reported within the grayscale 0, black, to 255, white
- Directly measuring it through the camera can be done if the image is not oversaturated, so below 255 in theory. Be aware that some cameras are already oversaturated around 240. A reference measurement than can only be done with the aid of a grey filter to reduce light.
- Regarding front light not only the light intensity is critical, but also the angle of the light source.
- The crimp should be shiny to detect distorting of it as one of the aspects. The above example is exaggerated, the center of the light source dropped in the neck.
- So after the initial PQ the angle should be established and documented.



Critical Design Element:
 There should be tools to control vision alignment but also the mechanical zero of machine and the zero of encoder
 Your AVI is like a swiss watch to handle & maintain with care

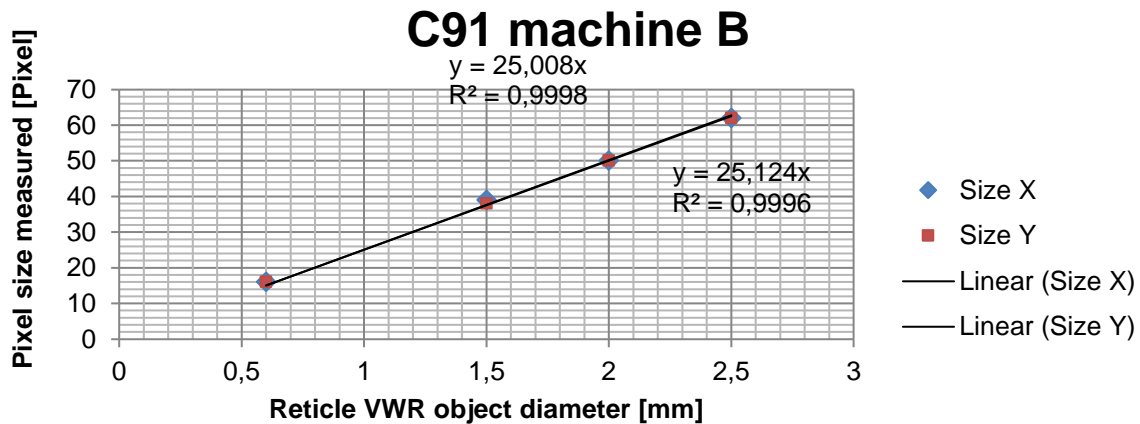
= to comeback to initial state of PQ, what ever appends in lifetime (big machine breakage, power failure, camera replacement, or CC)

- Mechanical Zero piece
 - Encoder Zero
 - Vision Zero
- } all must match



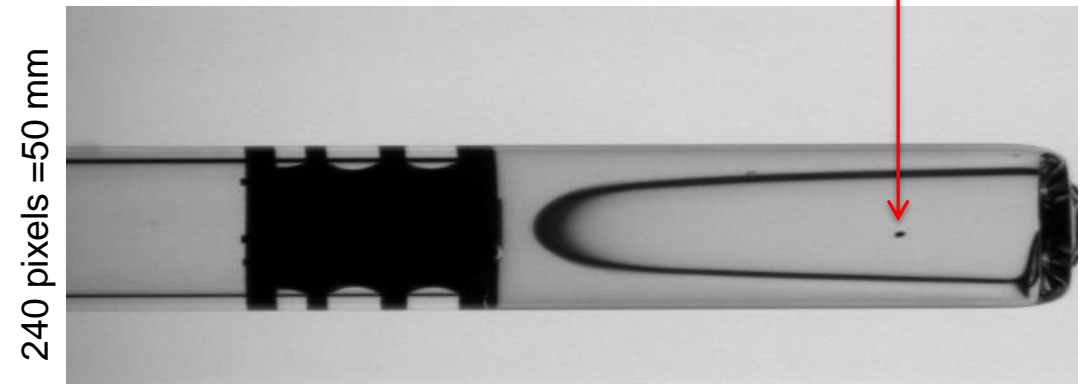


Critical Design Element:
With reticles that are calibrated,
you can correlate pixel to size



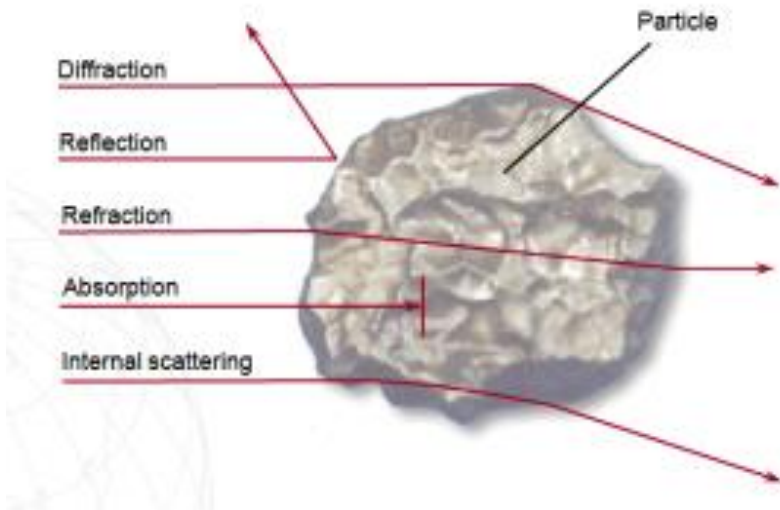
1.1 mm = 5,3 pixel

640 pixels = 134 mm (in this picture)



Camera C61 resolution: 0.05 mm per pixel or 5,3 pixel = 0,27 mm

Illumination





Spot LED



Line LED



Front Panel LED



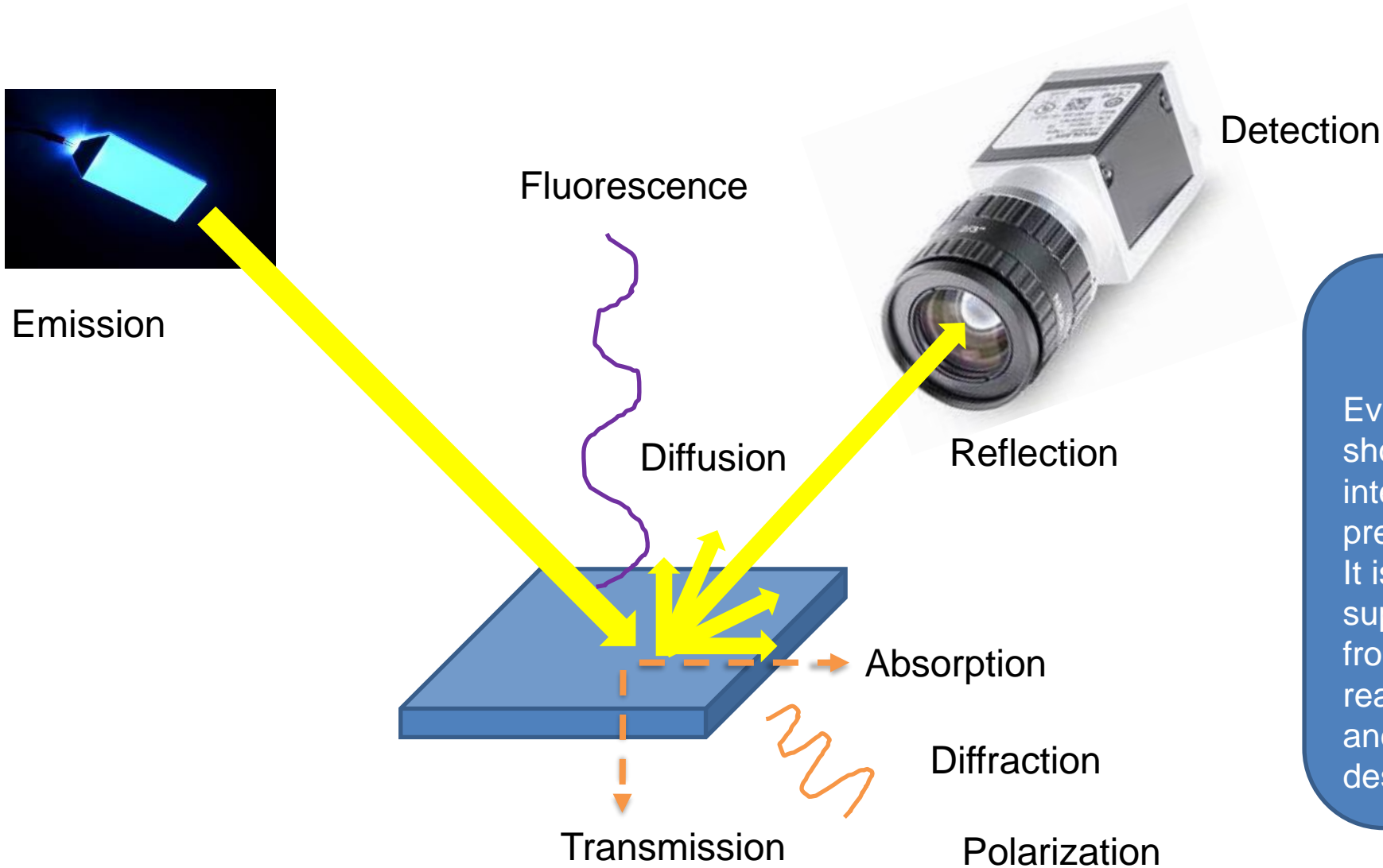
NIR LED



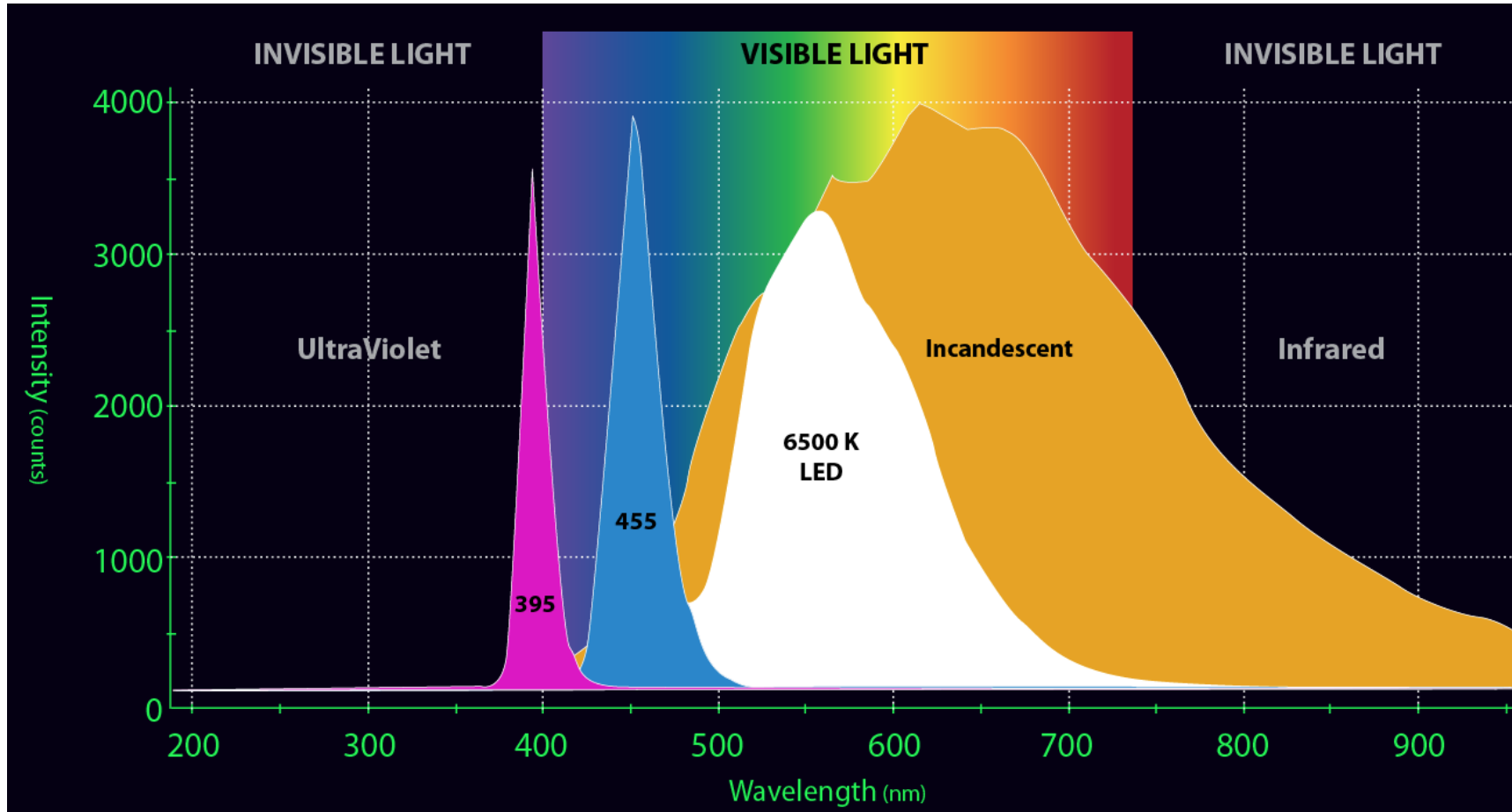
Back light LED



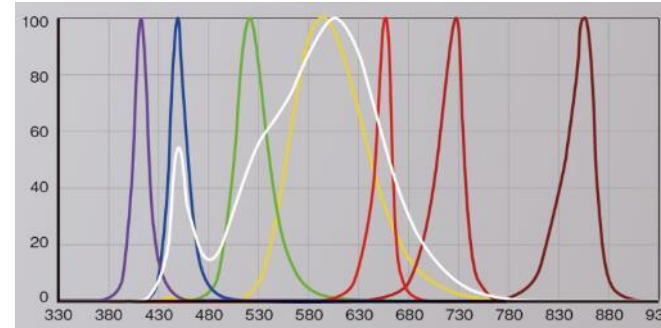
Ring LED



Critical Design Element:
Every illumination design should take into account interaction with product presentation, It is upmost critical to supply product samples from real production with real primary packaging and fill level during AVI design phase



Critical Design Element:
Spectral wavelength is critical to be studied with supplier,
Most of product will use visible range
Color LED may be optimal for some camera setup
Some emulsion scattering product could use NIR range



Conventional color camera



With conventional models, distinguishing between similar targets with little noticeable color difference was difficult.

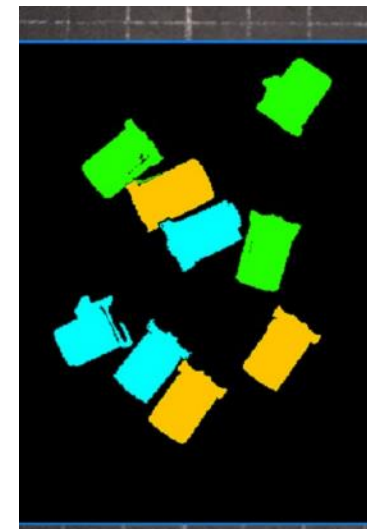


Multi-Spectrum Mode



A different type of cap is extracted virtually as the same color.

Multi-Spectrum Mode : Color picking

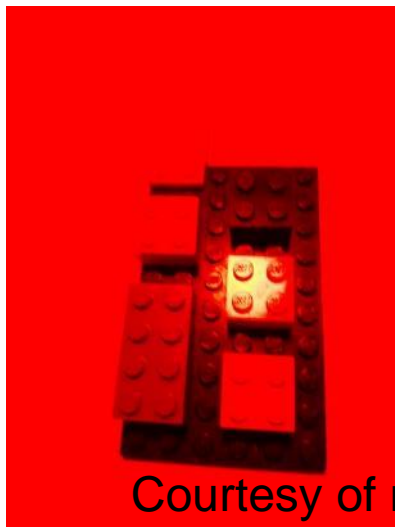
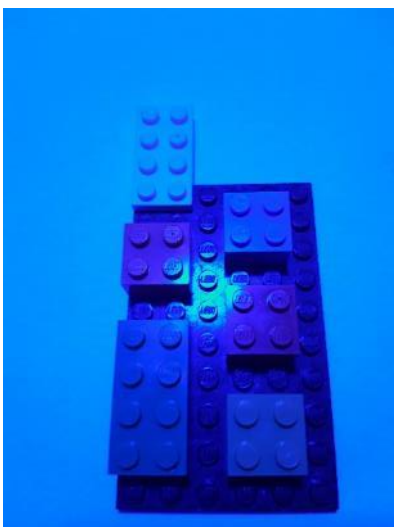
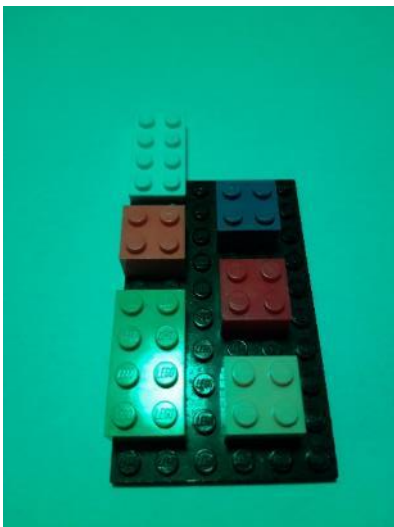


Slight differences in color are clearly defined.

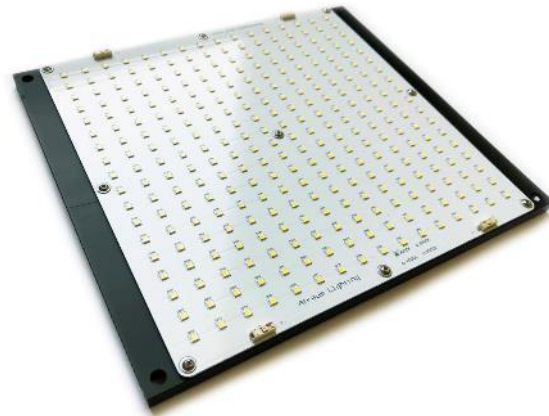
Color perception impacted by light color



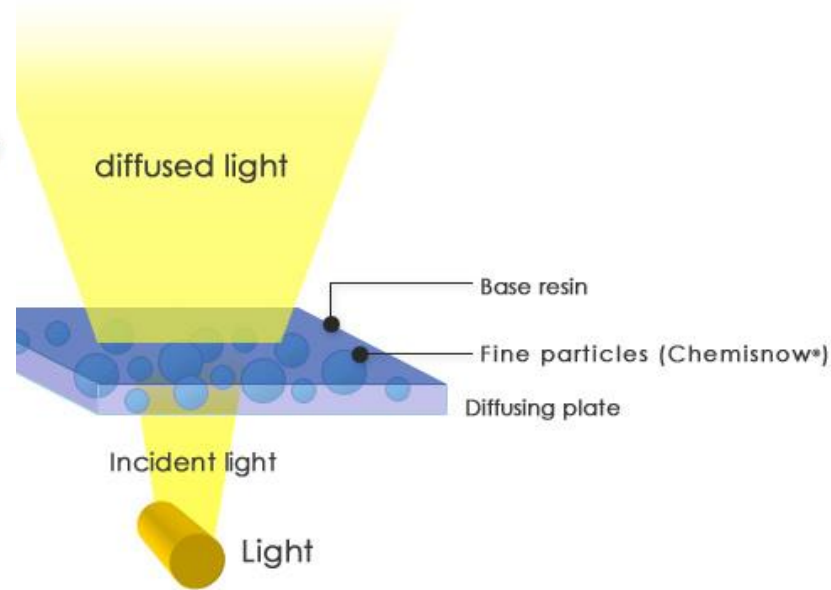
Critical Design Element:
LED color may change defect detection, like to like change is critical
Color camera calibration is necessary



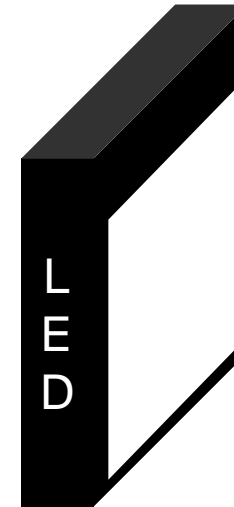
Courtesy of my kids !



Board



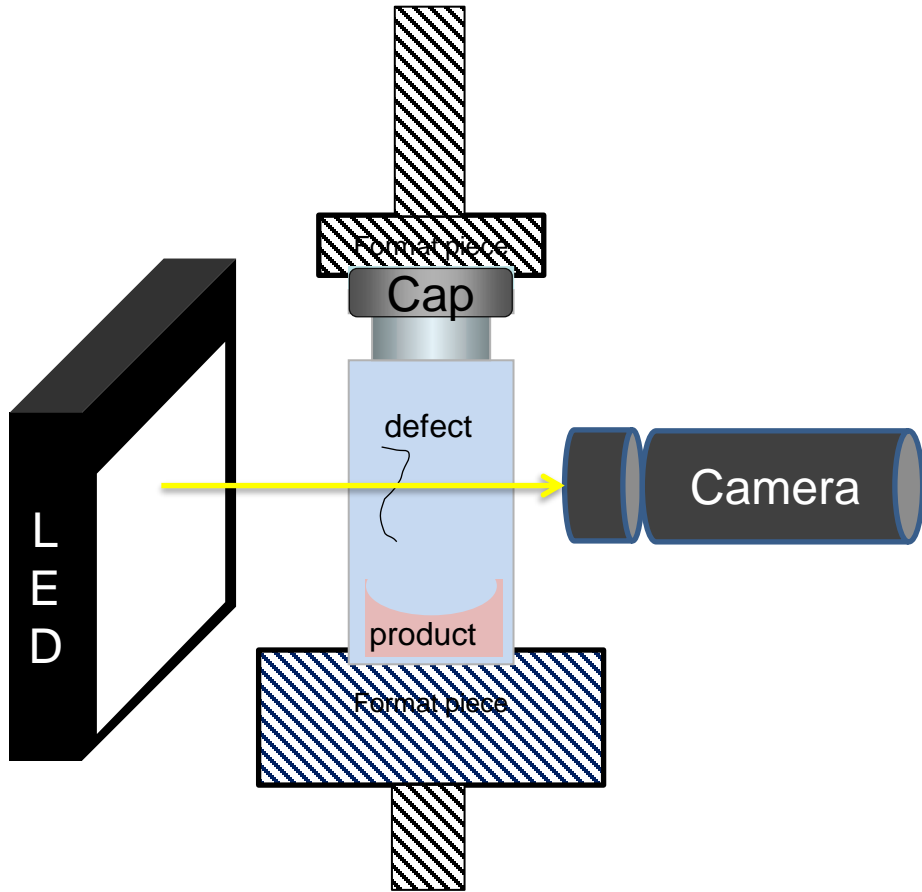
High quality diffuser



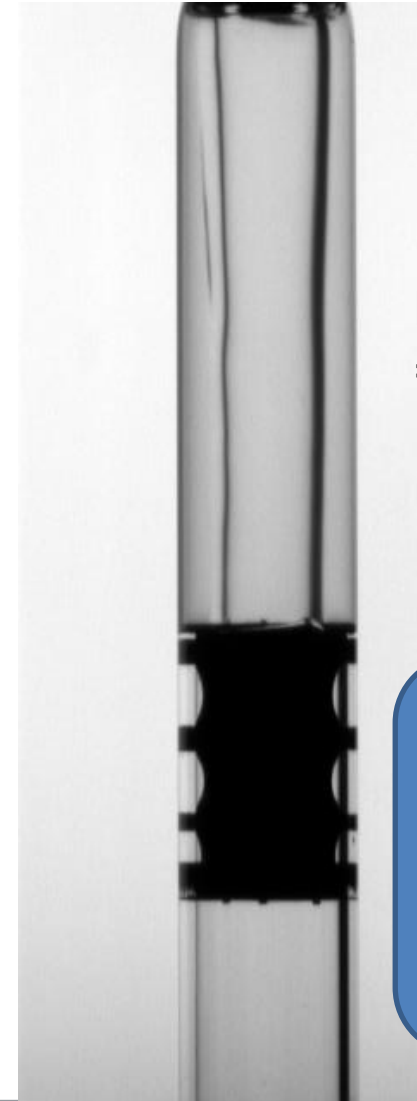
Back Light LED Assembly

Critical Design Element:

- Back light is easy to place in AVI (very common)
- LED must be replaced like to like or some equivalency studied must be done;
- mind the wire replacement, may impact the luminance

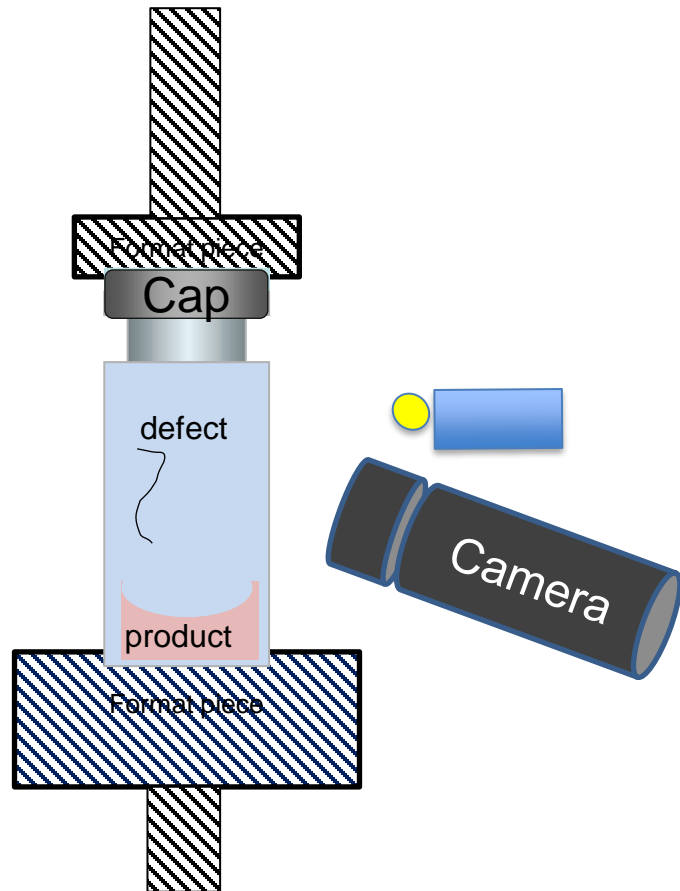


Low cost
back light =
gradient



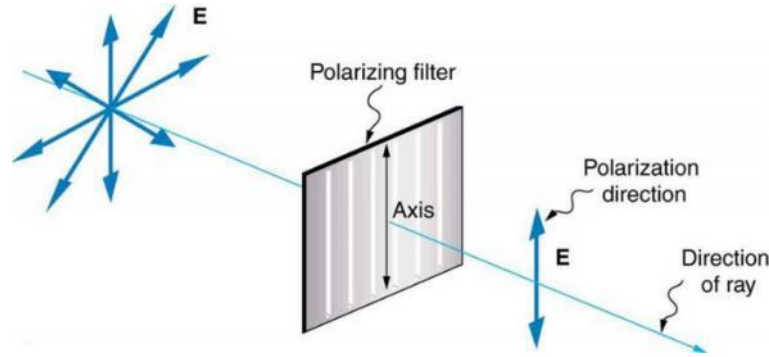
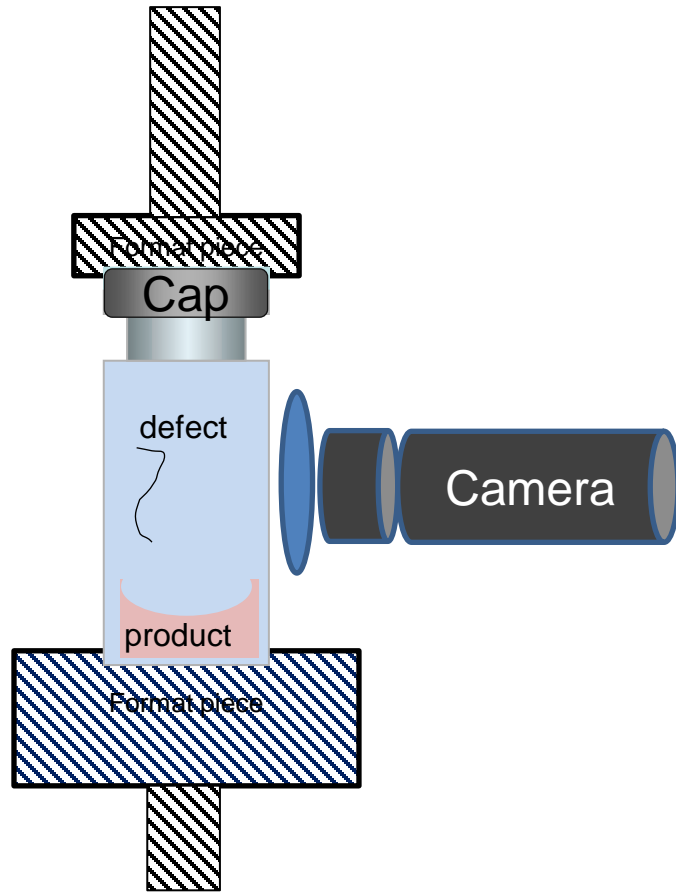
industrial
back light
= NO gradient

Critical Design Element:
LED distance / position
must be fixed,
control access level
do periodic check

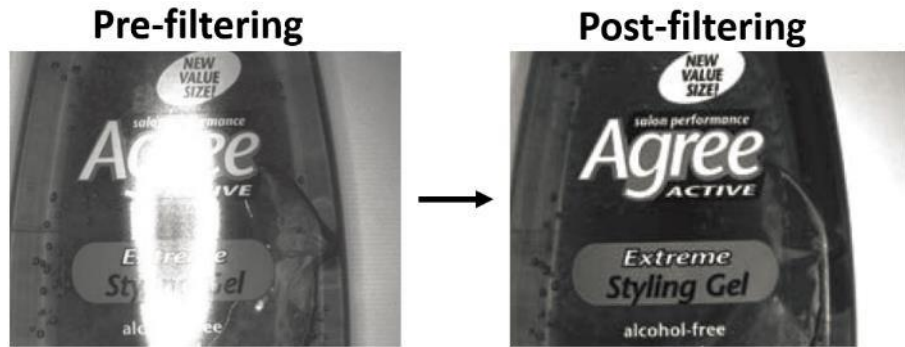


Shiny reflects

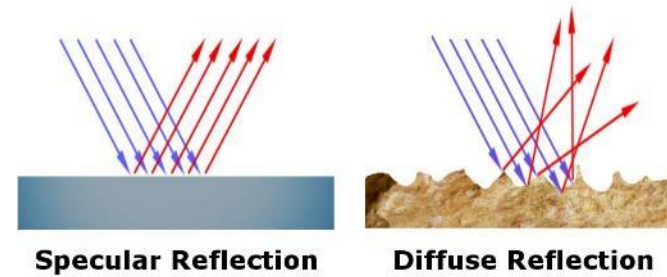
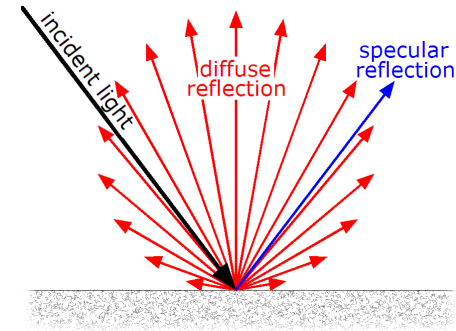
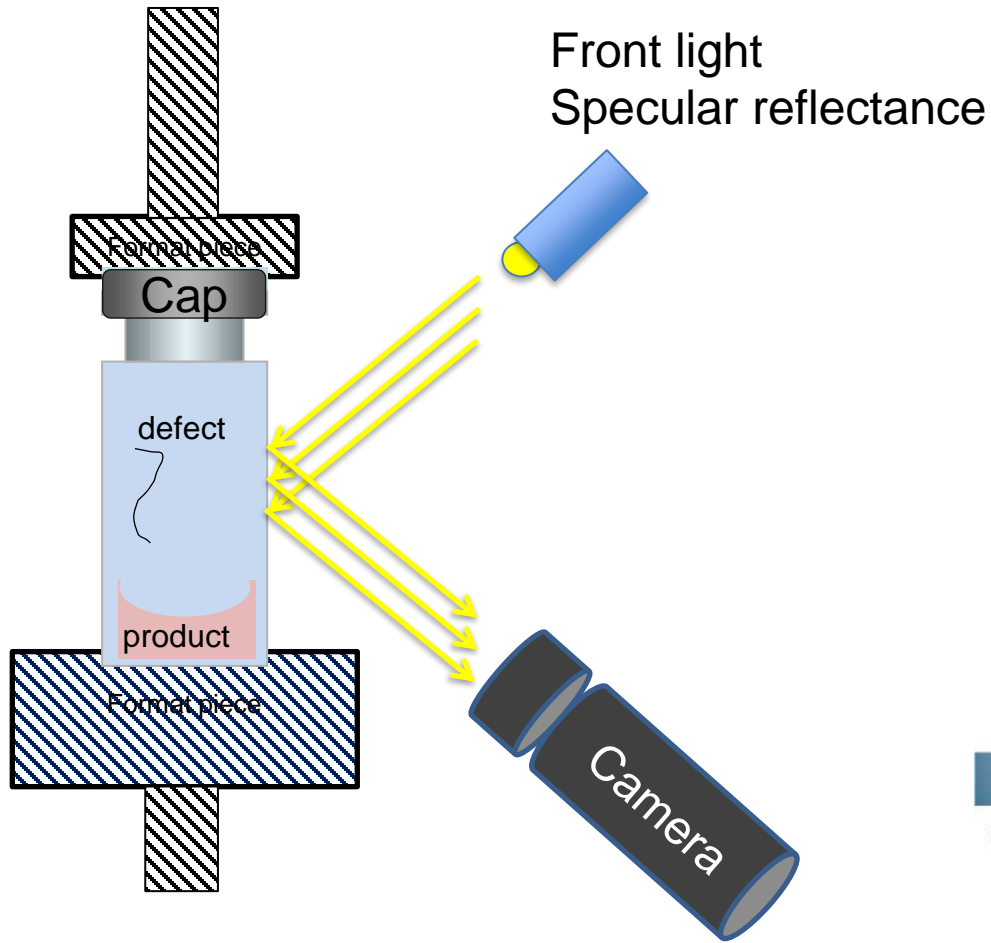
Critical Design Element:
Front spotlight may create reflects, control angle position, limit access and do reg check, use pol filters



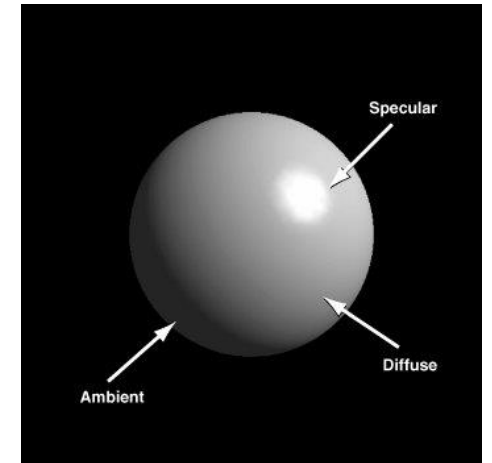
Critical Design Element:
 Polarization filter may impact luminance in function to positioning angle, lock and control the angle
 Powerful to block some glass reflects

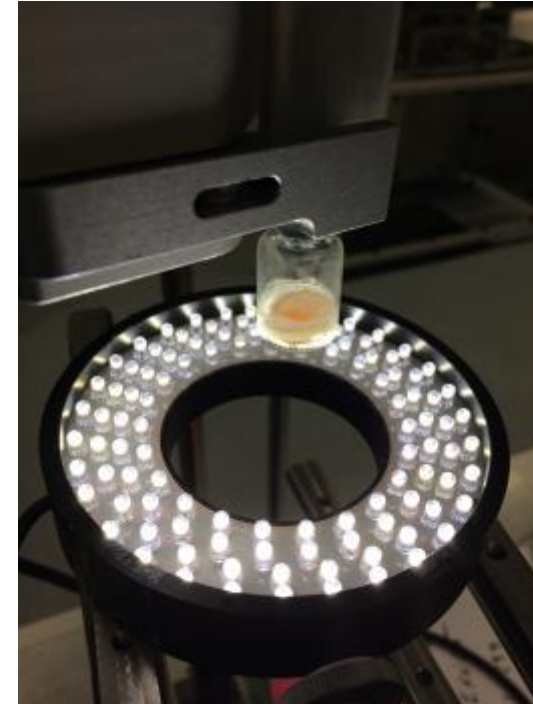
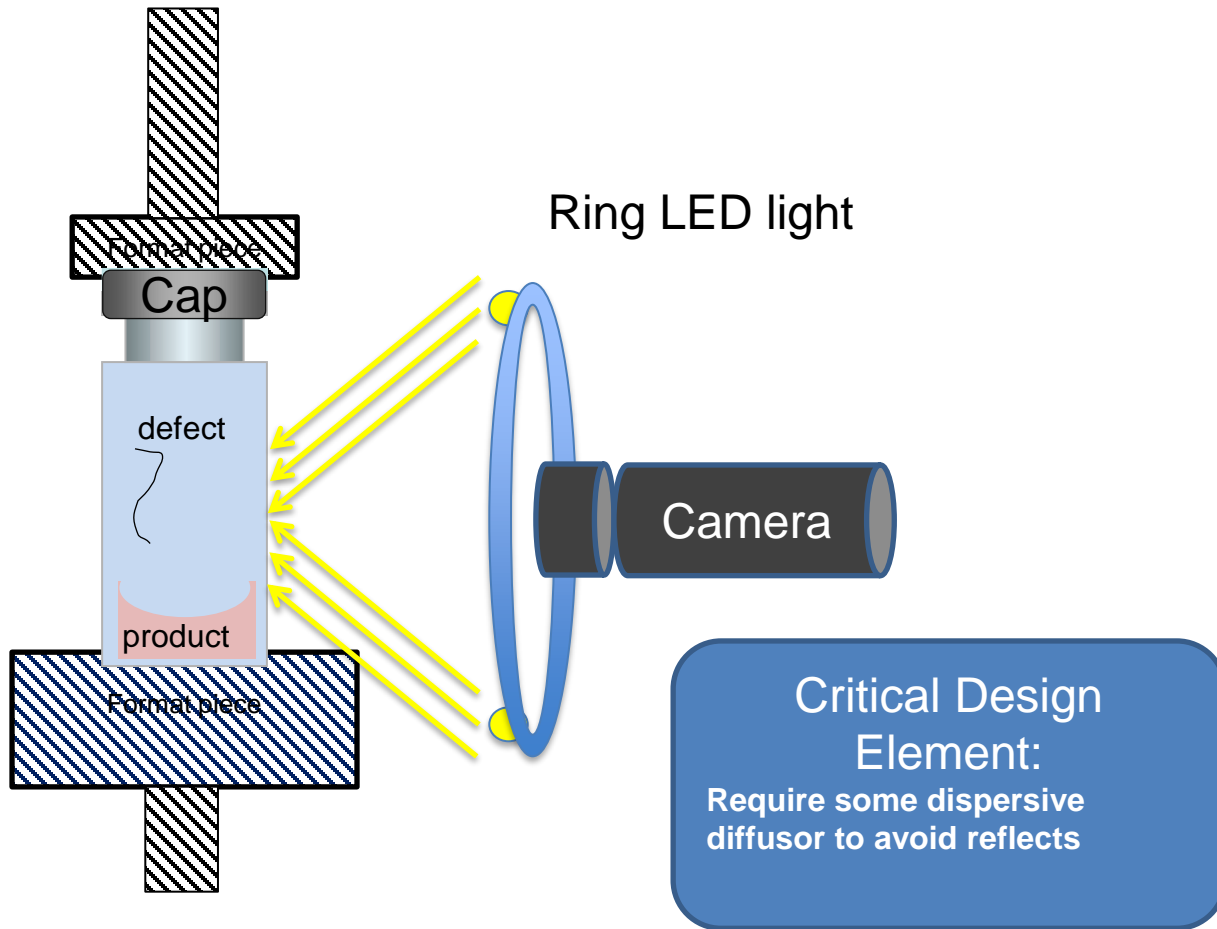


Specular reflectance



Critical Design Element:
Light position and Angle is utmost critical in term of stability, control access level and do regular check

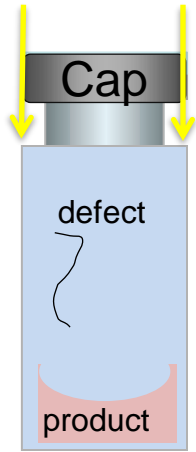




No dispersive filter = Reflect on glass

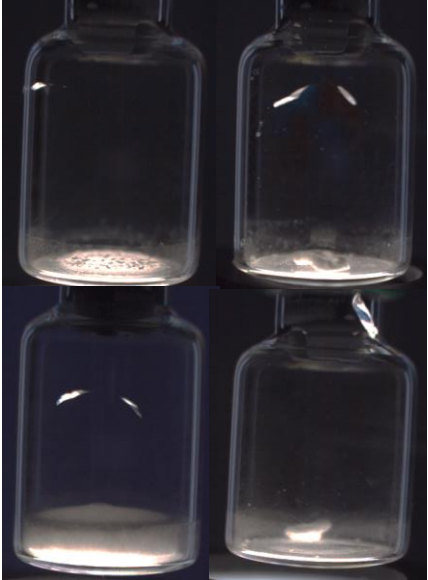
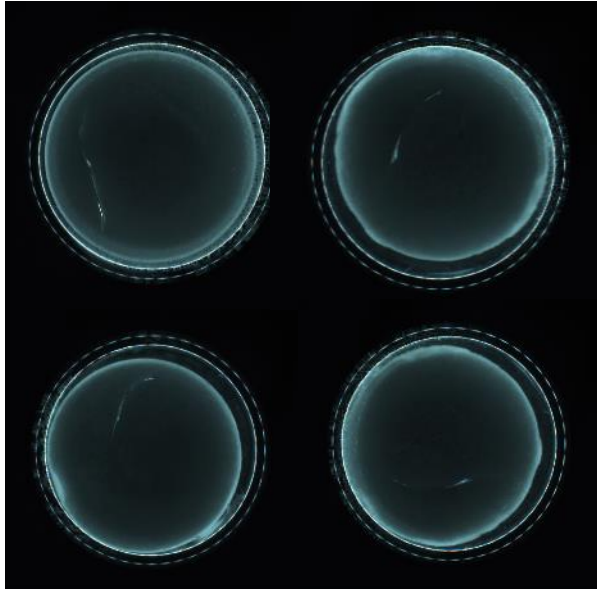
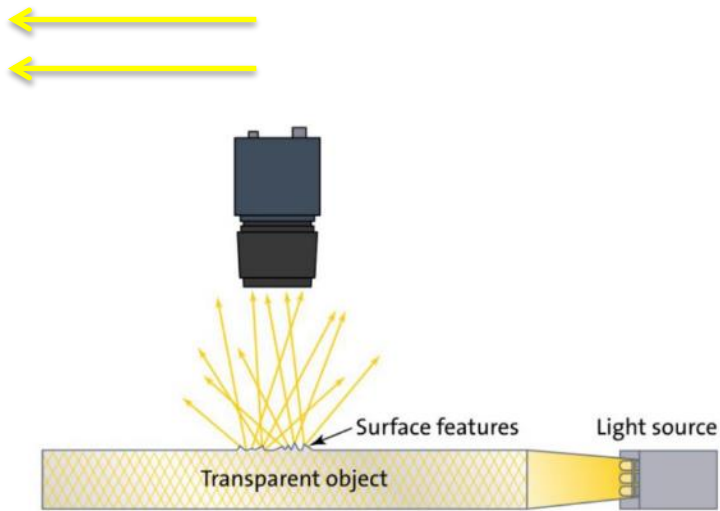


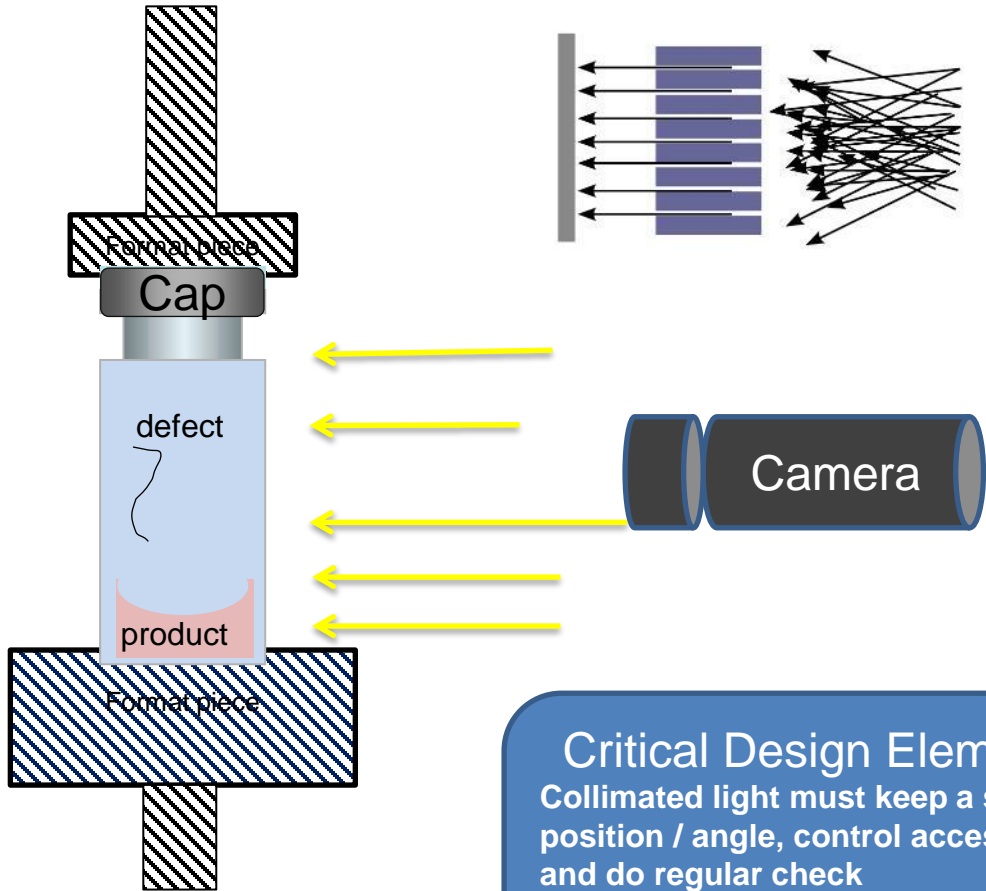
Reflect on glass



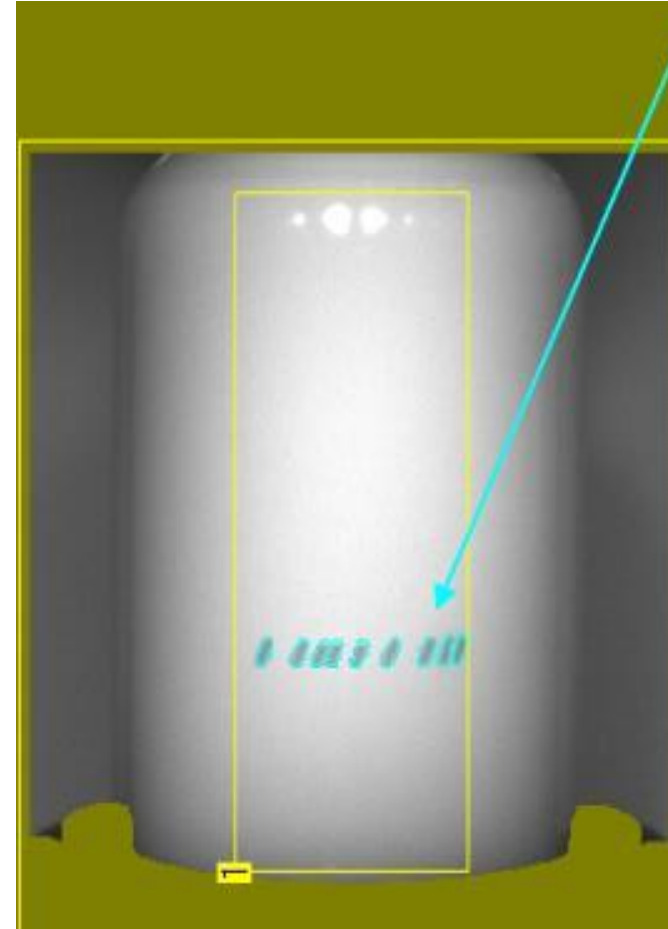
Critical Design Element:
Control glass specifications and mech stability to avoid cavitation from base holder

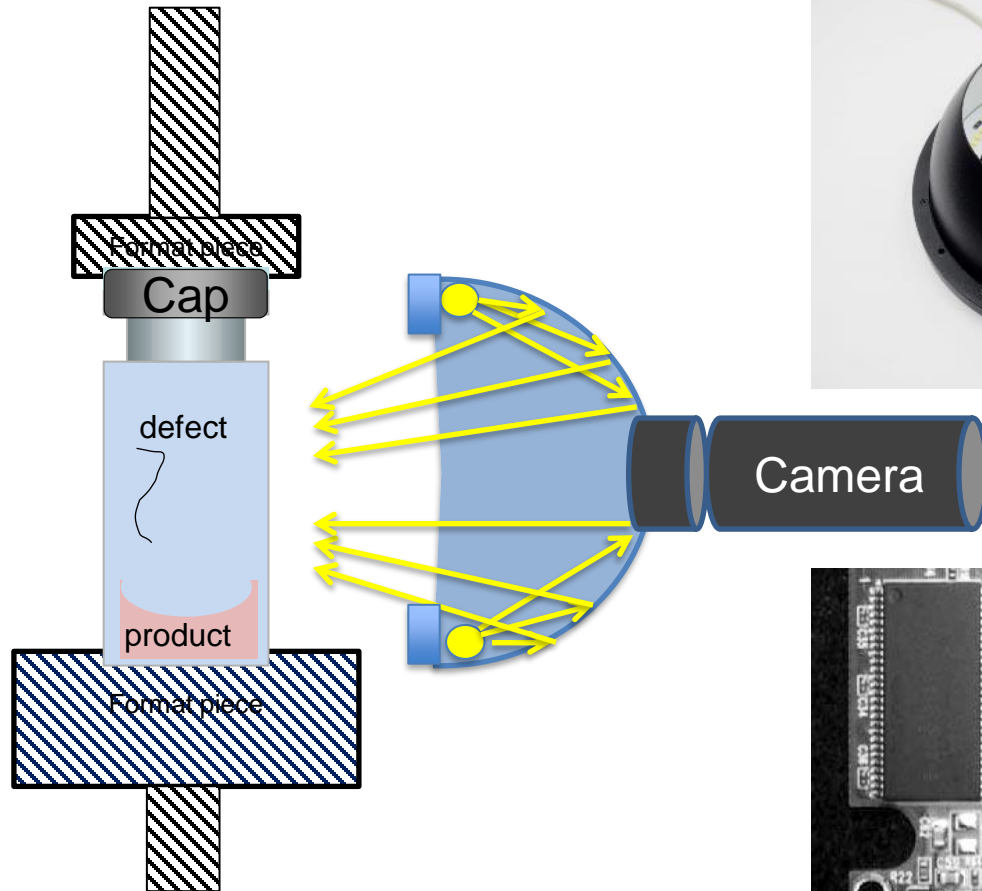
Very powerful for glass defect detection



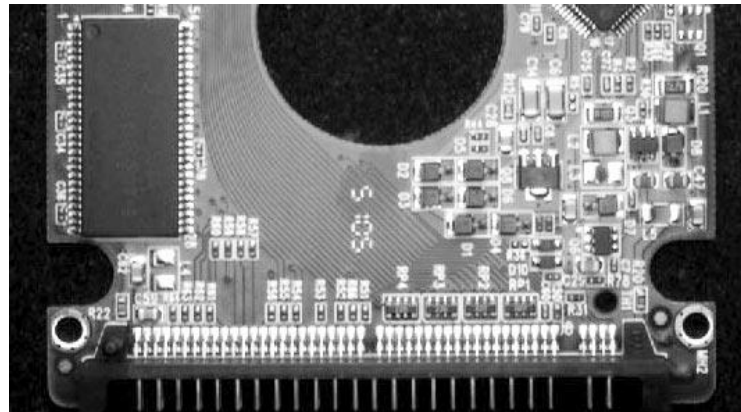


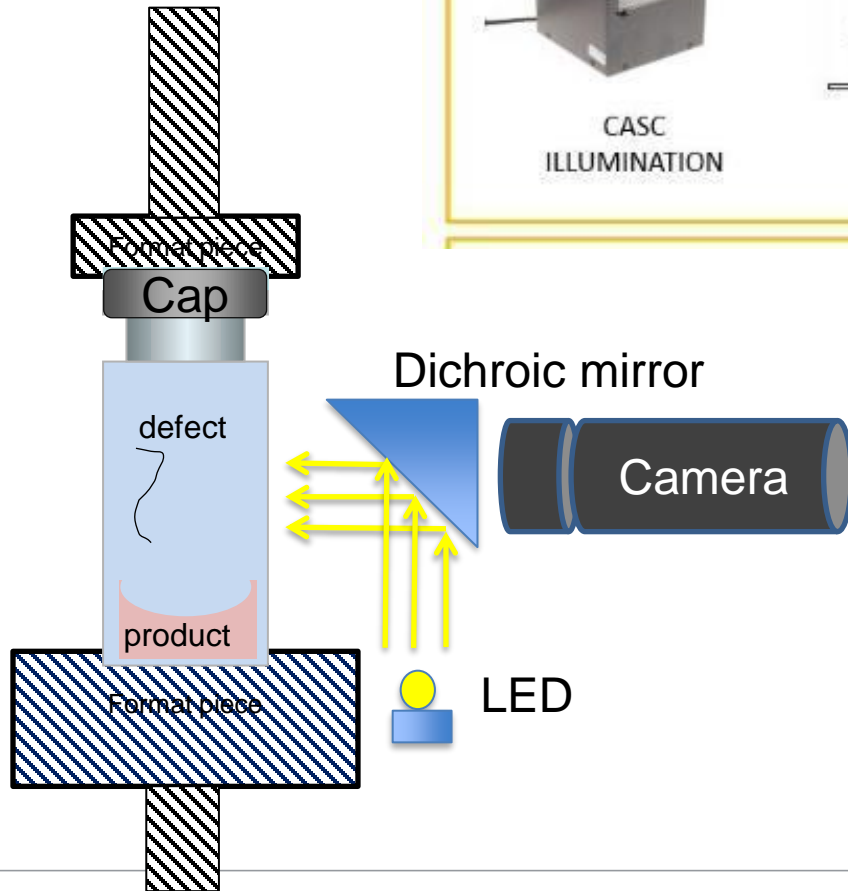
Critical Design Element:
Collimated light must keep a strict position / angle, control access level and do regular check
Interest for scattering product like emulsions





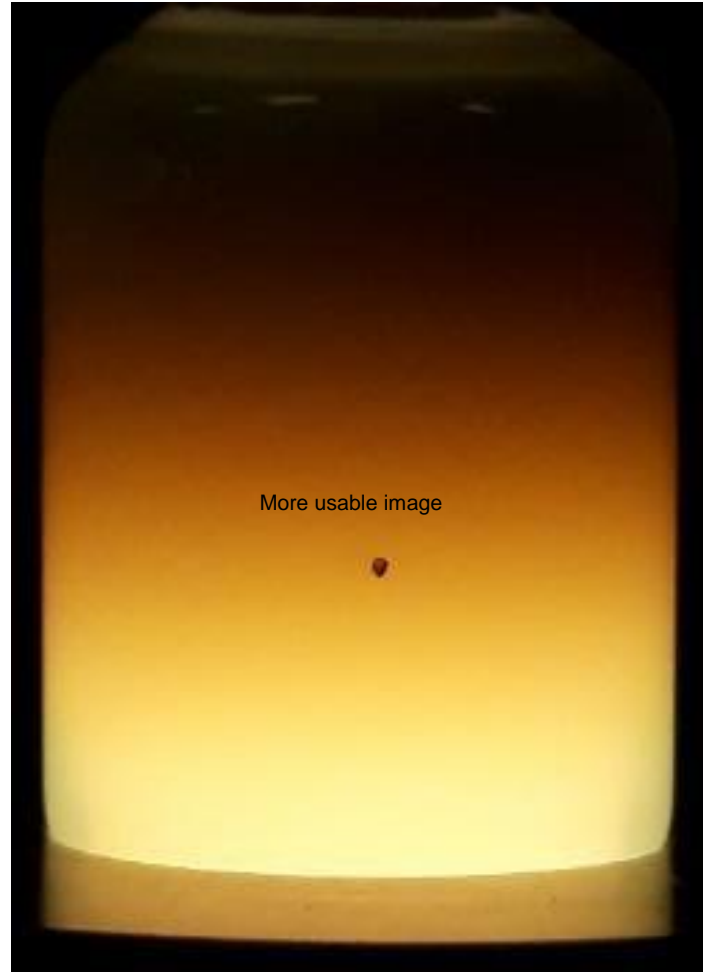
Critical Design Element:
Dome takes some space => mind stability of angle / position fixing
Multiple angle light, interest for glass defect detection



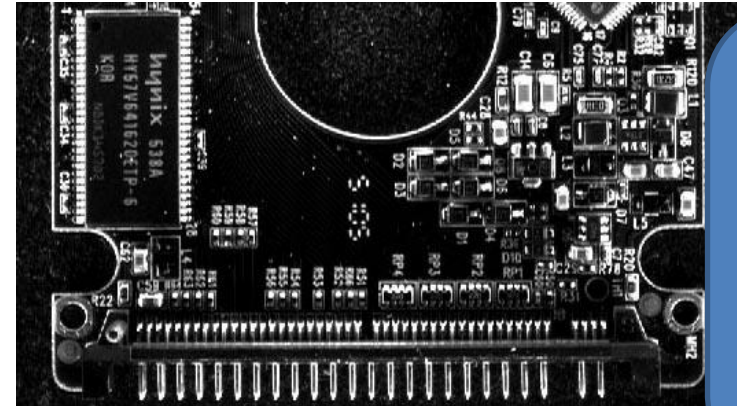
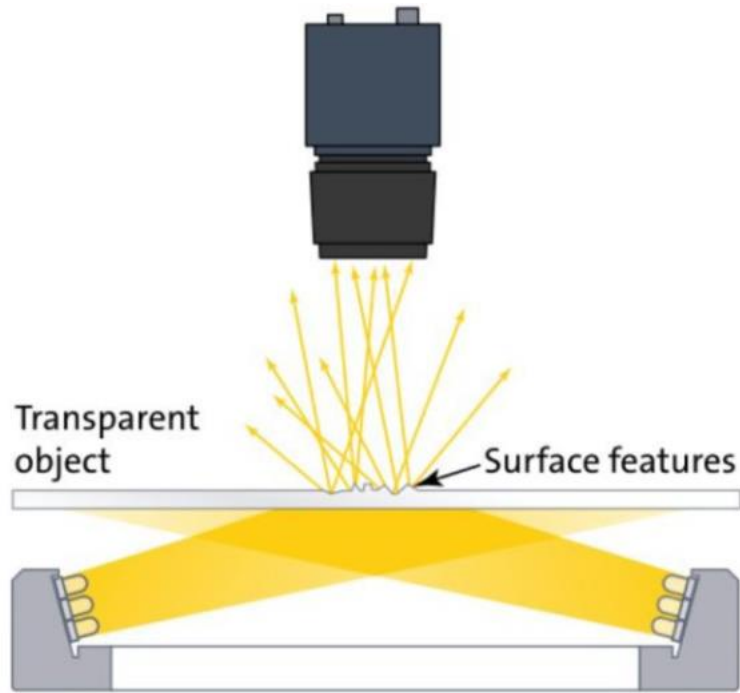


Critical Design Element:

- Can avoid reflect of glass
- Take more space
- The mirror may be obstructed by dust => regular cleaning



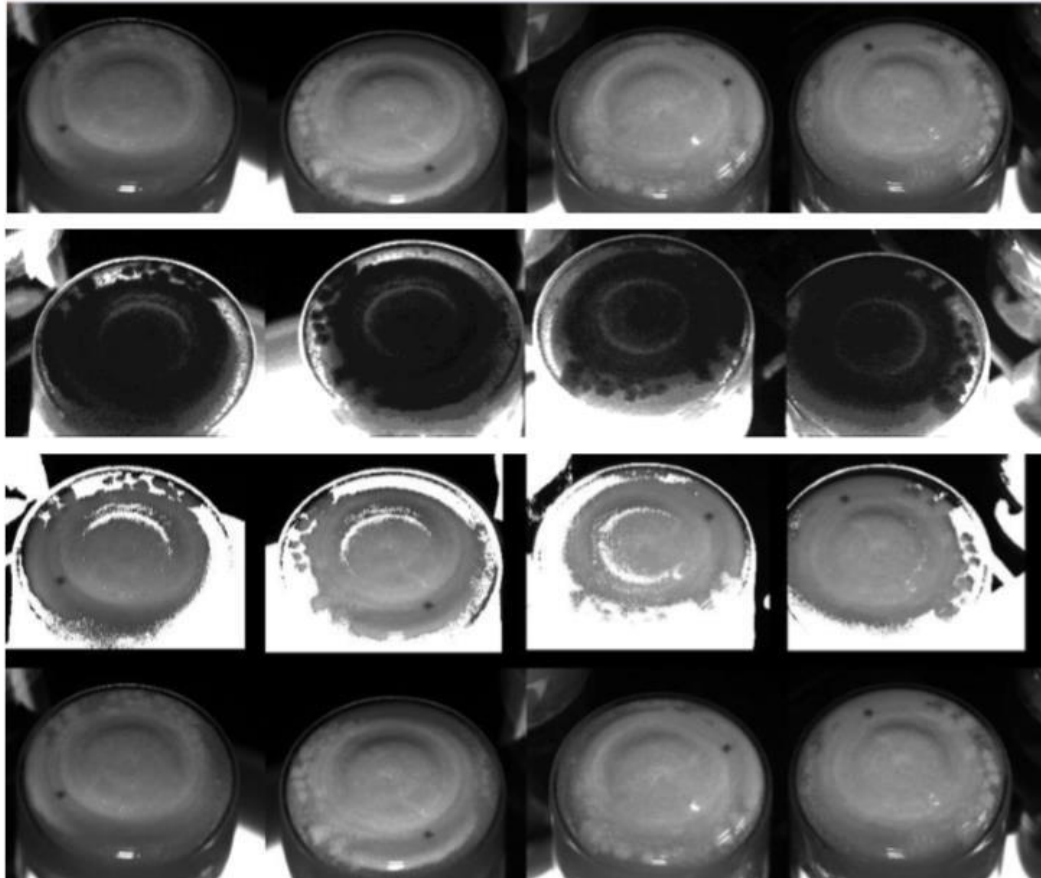
Critical Design Element:
Light from bottom vial may diffract light and burn the image, need to have a small diameter beam light



Critical Design Element:
 Dark field is very sensitive to powder on side walls => extra care in vial handling before AVI
 Darkfield can enhance surface defects

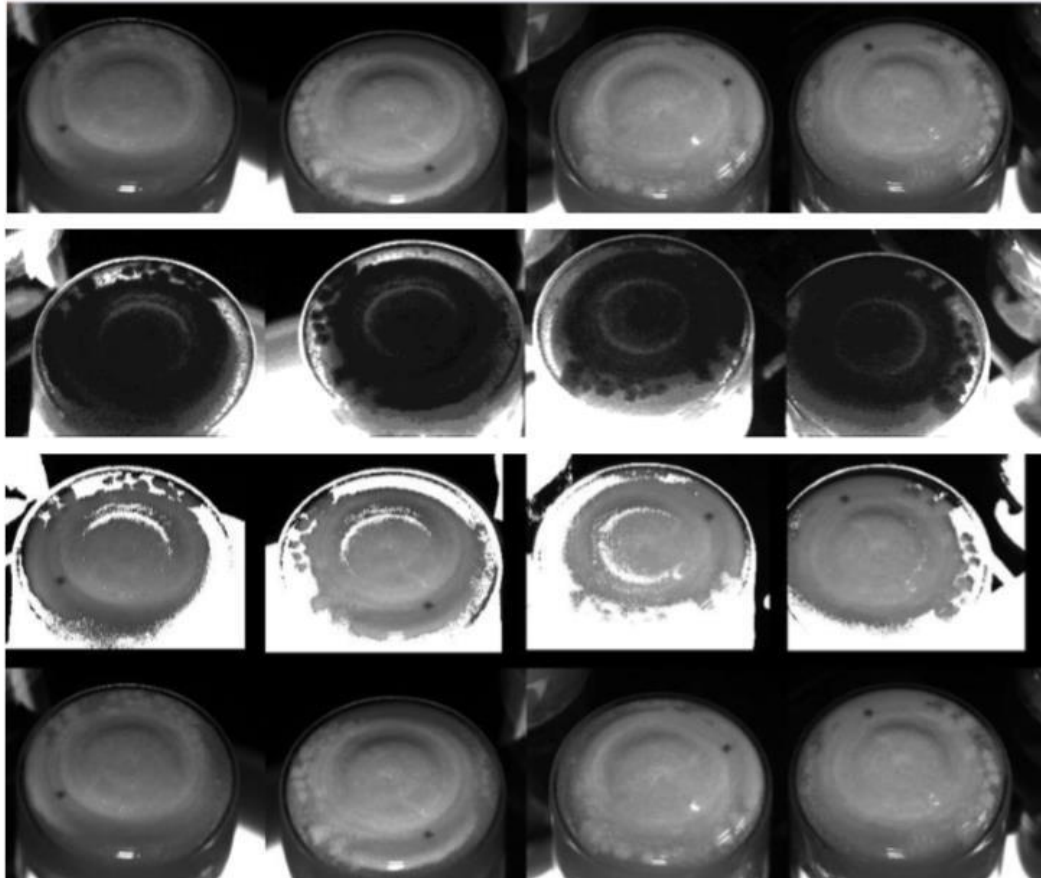


Combination of lightLight source

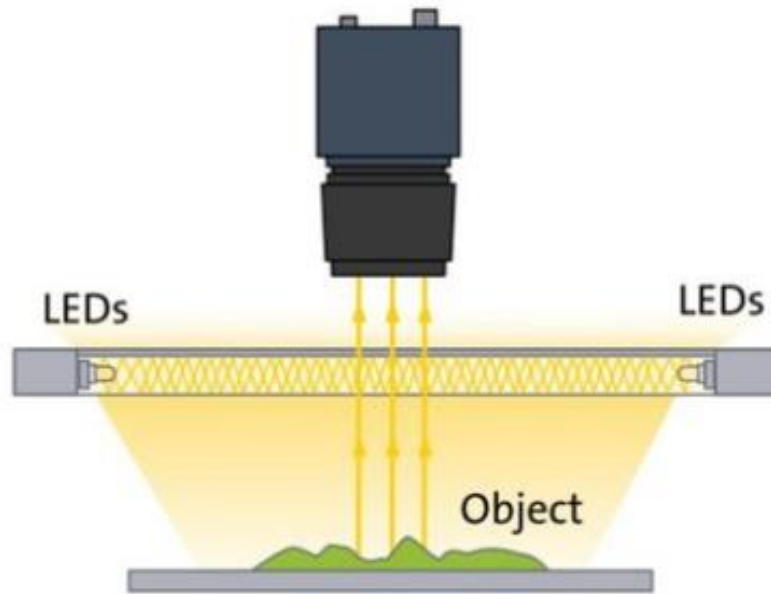


Critical Design Element:
Check no interference of LED from 1 station to other
Sequential strobing

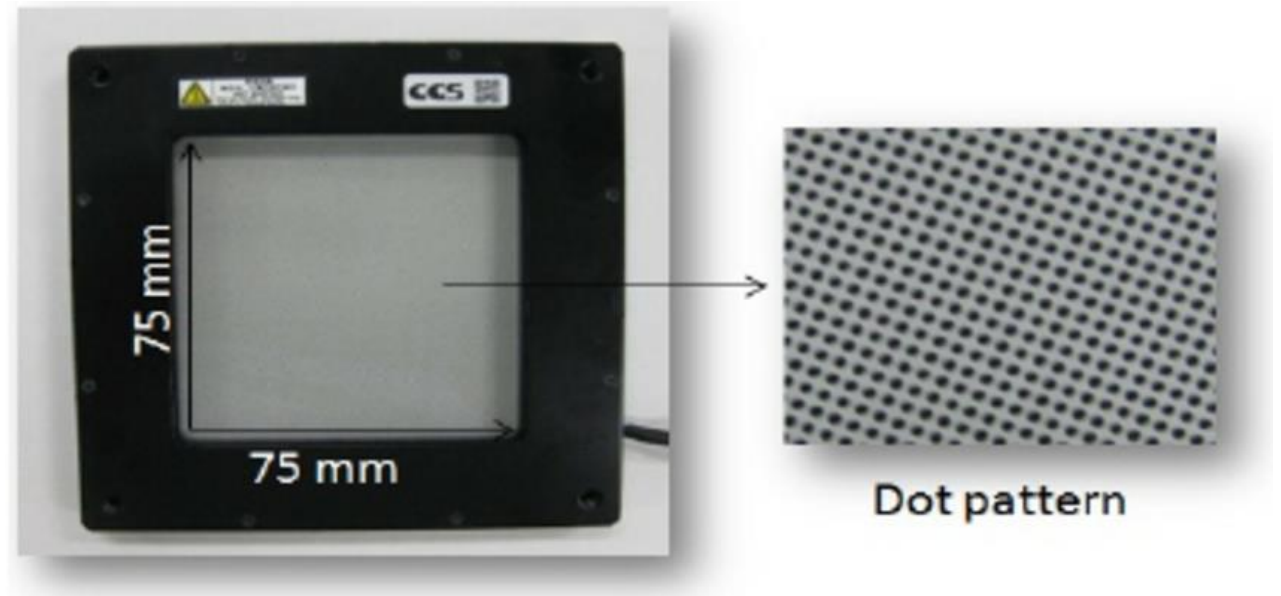
Combination of lightLight source



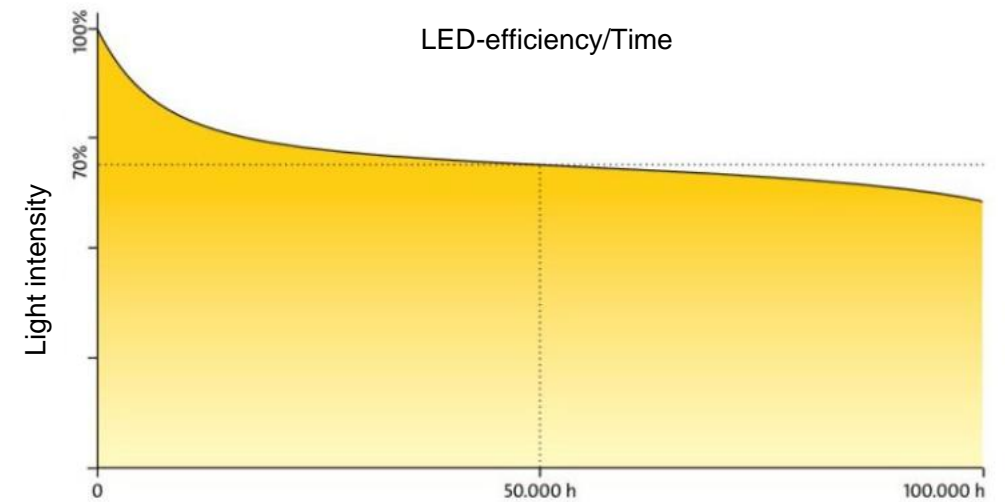
Critical Design Element:
Check no interference of LED from 1 station to other
Sequential strobing



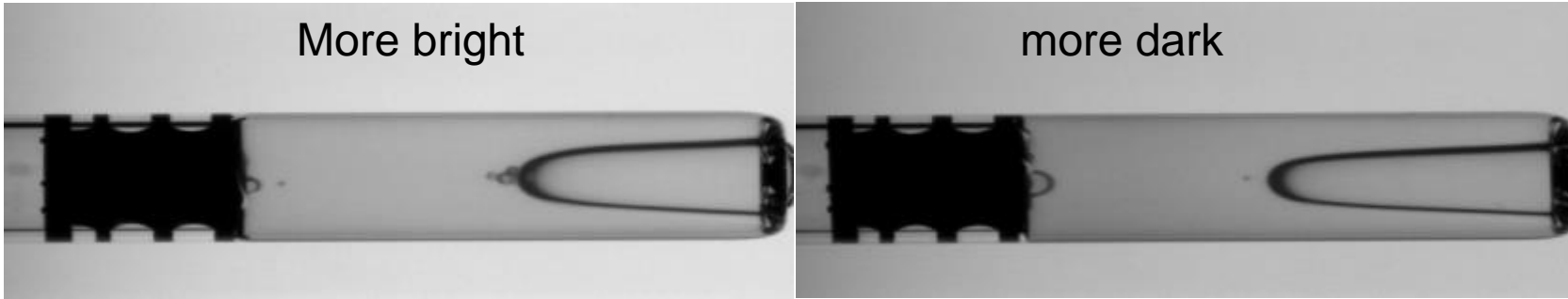
Critical Design Element:
Very powerful with on axial light to avoid reflects
Fragile surface with microscopic dots on glass



LED risks



LED are more stable butbeware of heat dissipation



More bright

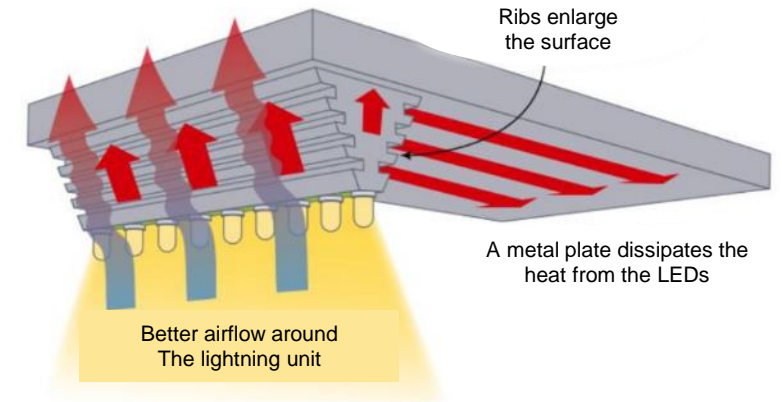
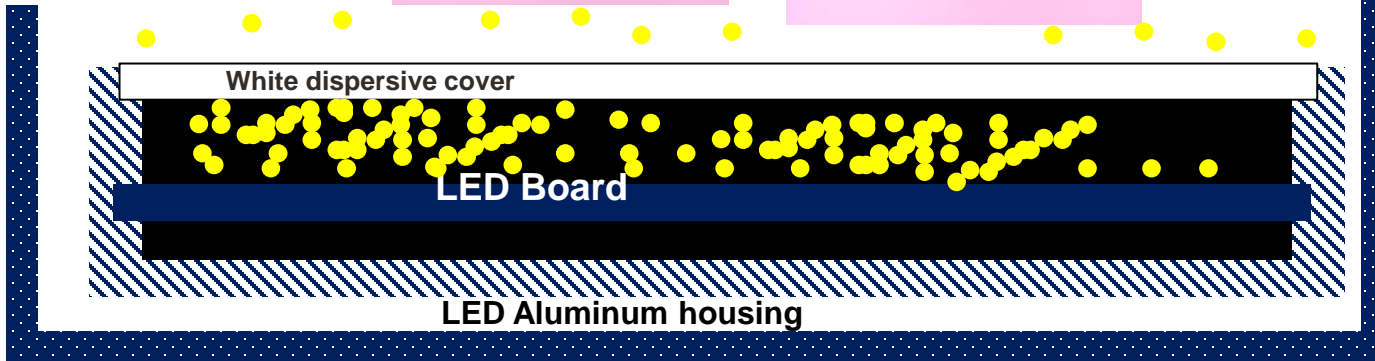
more dark

Conform

Crack



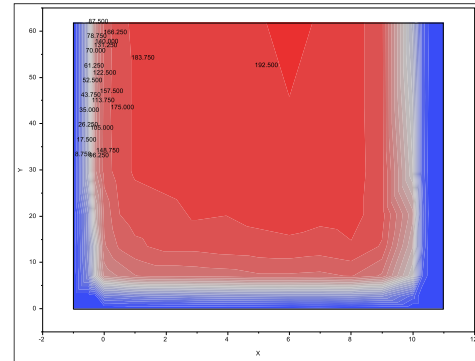
Critical Design Element:
LED are not stable if no good heat dissipation
Need a periodic ctrl or permanent
Good heat dissipation by design



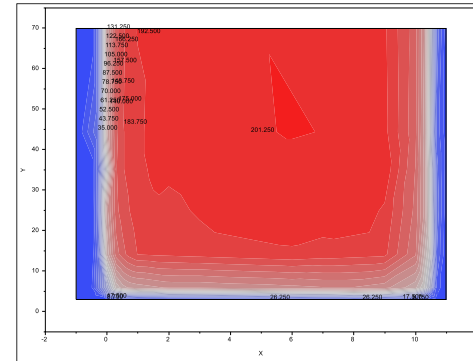
LED are more stable butbeware of boarder effect

Mapping of
Luminance
Level in X and Y
position
And Z position

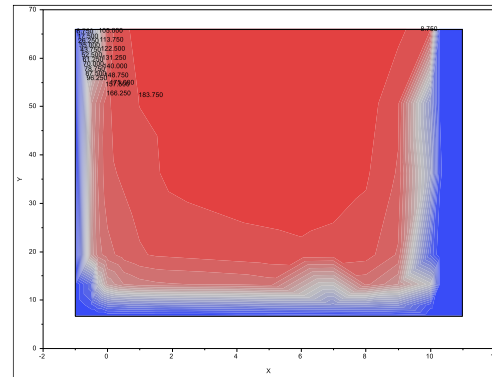
=> Very
Homogeneous
in area of use



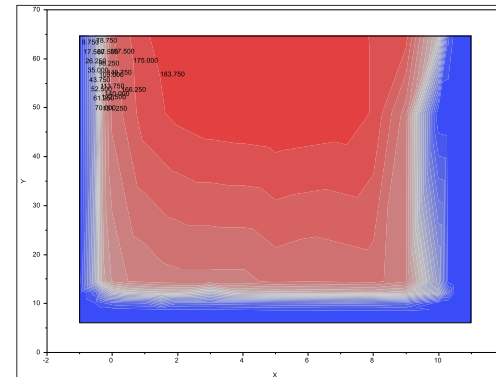
z =53.42mm



z =98.1mm



z =134.5mm

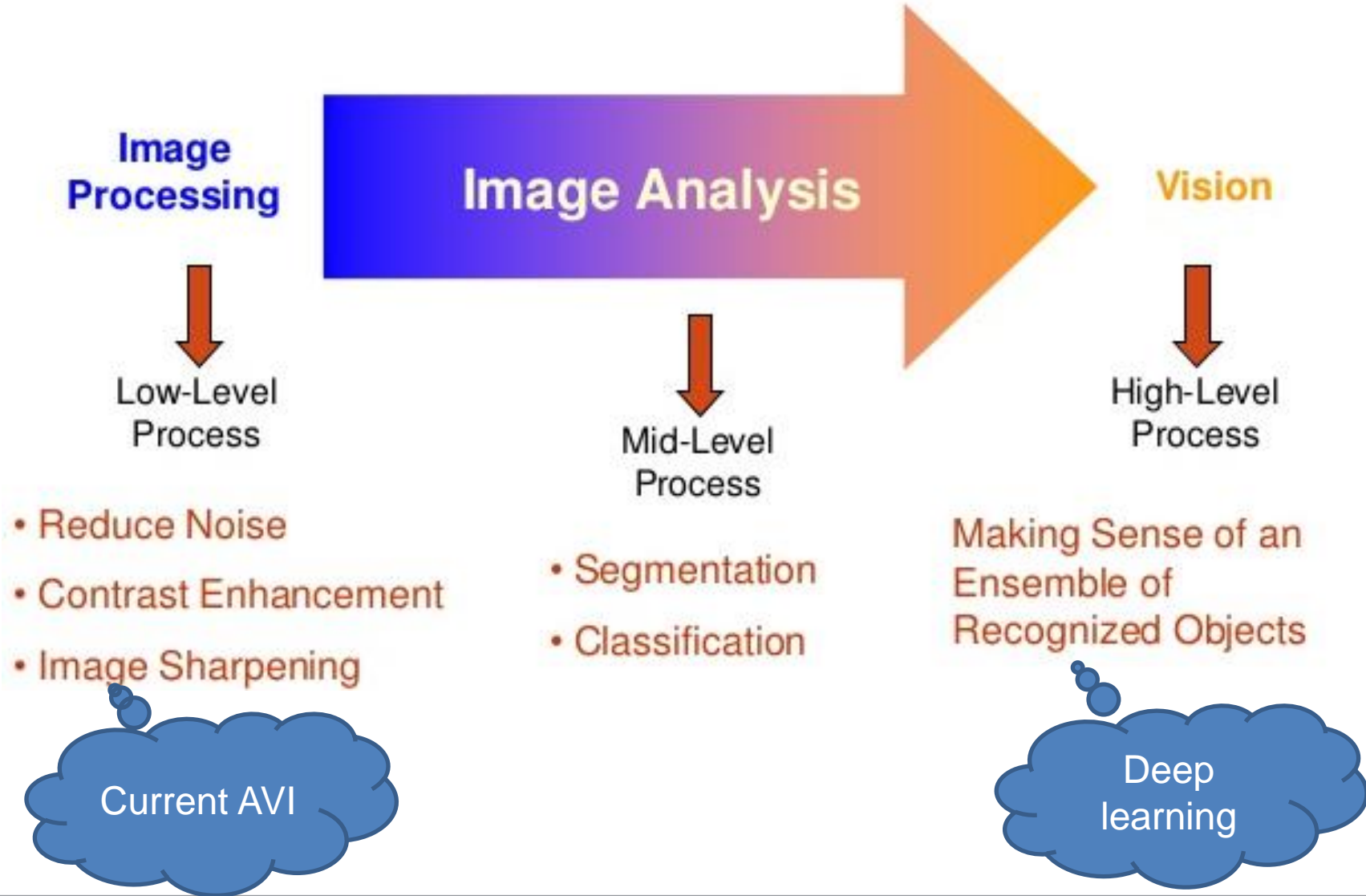


z =178mm

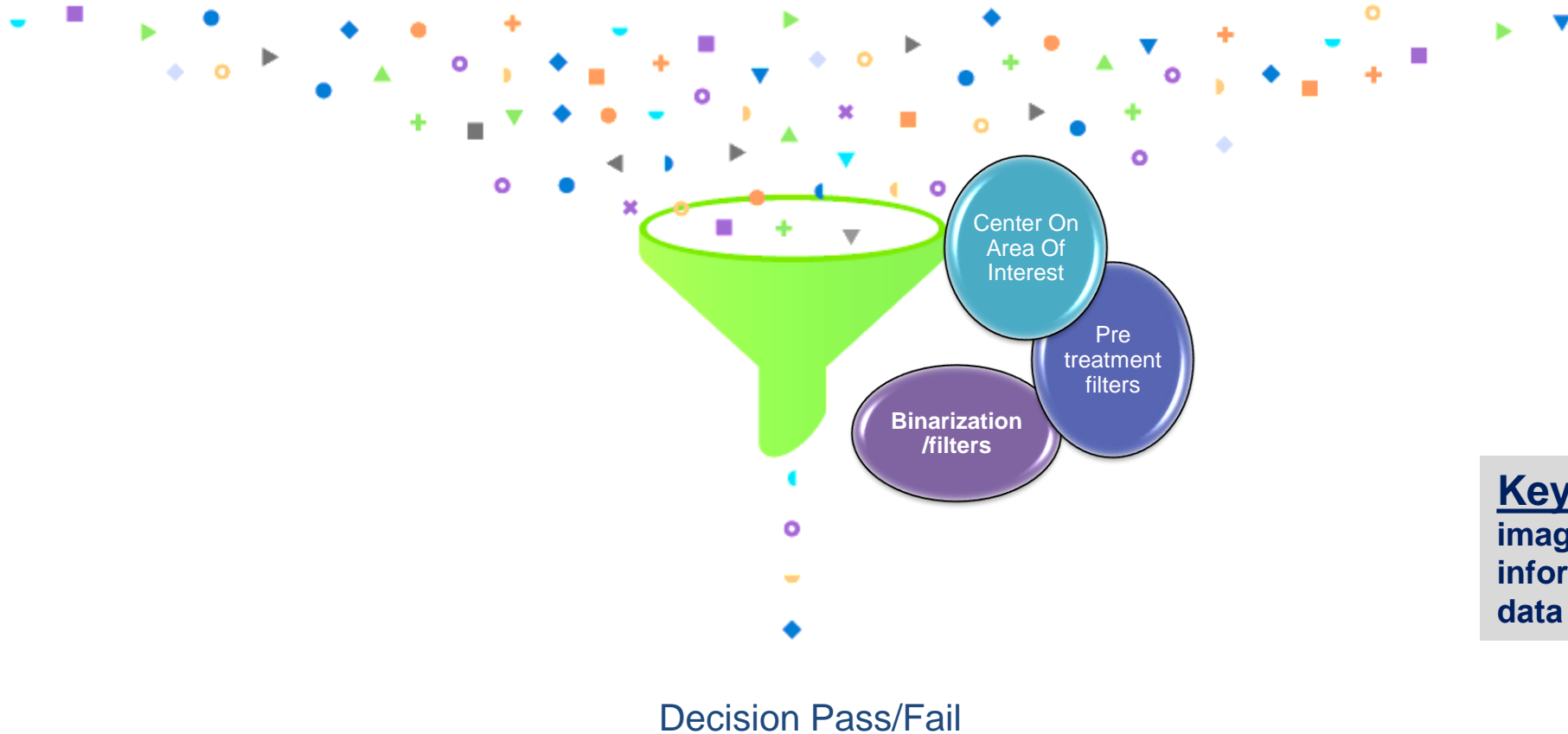
Critical Design Element:
LED have a border effect
Working area should be not so close from border
Need to have sufficient sized LED

Digital Image processing





A data reduction, a feature extraction

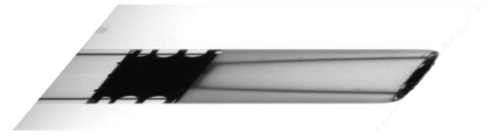


Key learning: an image has too much information need some data reduction...

1 3D Object presented



2 2D image



3 Area Of Interest (=AOI)



4 Binarization



5 Object detection



6

Feature Name	Current Value
Box X Min	227.0
Box Y Max	72.0
Box Y Min	70.0
Center of Gravity X	228.2
Center of Gravity Y	71.0
Convex Perimeter	12.0
Elongation	1.4
Feret Elongation	1.4
Feret Max Diameter	4.2
Moment Central X1 Y1	0.0

Image feature

7

Image understanding

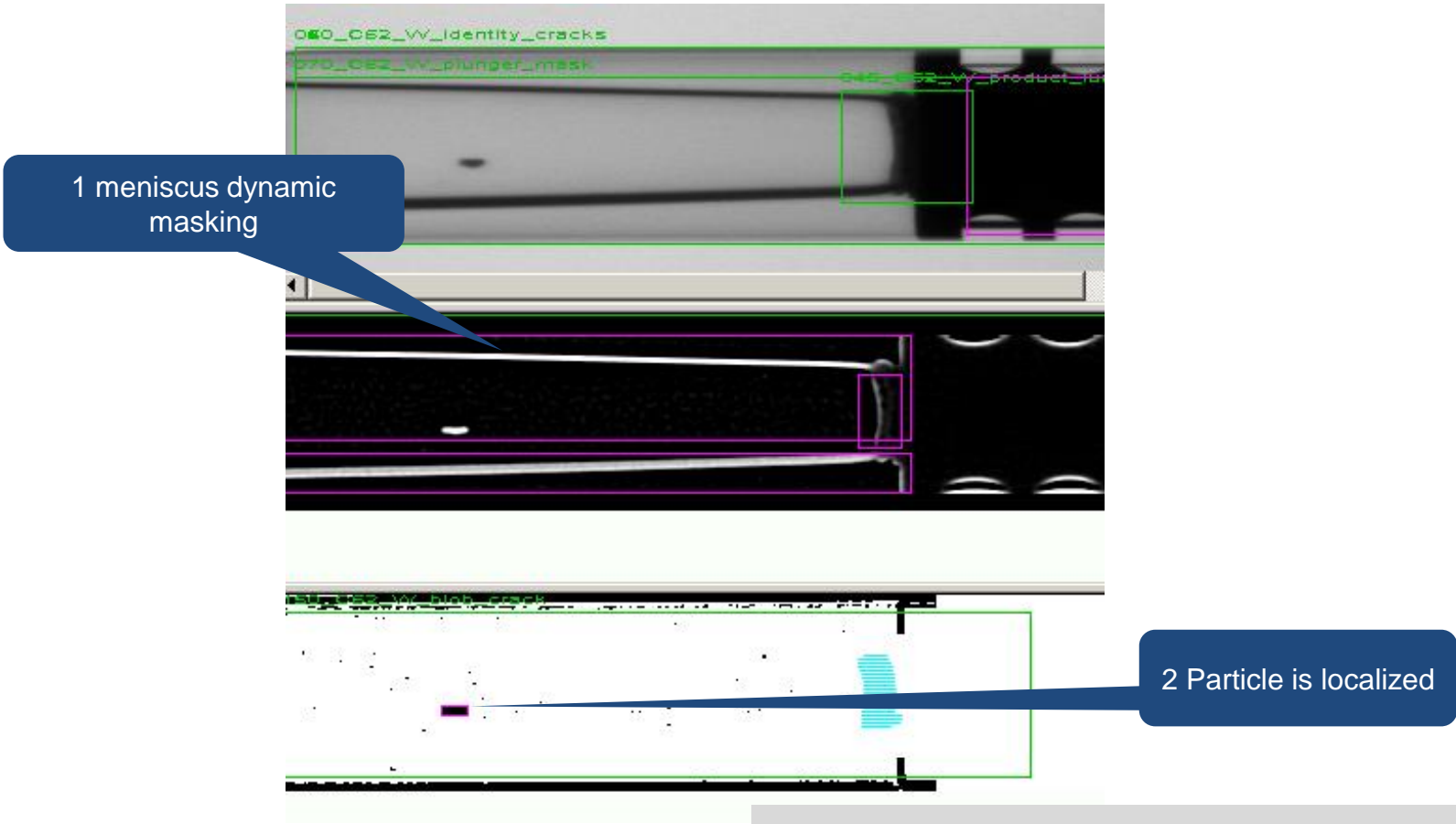
8

Pass / Fail

Key learning: this engineering step of vision recipe development is done to reduce information of images and to enhance specificity of decision...
.....in less than 10ms

<10ms

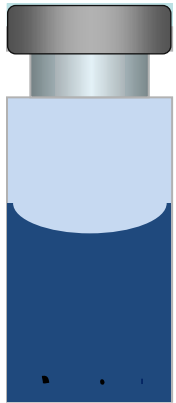
Critical Design Element:
Image processing must be editable with recipes (no hard coding)
Recipe must be version controlled
Any change on vision recipe must be tracked with audit trail



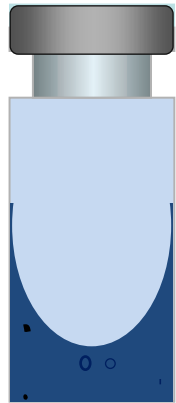
Key learning:
Color / Shape / Position features can help to discriminate particle and bubbles

Particle Detection strategies : image subtraction an old approach

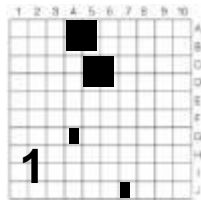
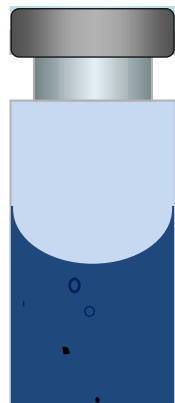
Vial with 3 particles



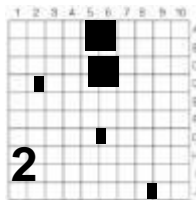
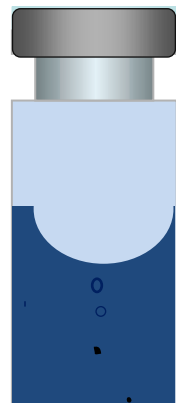
Rotation 600t/min 2 bubbles



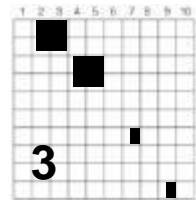
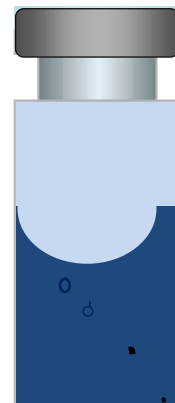
Stop 1st Image



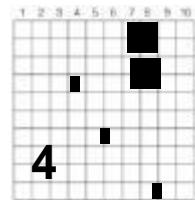
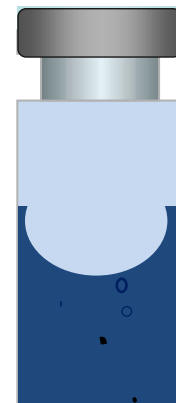
Stop 2nd Image



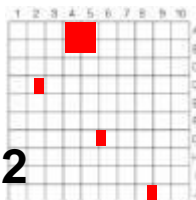
Stop 3rd Image



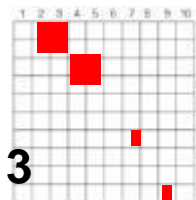
Stop 4th Image



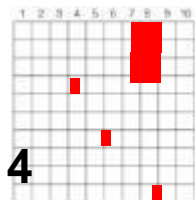
1- 2



1- 3



1- 4



NOT SENSITIVE TO FIXED PARTICLES + ABOVE liquid

Key learning:
 Image Subtraction is not very sensitive for particle detection in small suspension unit + no detection above liquid + no detection of fixed particles



How to inspect Automatically a suspension that has a high optical density + scattering?

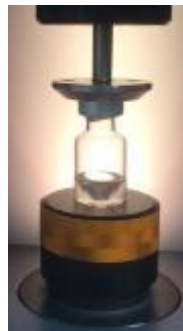
= Fast rotation To present liquid in thin layer

⇒ Lower optical path (density beer lambert)

⇒ Minimized scattering effect



0 t/min



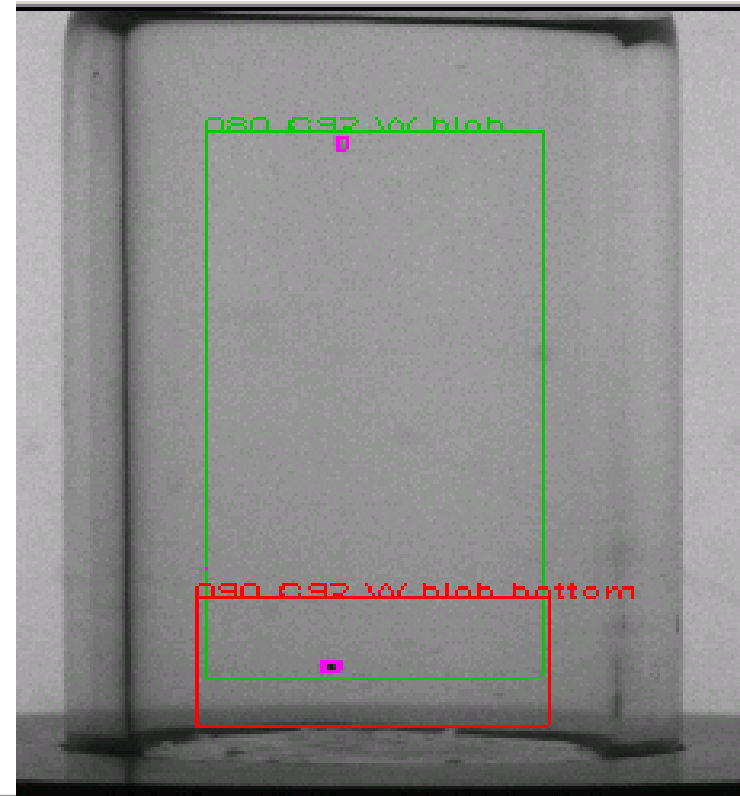
600 t/min



1800 t/min

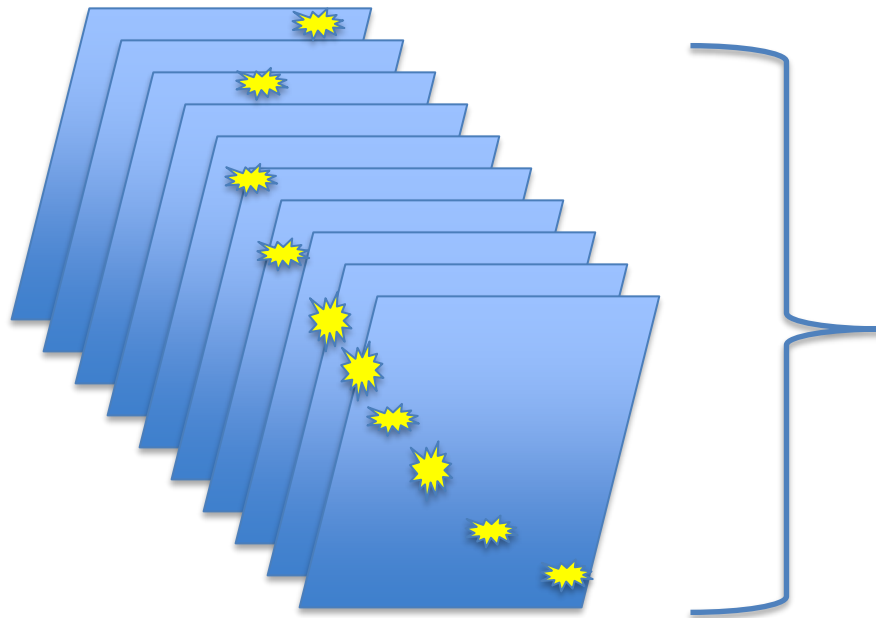


3600 t/min

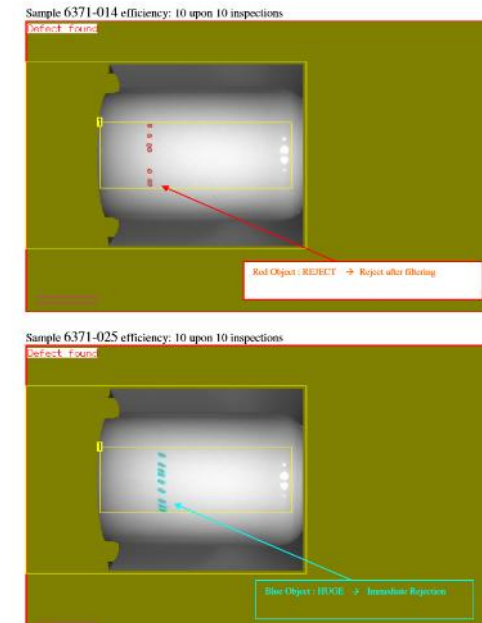


Particle Detection strategies : Particle tracking

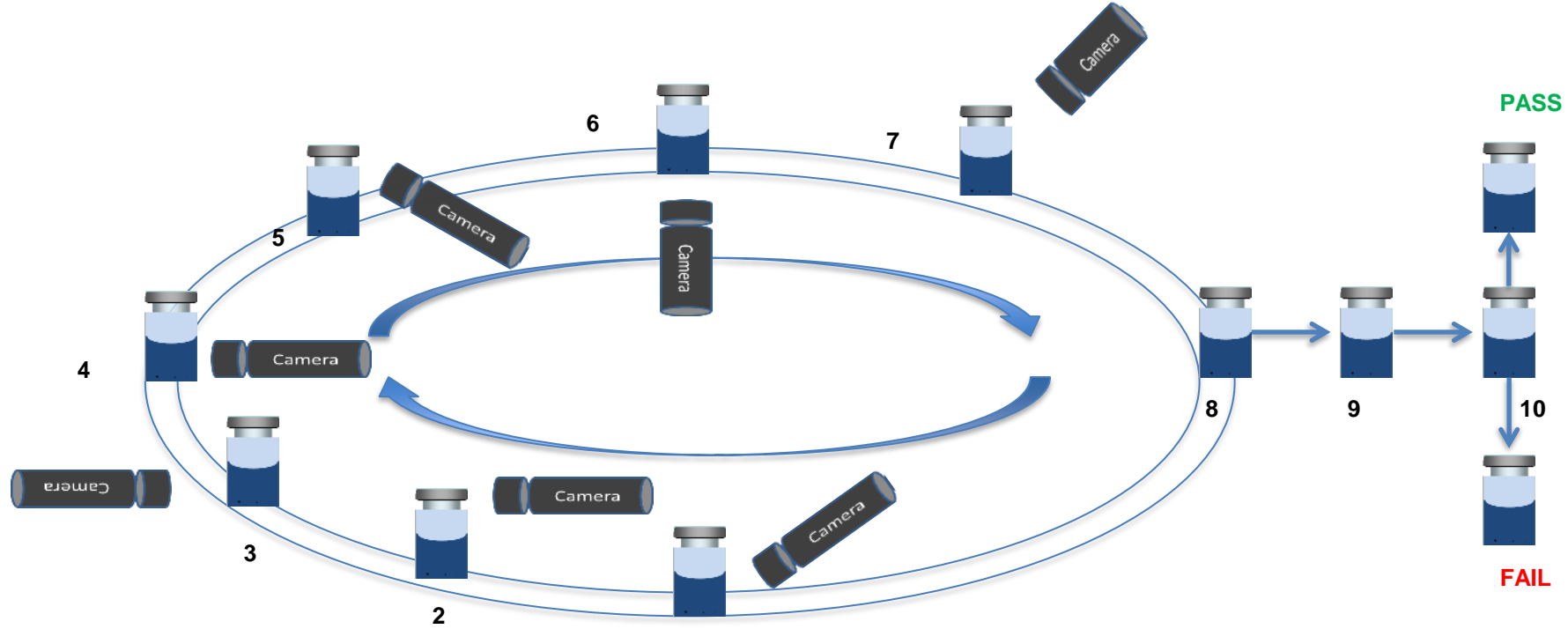
- With modern vision machine more images are available
- Images can be treated not only 1 by 1 individually but in stack of images
- Rendering particle trajectories analyzed
- And differentiation to artifacts like bubbles



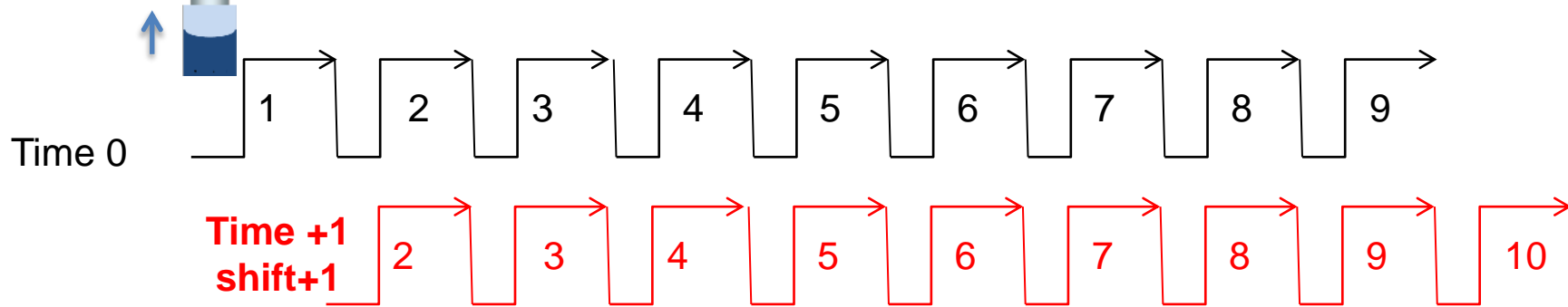
Analyze of 1
stack of 10 to
60 images all at
once to track
particle
trajectories



Automation principle of shift register

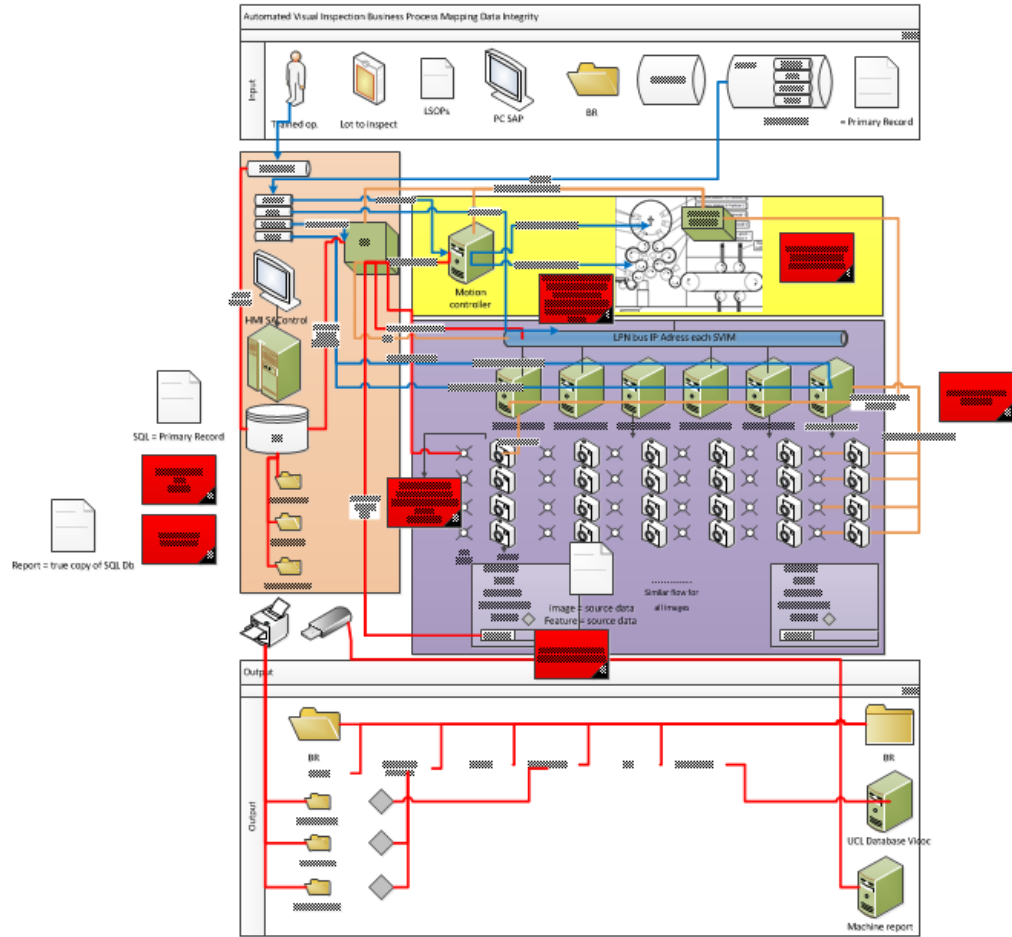


Critical Design Element:
Daily check is a very practical way to confirm that the shift register is functional



Automation business mapping

- move forward to elaborate a fully transparent flow of information inside AVI



Automation

Mechanic

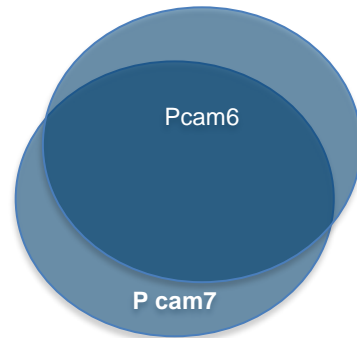
Vision

Critical Design Element:
Drawing a business process mapping for information flow inside your AVI is a way to share knowledge between experts, supplier and QA and end user

Concept of collaborative cameras

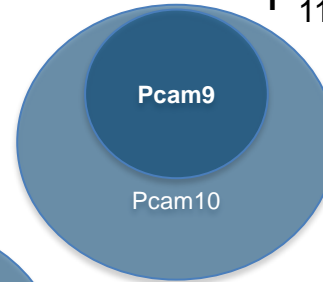
- Multiple camera on AVI machines**

2 collaborative
Cameras for a
specific area
i.e. = Syr. flange

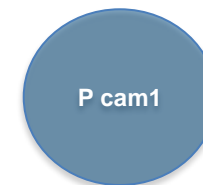


A & B mutually exclusive
 $P_{11+12} = P_{11} + P_{12}$

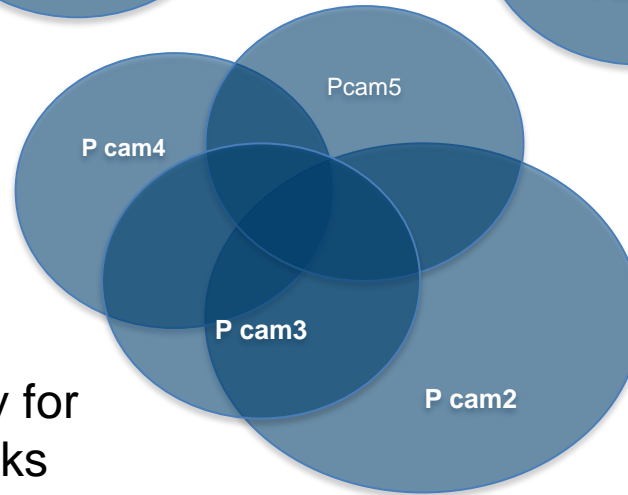
2 Camera specific
for a defect area
i.e. = Syr. closure



Camera specific
for a defect family
i.e. = Fill level

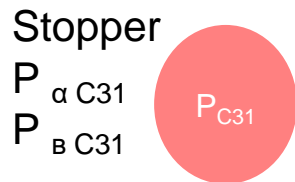


4 collaborative
Cameras for a
specific area
i.e. = Syr. Body for
particle or cracks

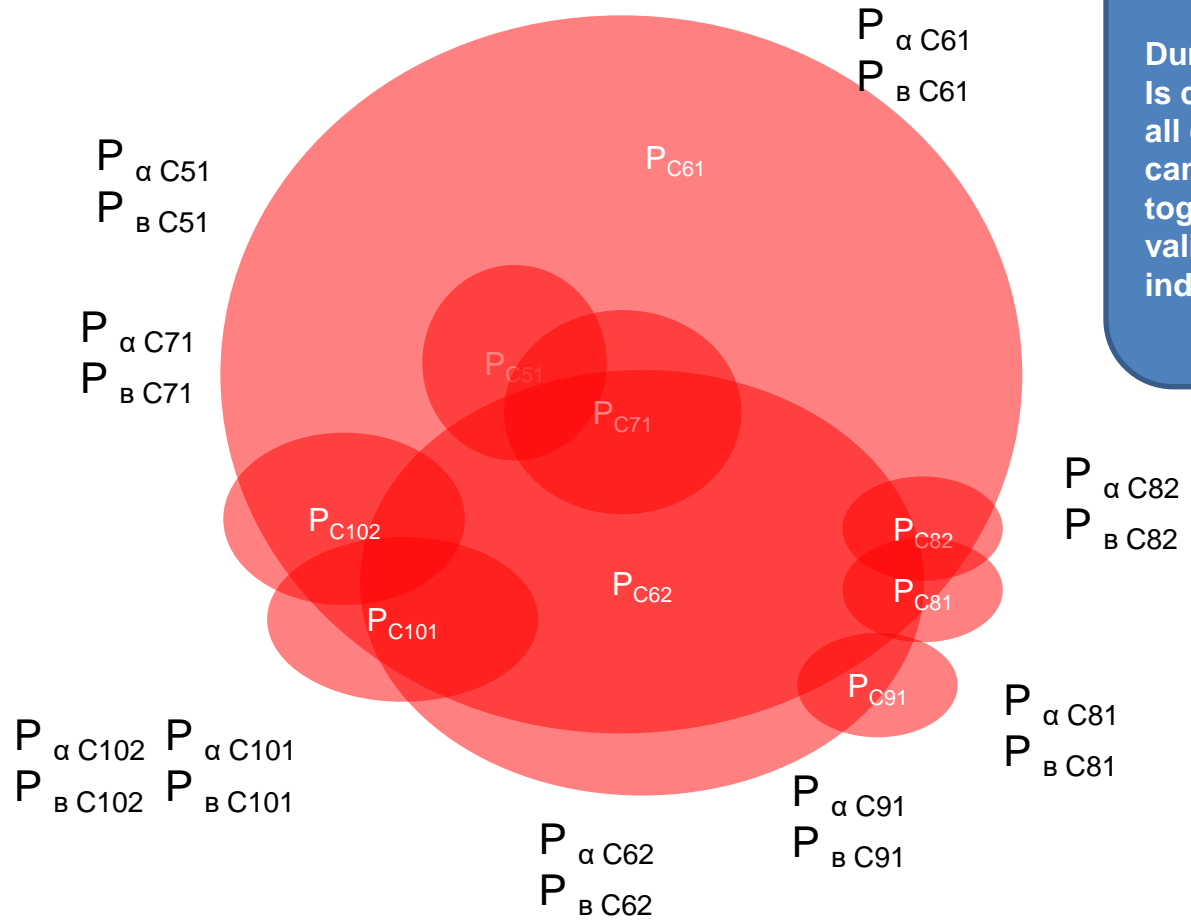




Key learning: Automated Inspection machine may be compared to an orchestra: each camera may be compared to an instrument group contributing to an overall particle detection. Each image may be compared to a individual player. We have up to 15 cameras and from 32 images to 150 images per unit



Venn diagram for detection probability



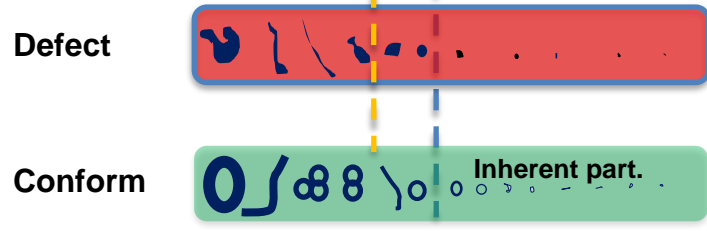
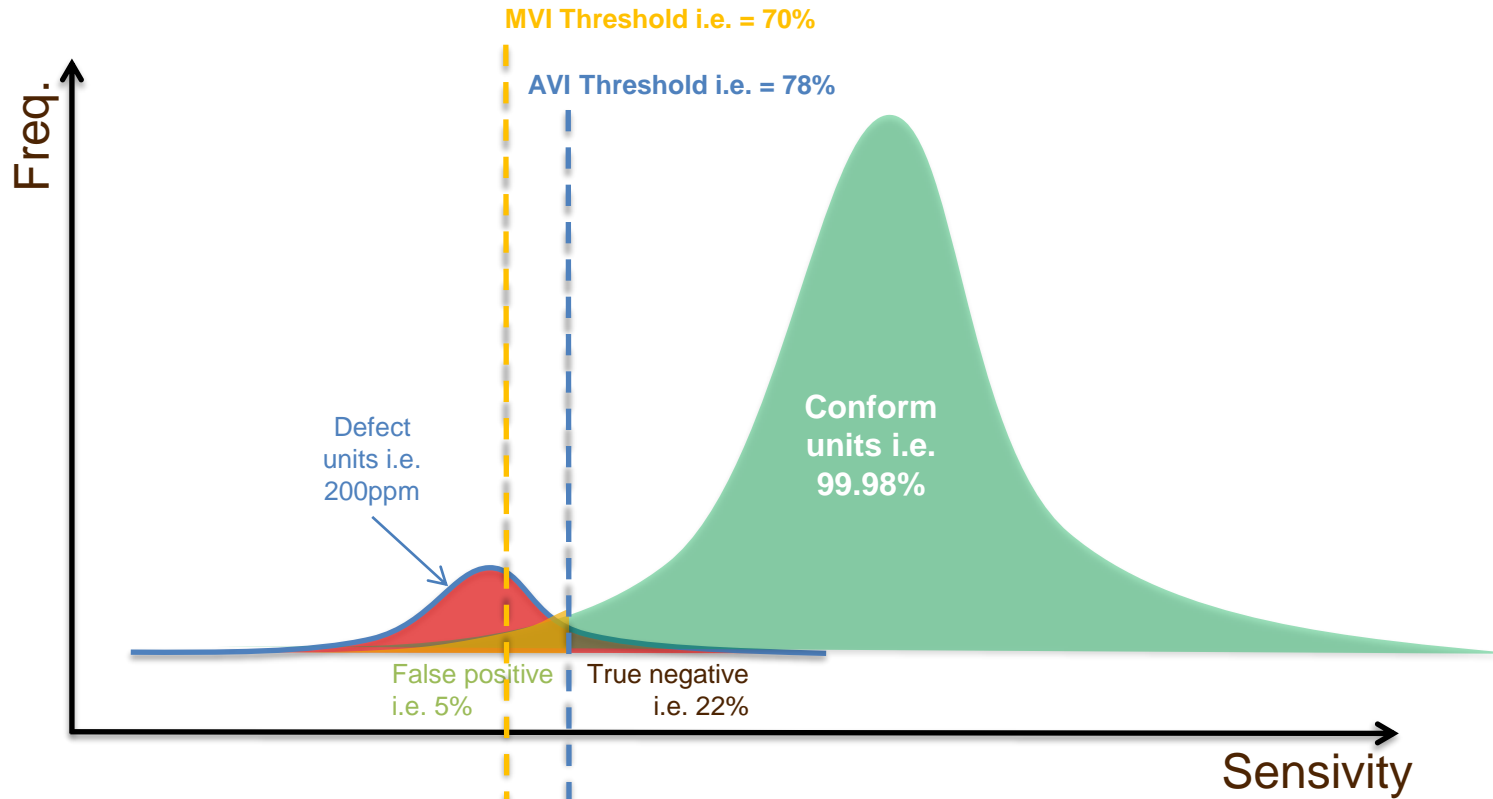
Critical Design Element:
 During validation it is critical to activate all collaborative camera working together, you cannot validate camera individually

● Vision stations for particles

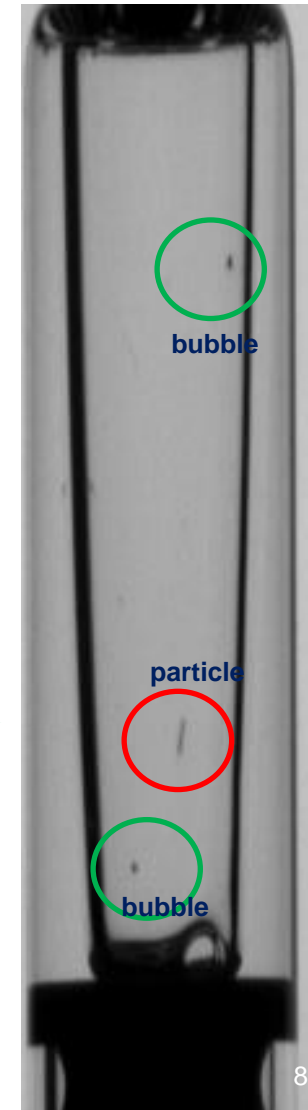
False reject

True reject

False reject / balance patient vs business risk



Key learning: Automated Inspection tuning is a balance between patient risk (Beta) and business risk (Alpha)



		Actual Value (as confirmed by experiment)	
		positives	negatives
Predicted Value (predicted by the test)	positives	TP True Positive	FP False Positive
	negatives	FN False Negative	TN True Negative

Critical Design Element:
 Control of false reject could be considered as a validity criteria
 Unit used for this test should be first inspected.

Binomial law shows that min 3300 units can give an accuracy of +/-1% of False reject rate

100 to 1000 units for evaluation of False reject has a poor accuracy

RECAP

You have learnt

AVI

- CQAs, CPPs
- critical design elements
- Core part of AVI
- Sequence images
- Mechanical presentation
- Camera
- What sees AVI
- LED
- Computer vision
- Automation
- False reject



AVI

- What CDEs, CPPs, CQAs
- Why is capability management key
- What are the core parts of AVI
- What tools do you need to keep AVI in validated state
- Do you validate per camera or the whole