



# Mastering AVI

## Part 3: Introduction to technical principles of automated inspection machines

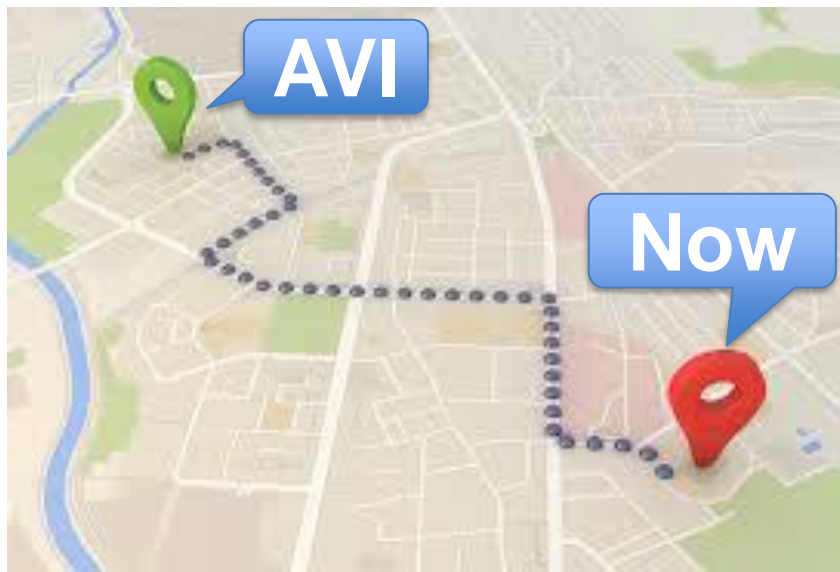
- Camera systems / light / motion
- Image processing and database system
- Interlinkage of parameters:  
Speed, Rotation speed, Inspection parameters,  
Detection probability, False reject rate
- Properties, capabilities and limitations of automated inspection systems
- Scope of Automated Visual Inspection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



Instructor Lead: Romain Veillon / Fernand Koert / Sébastien Koch

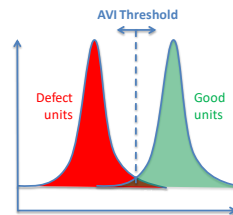
# Mastering Automated Visual Inspection

.....A long way, let's guide you !

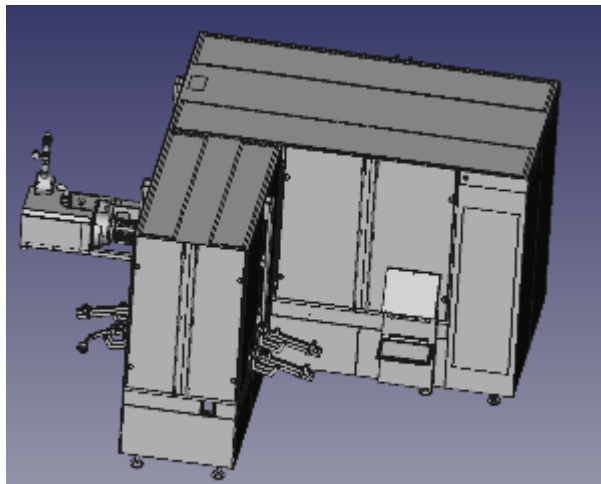


## Part3: Introduction to technical principles of automated inspection

- 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

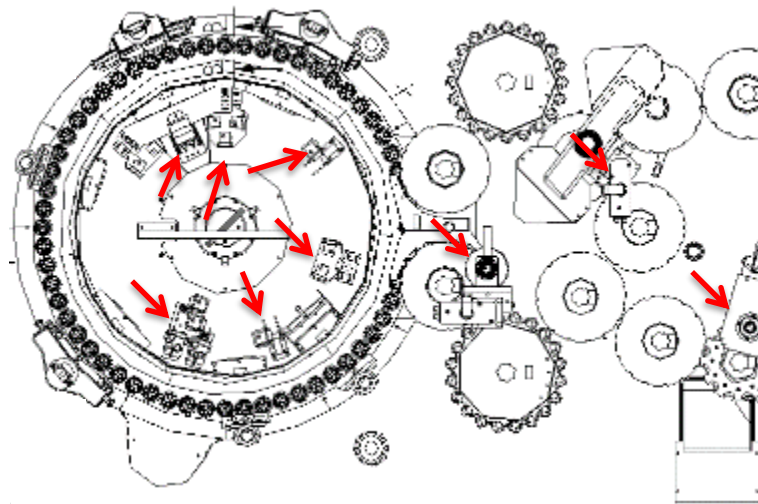


# Intro



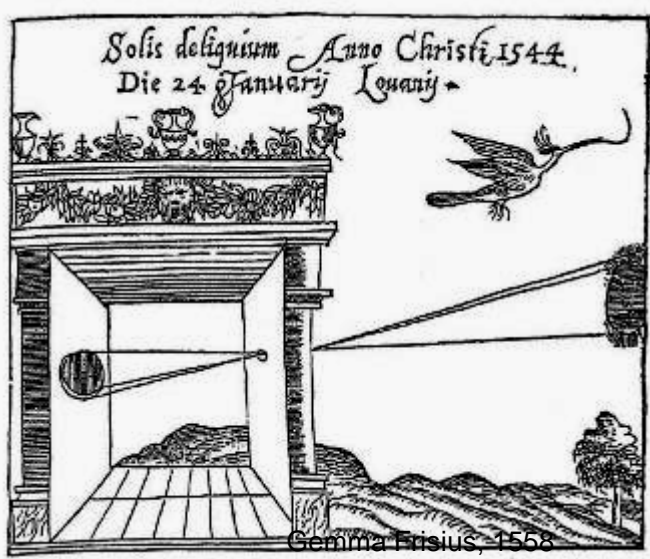
Just a black box ?

Certainly no more!!



## Part3: Introduction to technical principles of automated 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 »

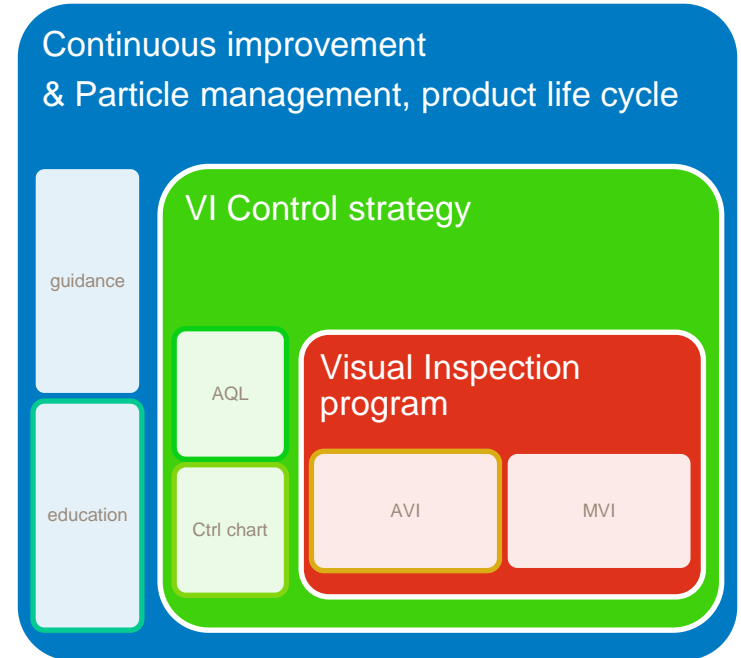
Aristotle, De Anima, Book 2, 10

Camera Obscura

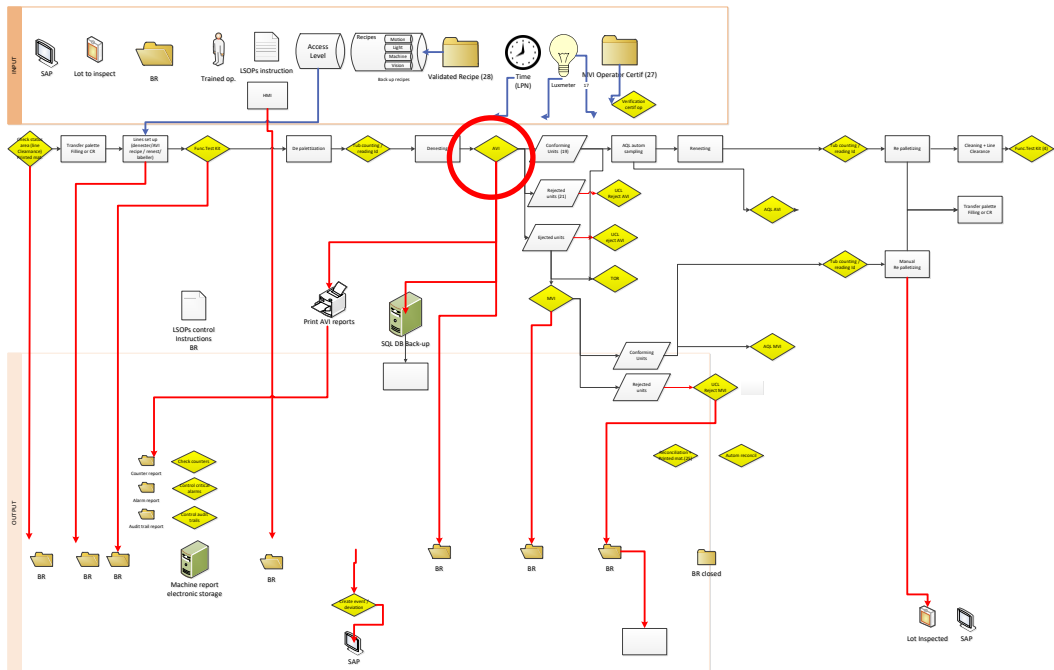
- Basic principle Aristotle (384-322 BCE)
- Drawing aid for artists: described by Leonardo da Vinci (1452-1519)
- .....first industrial CCD camera 1975
- 2017 AVI

## 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 mngt. The Particle management guidance is a key to success with particle control and associated WOW & education, product life cycle approach



# AVI Equipment is part of an overall VI process



## For AVI mastery ....People capability management is key !

### Best in class organization for VI (People mngt)

Transformation is not only buy 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



**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





# what are your CQAs / CPPs for VI process ?

Can you list some of them ?

- CQAs:

=> think about USP<1790>....

Atributes						
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

- CPPs:

# Core parts of AVI ?



**Motion of units**

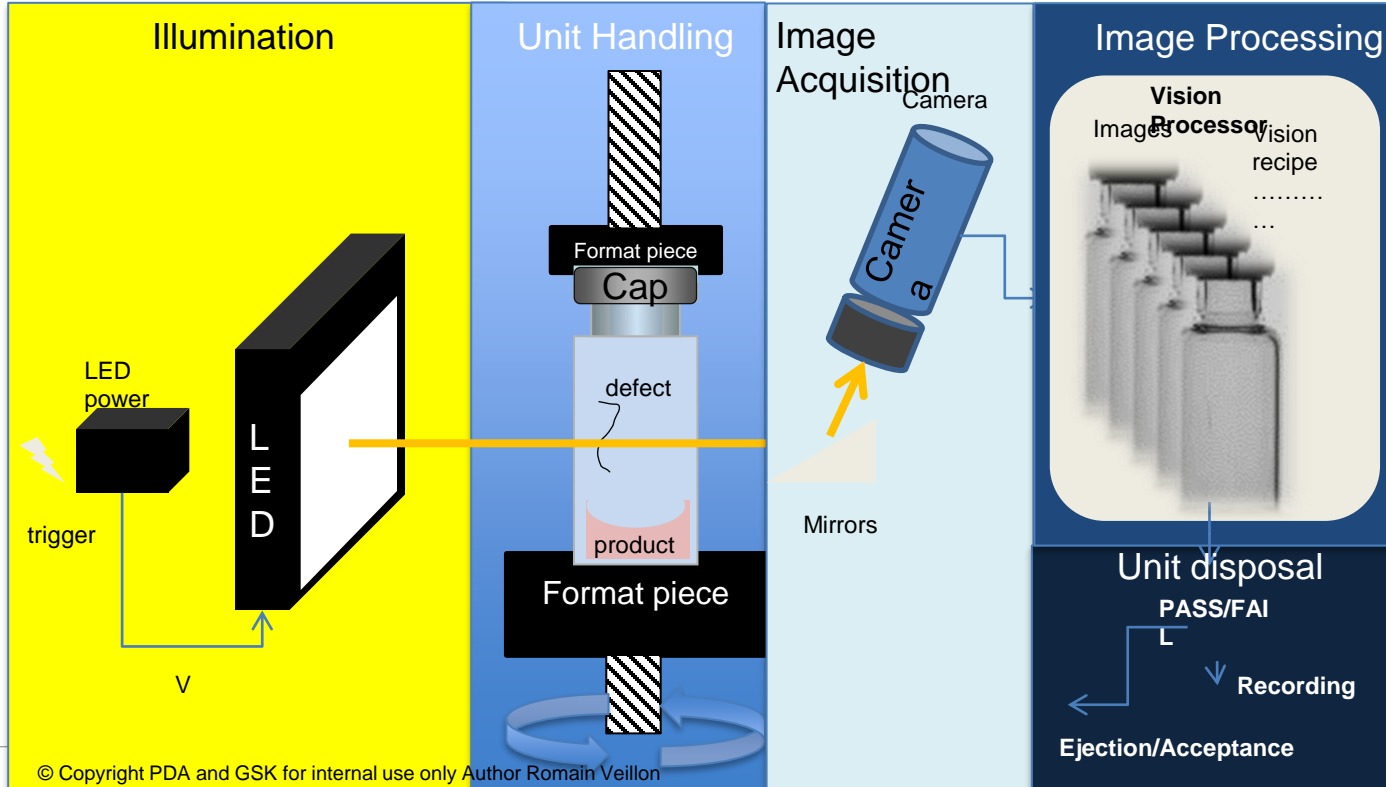


**Light illumination**

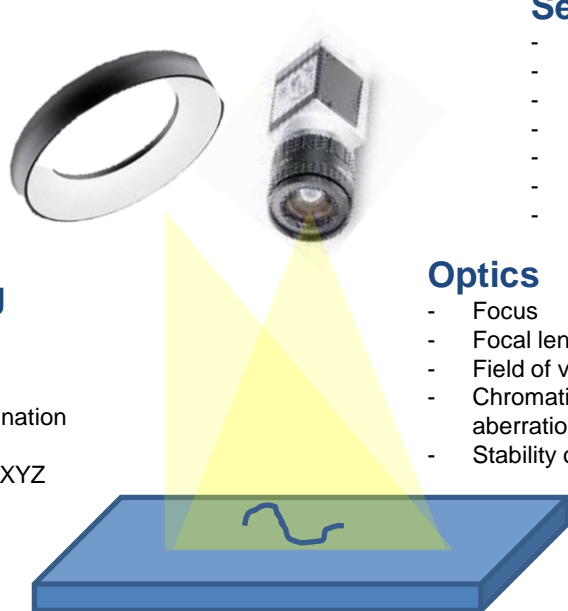


**Digital image processing**

# Critical Design Elements



# Vision System critical elements



## Camera Sensor

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

## Machine vision

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

## Lighting

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

## Optics

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

## 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

## AVI by block of critical function

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 (SQL)
11. Batch closure and local report creation
12. Central reporting & archiving

# Object presentation to camera

# Different way 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>

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

Side clip conveyor Innoscan: [https://www.youtube.com/watch?v=\\_5oueC3ilxY](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>

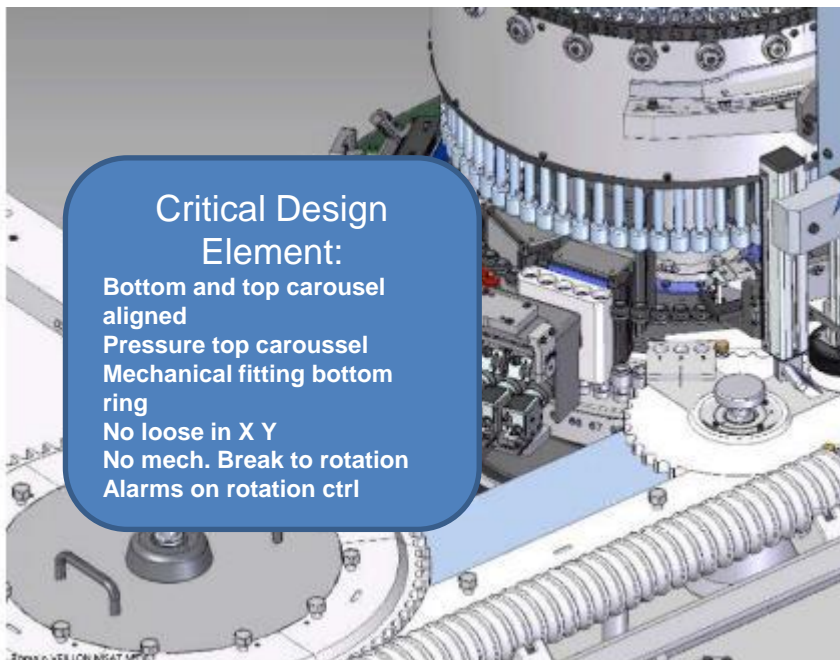
Base holder / Gripper / sucker

Those are pieces with ageing / regular checks / changes

Critical Design  
Element:

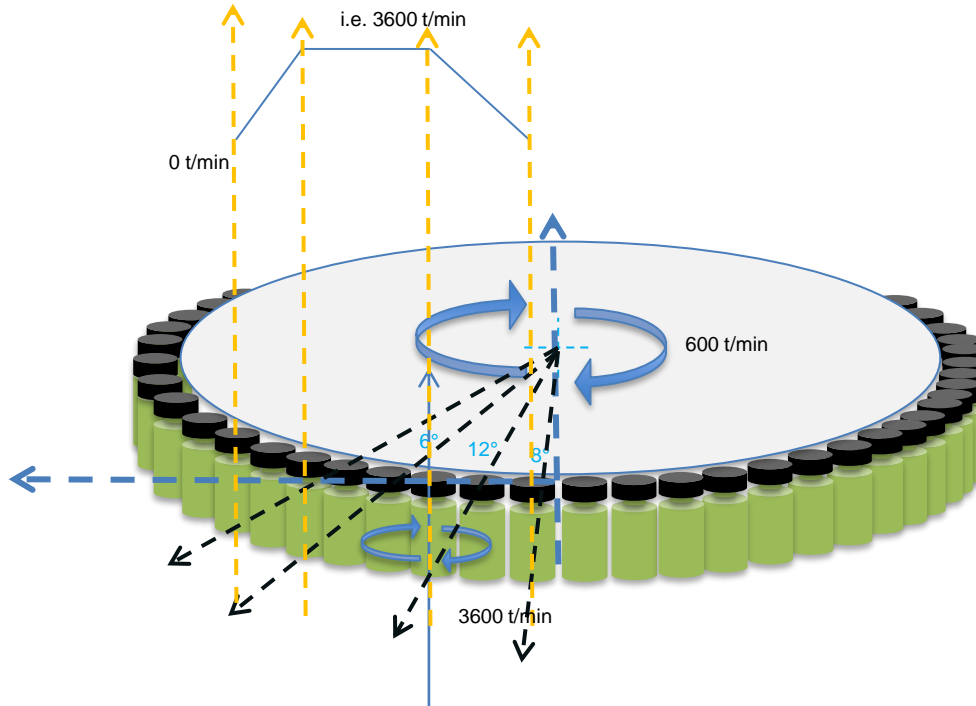
Mechanical stability  
Axial Rotation no cavitation  
Aging parts maintenance

# Unit Handling





# Unit presentation to camera



## Critical Design Element:

No slip on bottom plate  
No cavitation on bottom plate  
Continuous movement no stop&Go  
Axial rotation

**Key learning:** Modern AVI machine is very complex in term of unit motion;

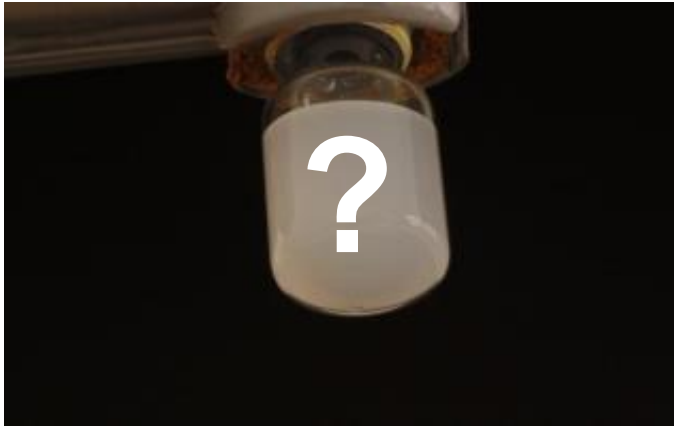
Double motion main

- carousel rotation
- each unit individual fast rotation

+ all synchronized to image acquisition every few ms



## Unit presentation to camera => Fast spin rotation



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

- = Fast rotation To present liquid in thin layer if you have remaining headspace in unit
- = Lower optical path (density beer lambert)
- = Minimized scattering effect

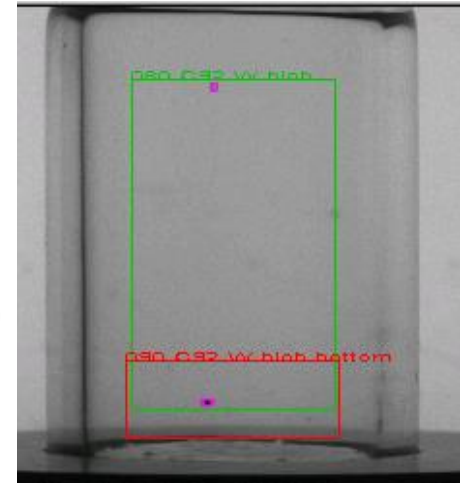


0 t/min

600 t/min

1800 t/min

3600 t/min



# Fast speed rotation issues

1000 images Conform overlayed



1000 Crack image overlayed



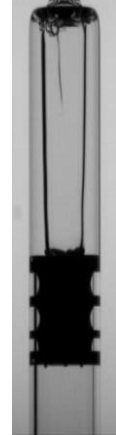
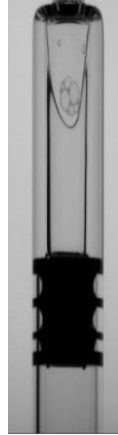
- Conform images are clearly shifted to the left and more shaky
- Crack images are more stable

## Critical Design Element:

Fast spin requires strict mechanical alignment

- Vial baseholder design
- Vial design
- Multiple sourcing management

# Fast speed rotation issues

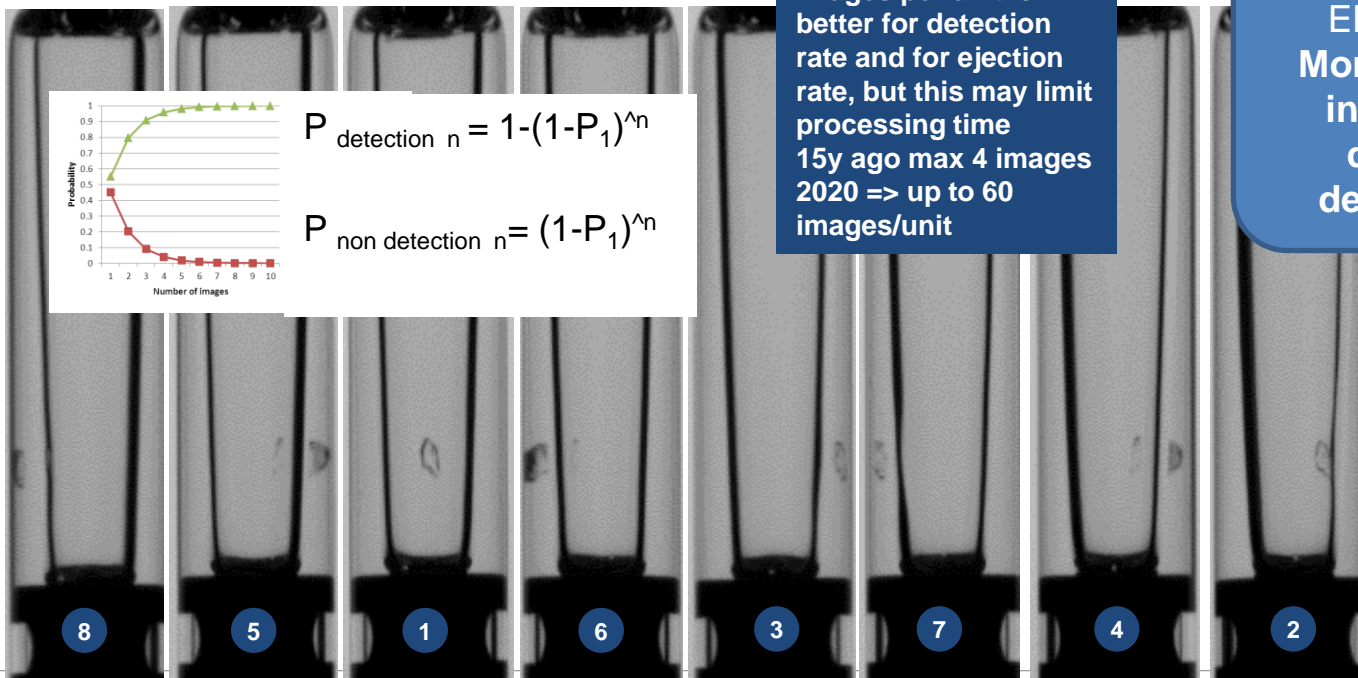


Normal

Distortion due to waves

- Not only mechanical
- Glass quality plays an even important roll
- If eg. the flange is not perfectly aligned 90 ° with the body, which might be the case with cheaper glass, you will get the same issues

## Unit rotation / multiple images



**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

**Critical Design Element:**  
 More image increase defect detection

# Camera and image acquisition

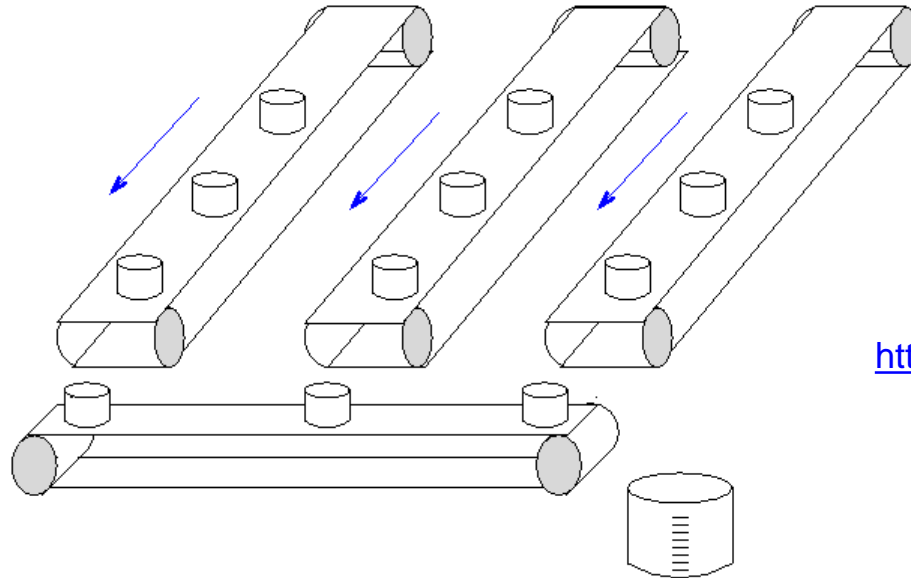
# Camera



- Integration
- Transfert
- Amplification

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

# Transfer of electron on a CCD

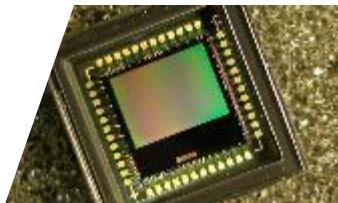


[https://youtu.be/ZwN0DT\\_4FhY](https://youtu.be/ZwN0DT_4FhY)

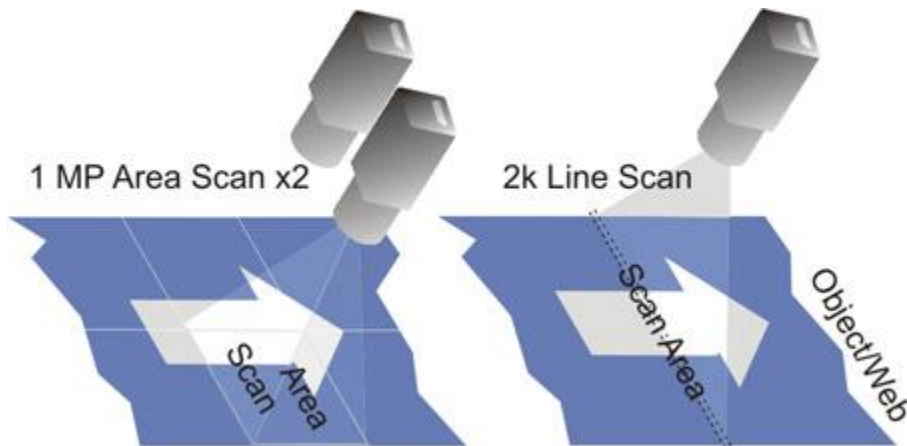


# Camera types

- Matricial Sensor : X and Y image

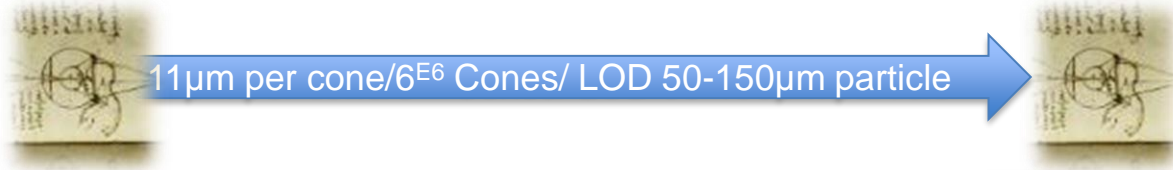


- Linear Sensor = Line Scan

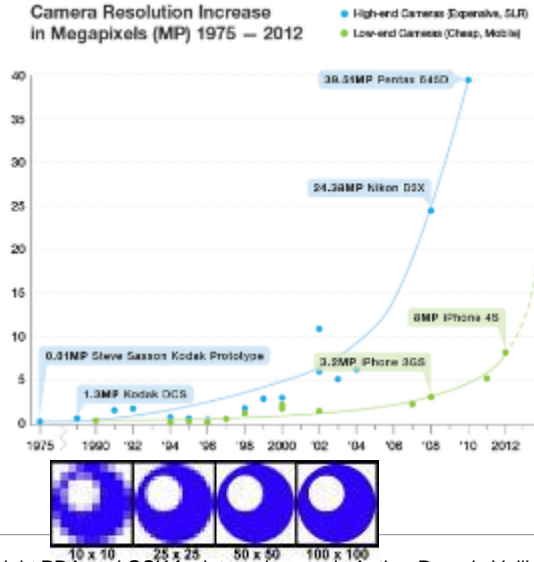


# AVI improvement last 2 decades, soon matching Human Eyes

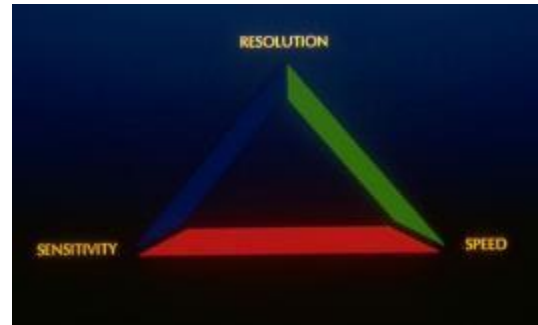
MVI



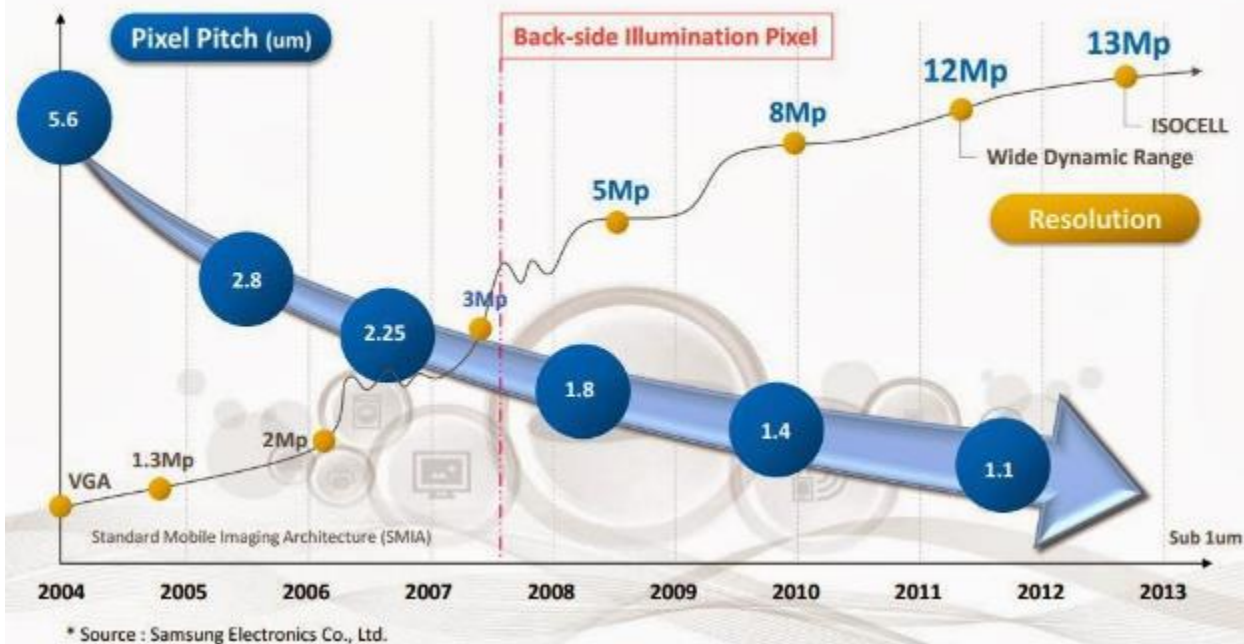
AVI



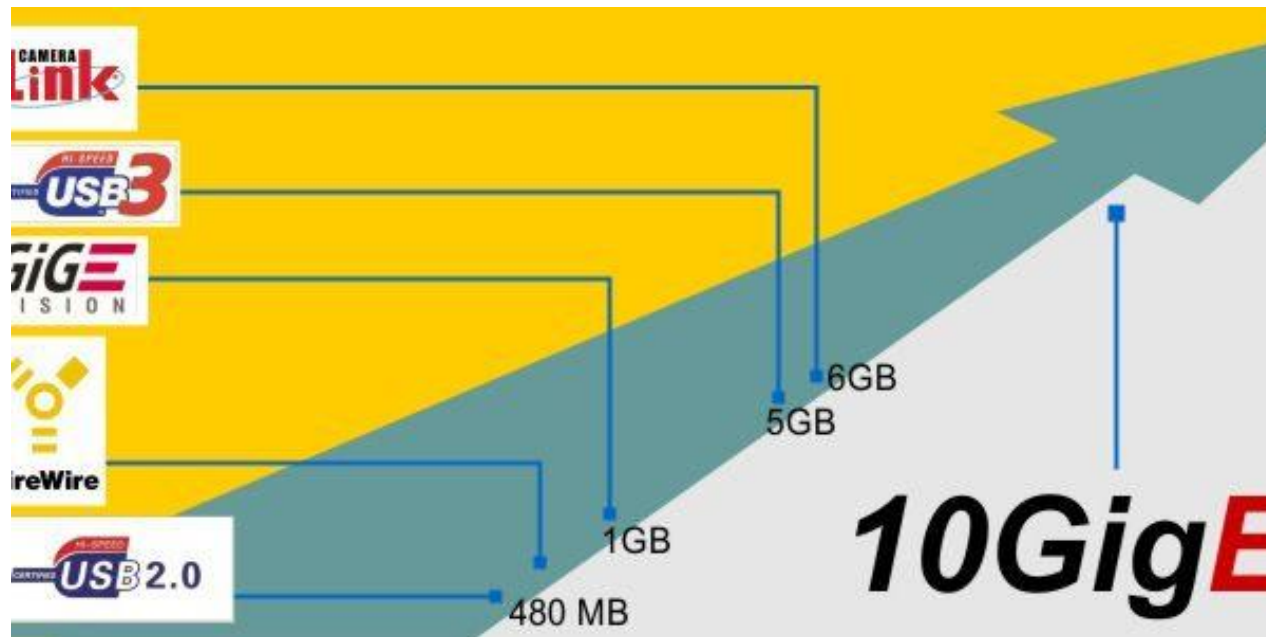
2020  
2-5 MP  
6µm /pixel  
48 images  
/vials



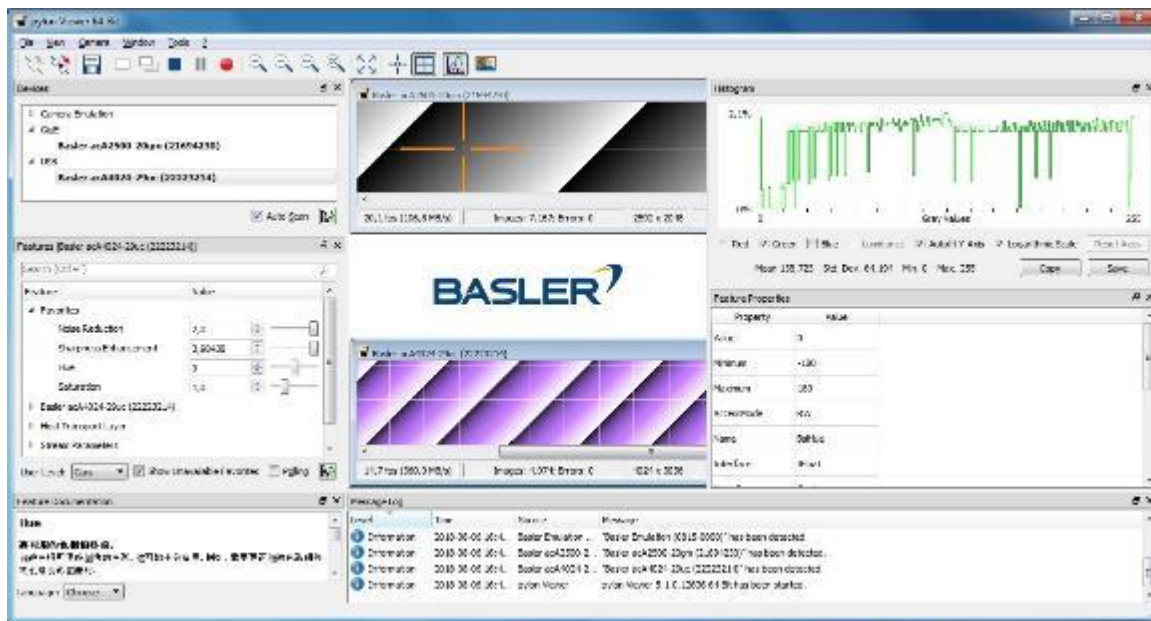
- Higher resolution & smaller pixel have driven sensor industry



# Camera transfer protocols



# GigE camera setup

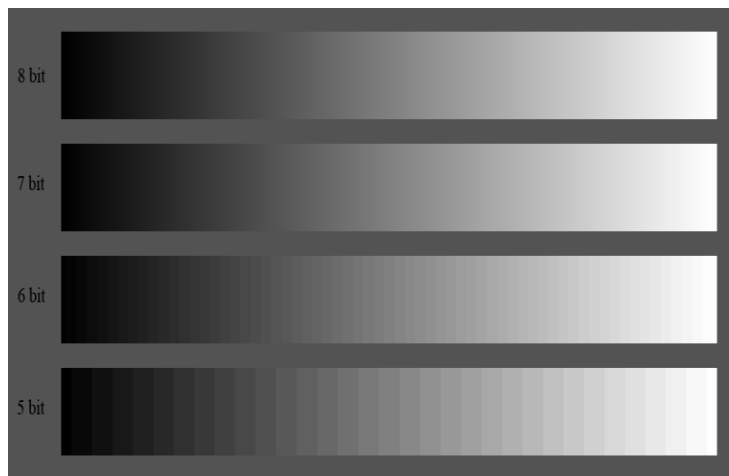


**Critical Design Element:**  
 GigE camera have tones of parameters....access ctrl!  
 Change over documentation

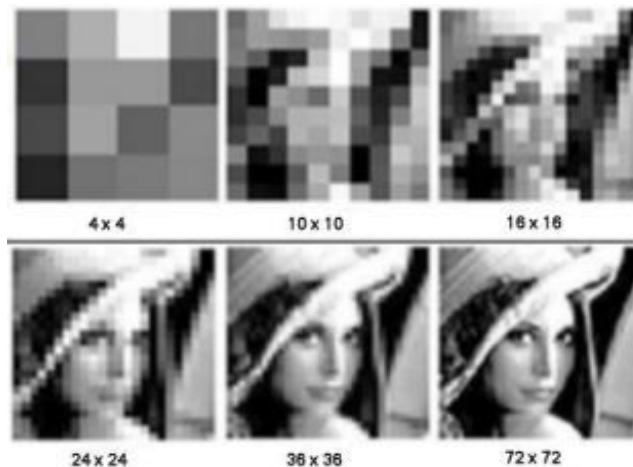
## What is your Image resolution ?

**Key learning:**  
Tonal resolution  
Spatial resolution /  
Size sensor

tonal resolution

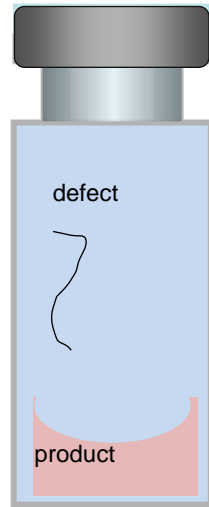


Spatial resolution

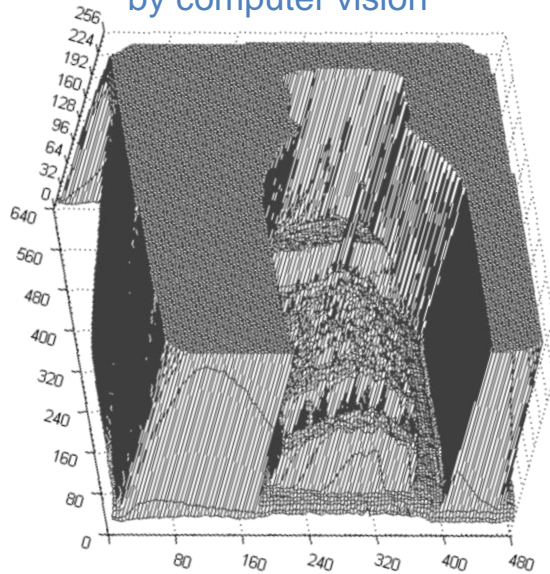


## What a machine really sees, what is DIP?

Object as seen  
by human



Same Object as  
represented  
by computer vision



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

**A matrix of Variable with grey level by color channel**

- discrete spatially
- discrete quantitatively

# Optic Fundamentals



# Image Acquisition => optic parameters

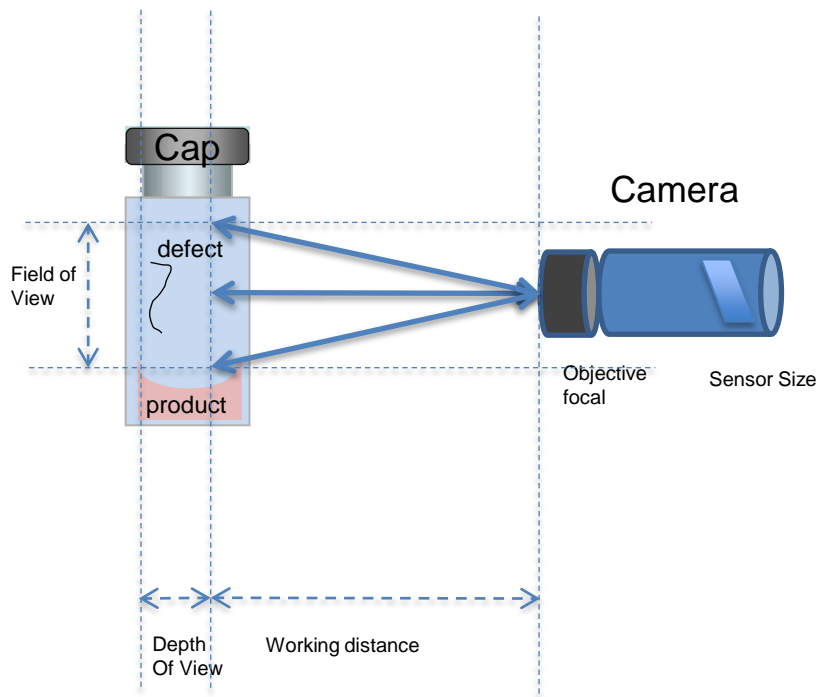
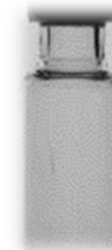


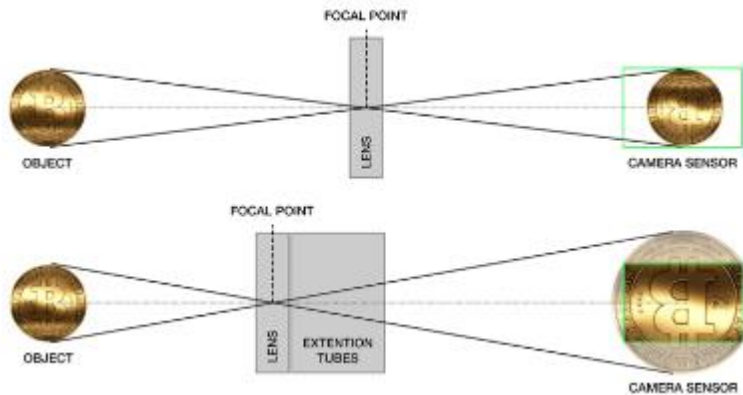
Image Acquisition



Critical Design Element:  
Optical parameters are CDEs

## Image Acquisition => optic parameters

Extension tubes and mirrors are used to cope with lack of space to shorten focal distance



**Critical Design Element:**  
Extension ring use must be documented with specifications

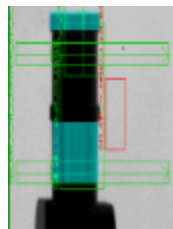
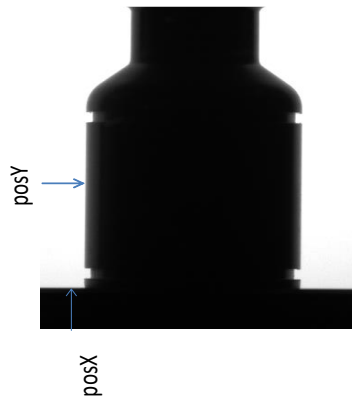


# Vision mechanical alignment

Dummy syringe



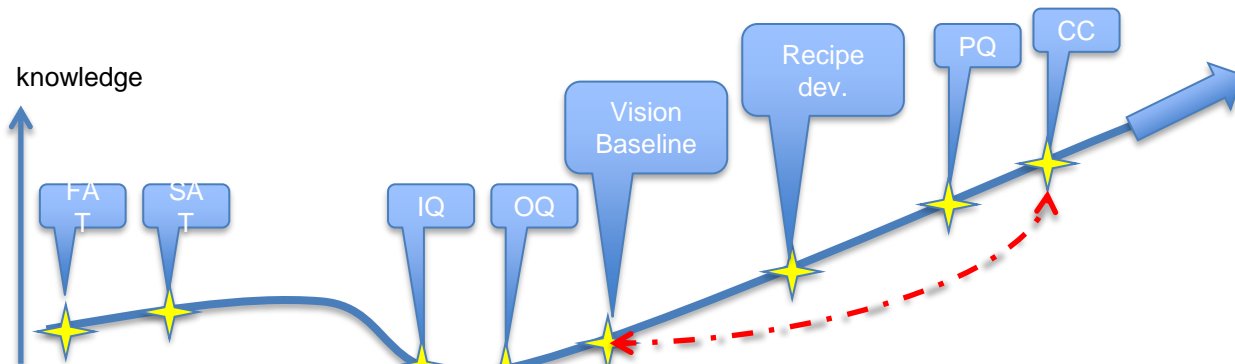
Dummy vial



**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

## Baseline definition to keep zero alignment



Critical Design Element:

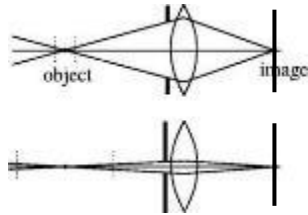
OQ vision must establish vision parameters baseline

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

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



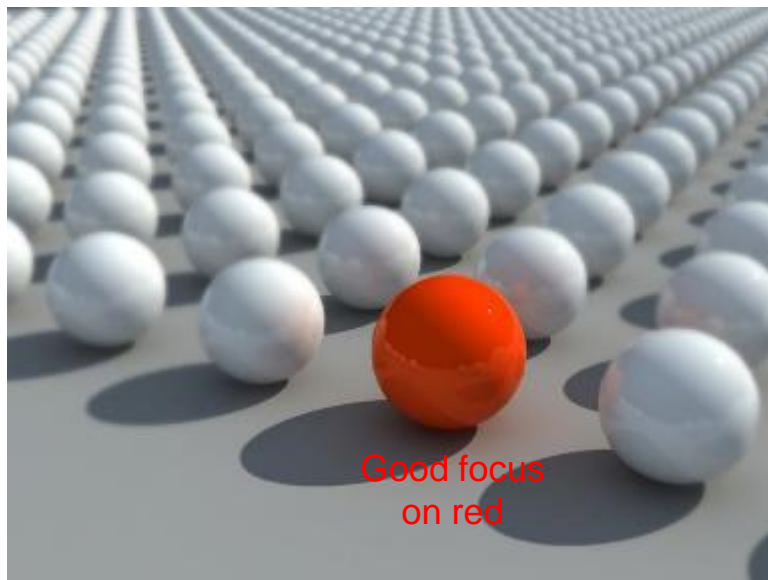
# Depth of field



## Key learning:

**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

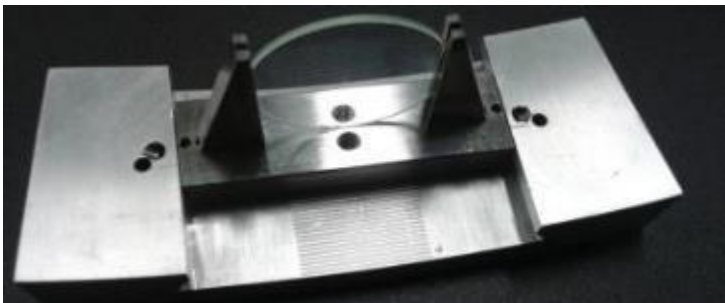
# Image Focus



## Critical Design Element:

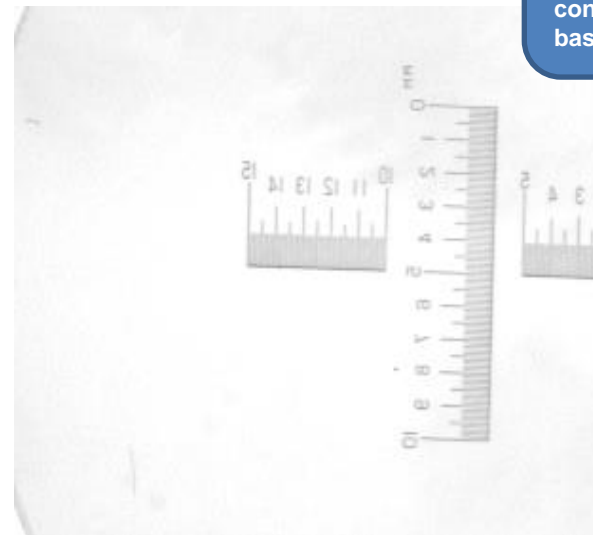
Optic must be well  
tuned  
Review images  
before FAT  
Lock optics with a  
screw and physical  
mark

# Image Focus control

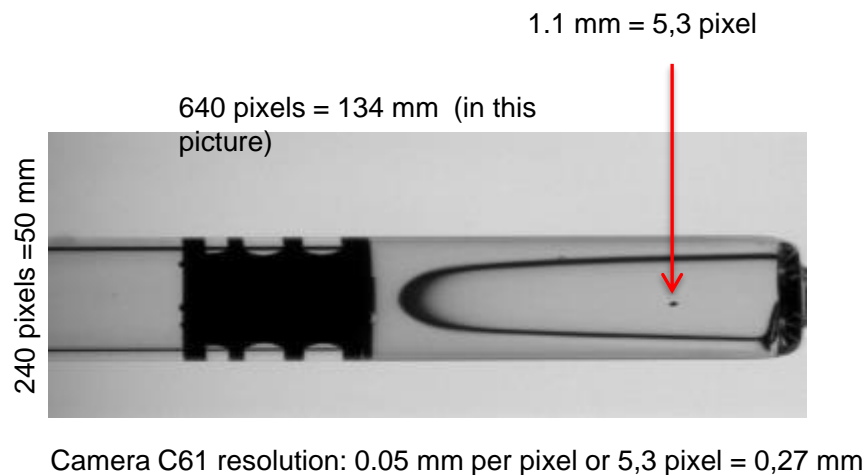
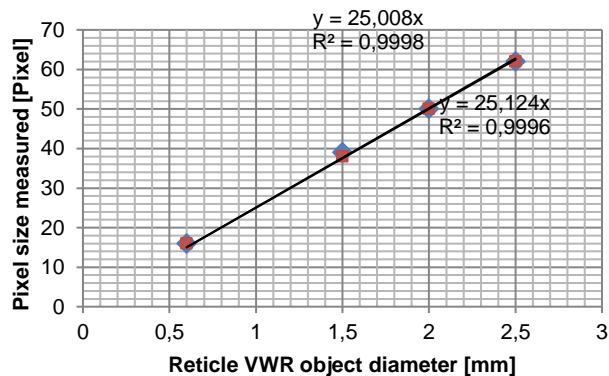
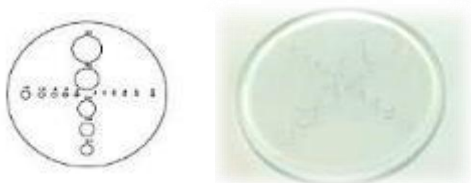


Control focus with  
calibrated reticule

Critical Design  
Element:  
Focus must be  
controlled during  
baseline



# Image correlation pixel to size





# Illumination

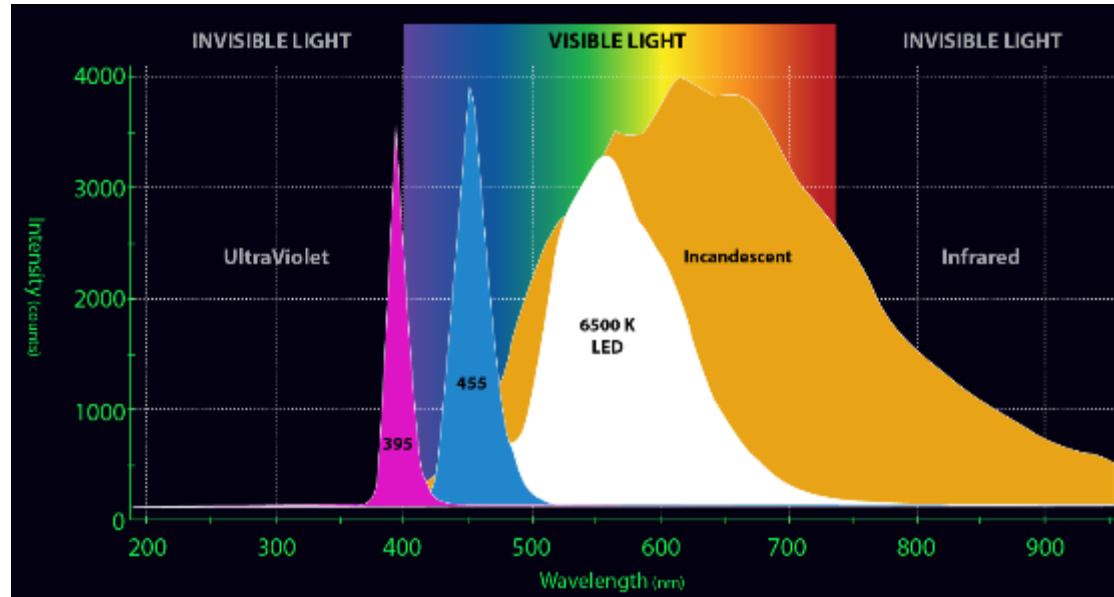
## LED allow to sculpt light in many plan / geometry / orientation .....



Critical Design  
Element:  
LED Shape orientation  
angle distance are  
CDEs

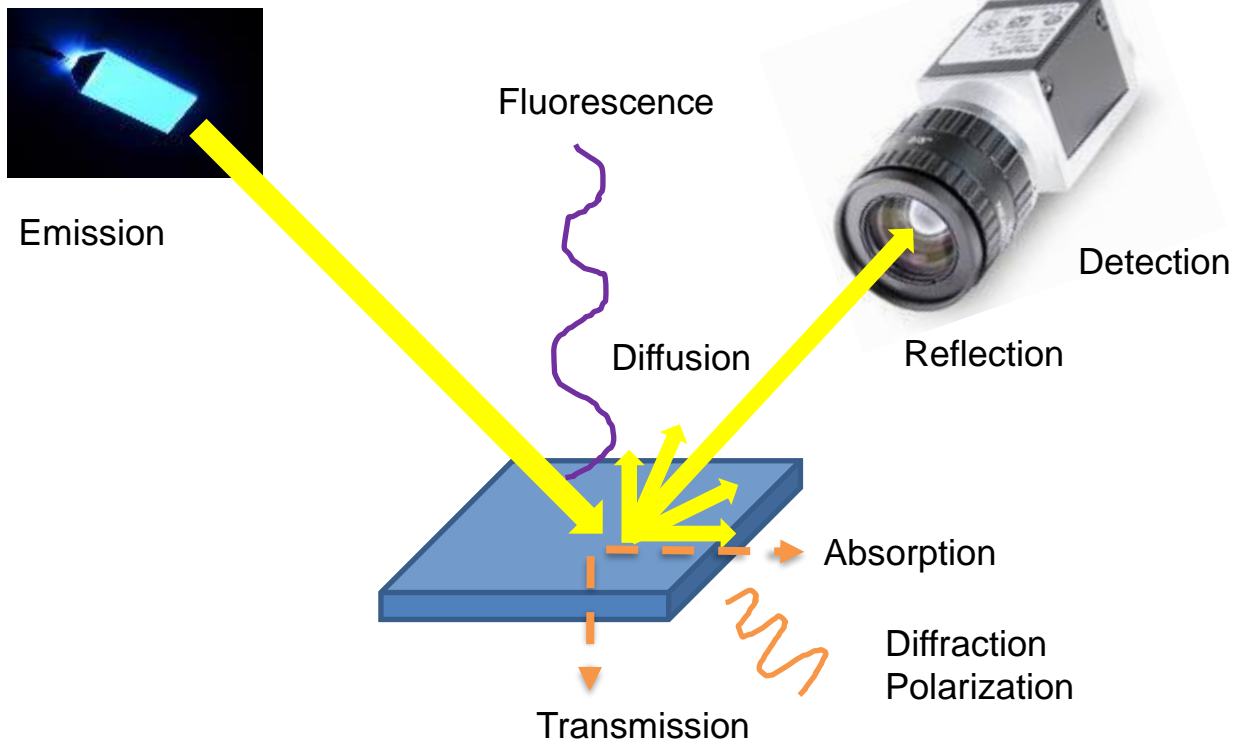


# LED spectrum

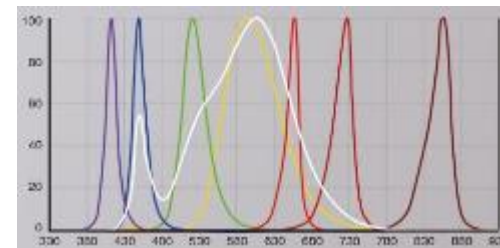


© Copyright PDA and GSK for internal use only Author Romain Veillon

## Light interaction paths with an object



# LED can be multispectral wave length



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



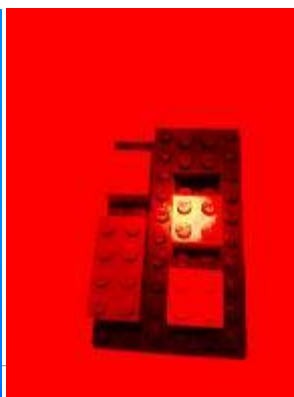
Slight differences in color are clearly defined.

## Color perception impacted by light color



Critical Design Element:

LED color may change defect detection, like to like change is critical



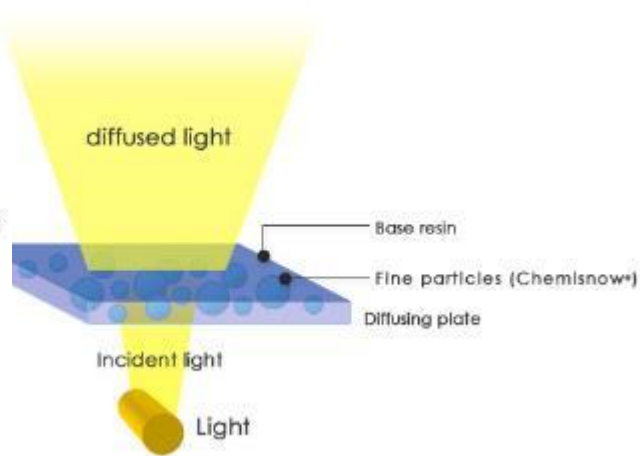
Courtesy of my kids !

# Back Light

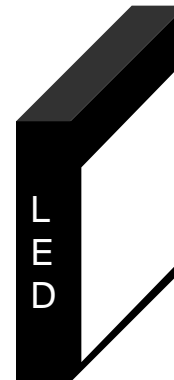
Critical Design Element:  
LED must be replaced like to like or some equivalency studied must be done; mind the wire replacement!



Board



High quality  
diffusor

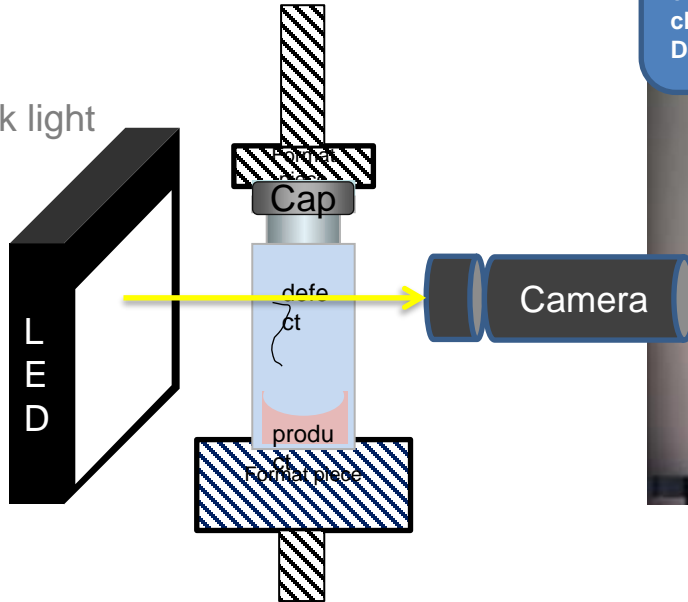


Back Light LED  
Assembly



# Backlight gradient

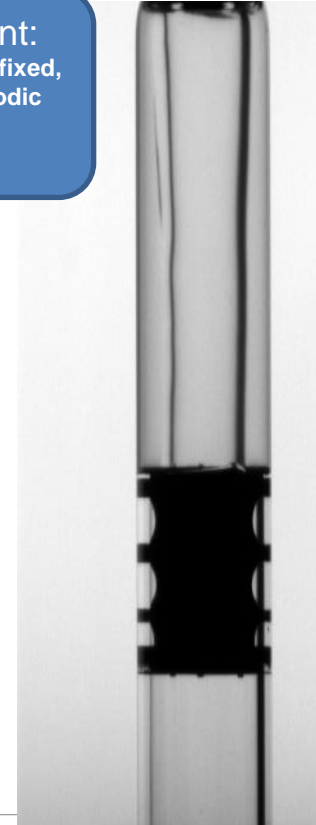
- Back light



**Critical Design Element:**  
LED distance / position must be fixed,  
control access level and do periodic  
check  
Design should have no gradient



Low cost  
back light =  
gradient



industrial  
back light  
= NO  
gradient



# Backlight gradient

- Molded Glass

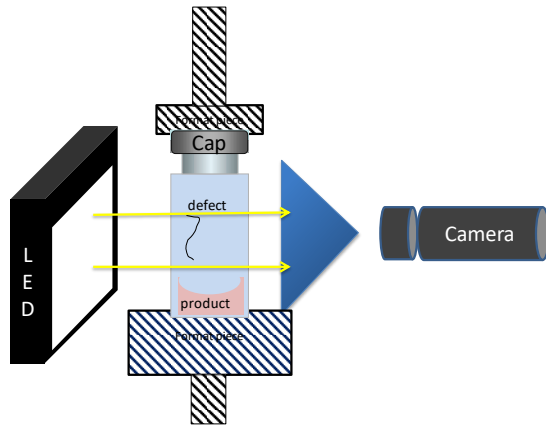


- Tubular glass



- Industrial back light = NO gradient
- However, when using molded glass, one certainly will have due to wall thickness variations.
- Variations between 2 – 4 mm are not uncommon
- With brown glass starting at 50 ml or above, this can be a pain.

# Back light + Prism

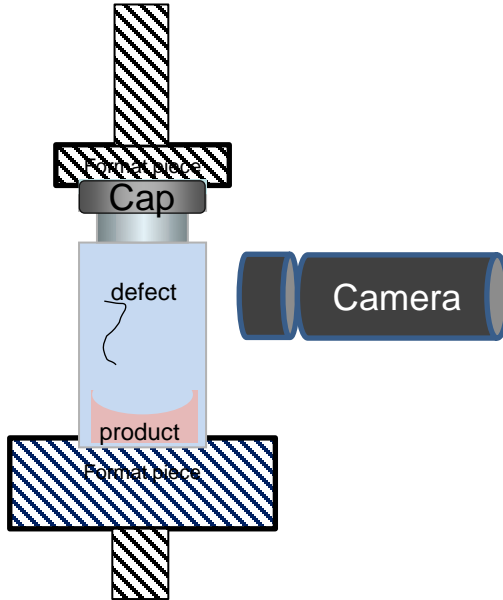


Critical Design Element:  
Prism or mirror position and dust may impact image, do periodic check

Below are two examples of a good and bad inspection respectively.

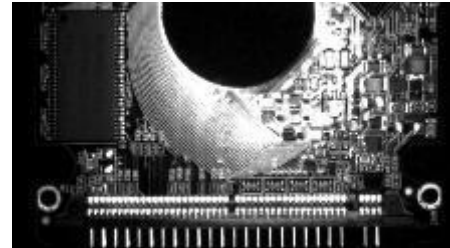


# Front spot-light



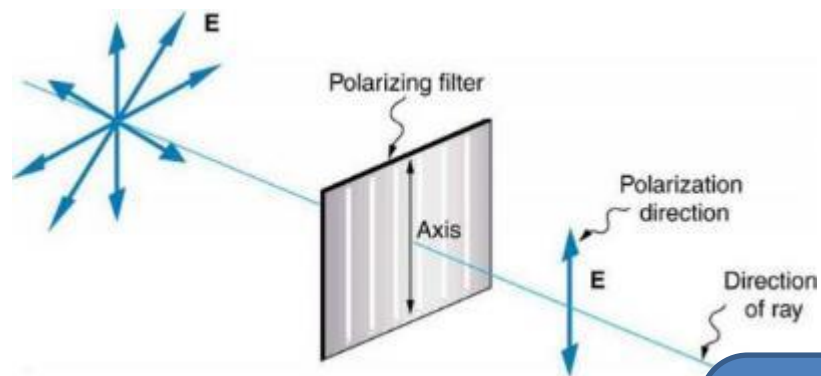
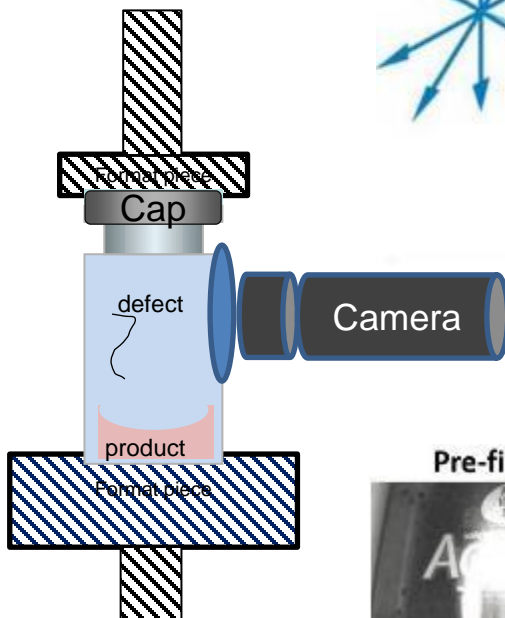
Shiny reflects

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



## Light source + Pol filter

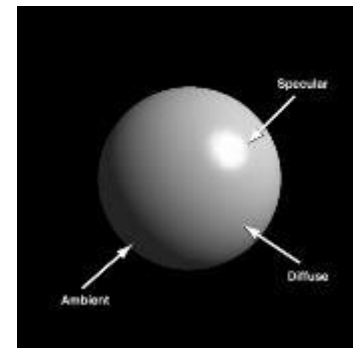
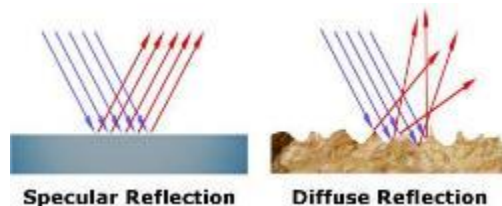
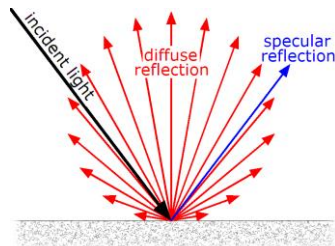
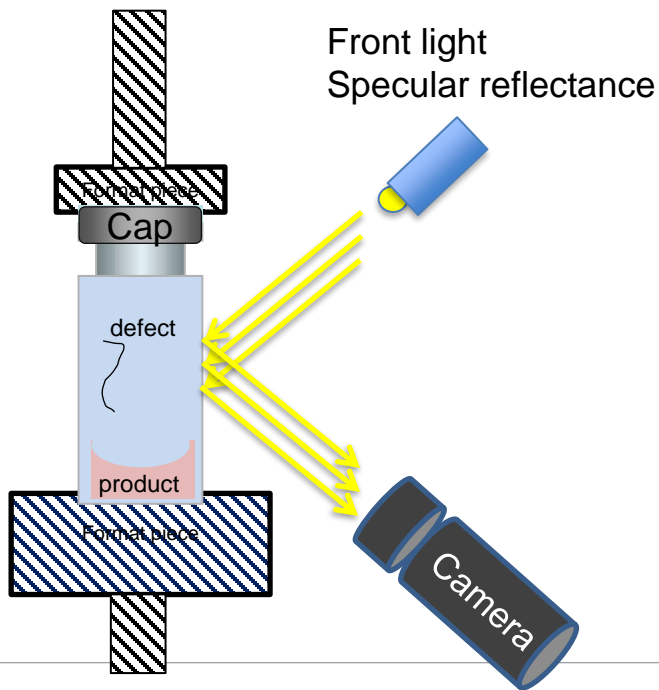
- Front light + Pol Filter



### Critical Design Element:

Polarization filter have different chromatic extinction quality, control spare part replacement to identical

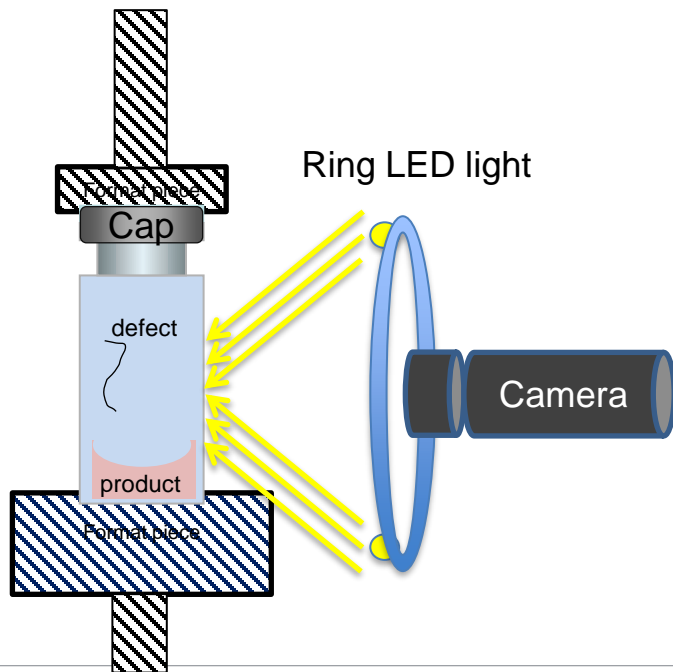
# reflectance light



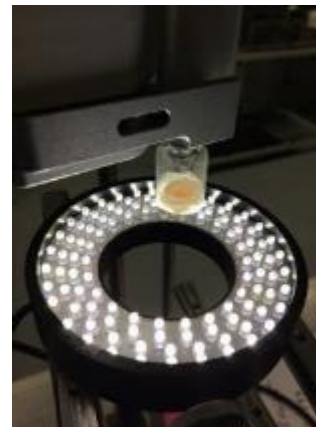
## Critical Design Element:

Light position and Angle is utmost critical in term of stability, control access level and do regular check With reflectance light angle is critical

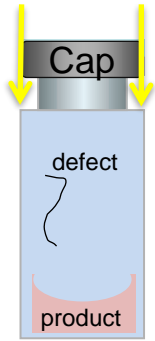
# Ring LED light



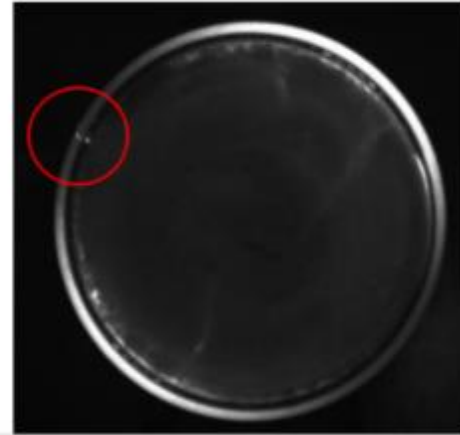
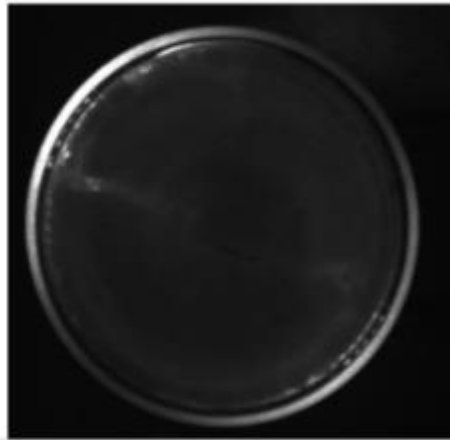
Critical Design Element:  
Require some dispersive diffusor to avoid reflects



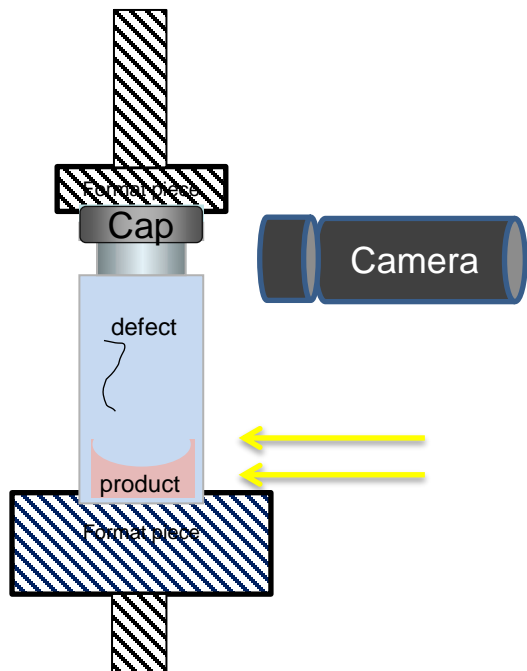
# LED channeled via glass walls



**Critical Design Element:**  
Alignment must be very accurate and glass spec well controlled with handling parts. Cheap glass will have issues. Molded glass in particular due to high bottom variations and thickness

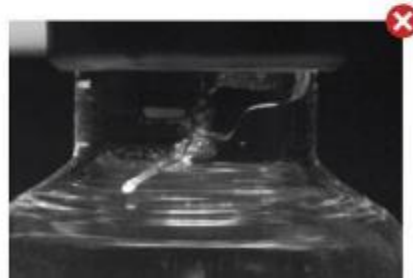
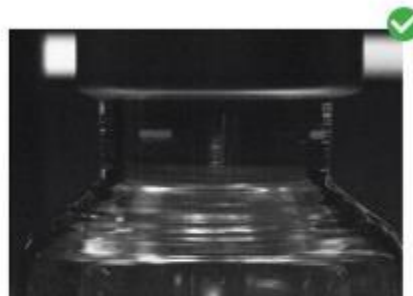


# LED channeled via glass walls



## Inspection Images – Upper C&C Inspection

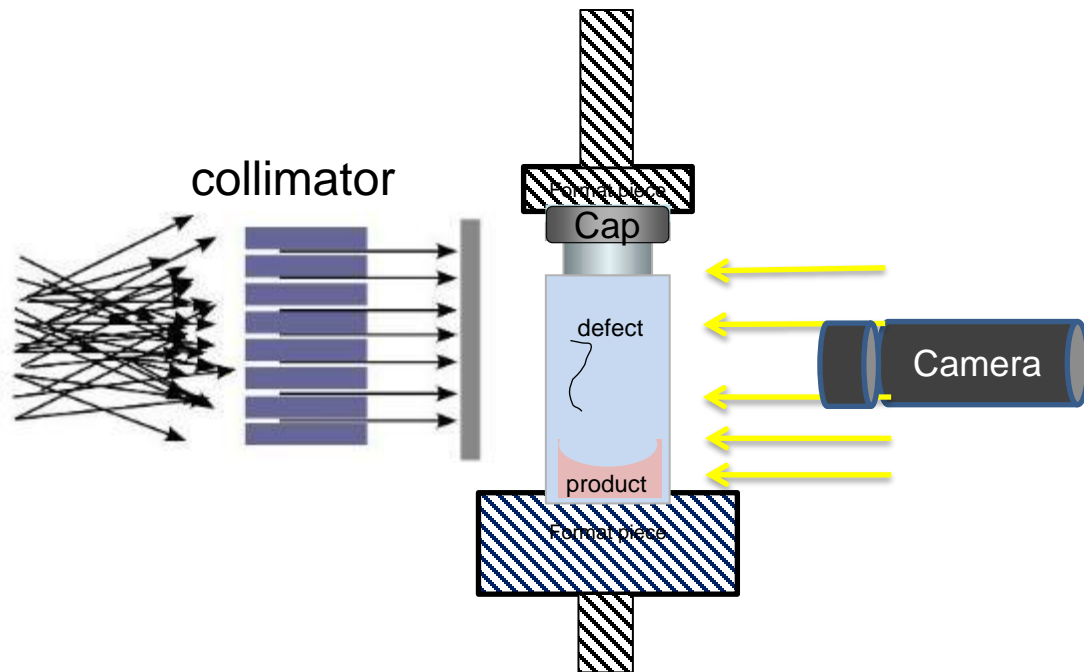
Below are two examples of a good and bad inspection image respectively.



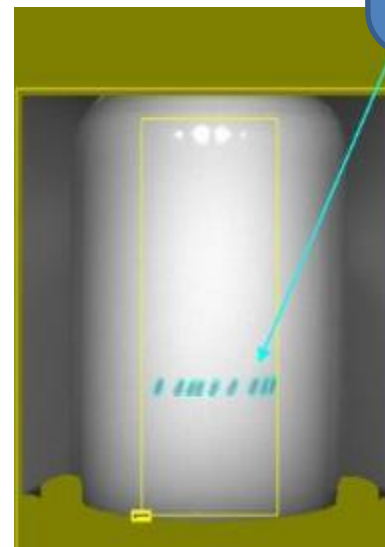
**Critical Design Element:**  
Control glass specifications and mech stability to avoid cavitation from base holder + light angle



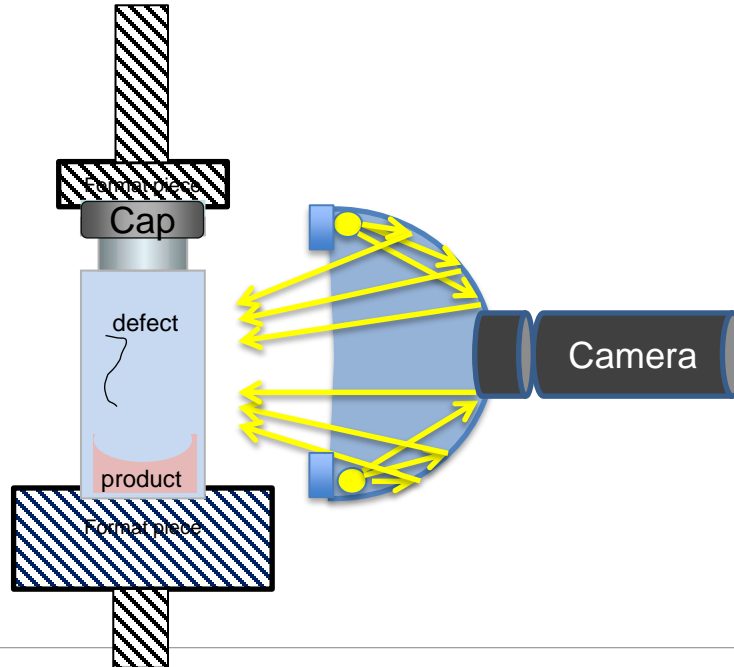
# Collimated light LED



**Critical Design Element:**  
Collimated light must keep a strict position / angle, control access level and do regular check

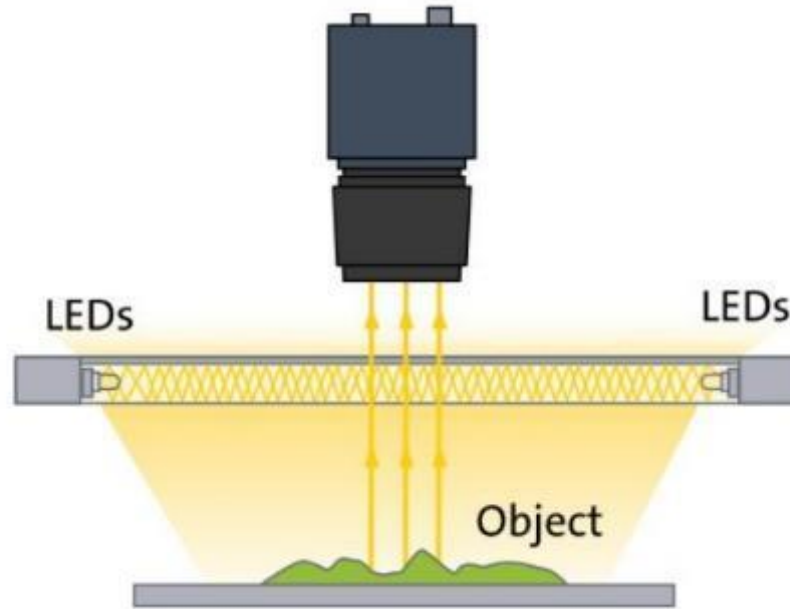


# Dome light



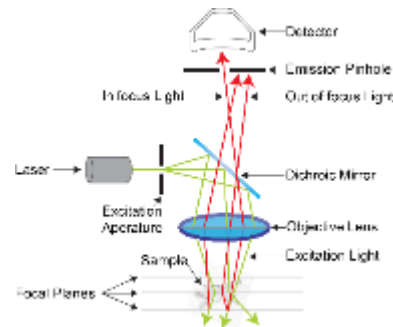
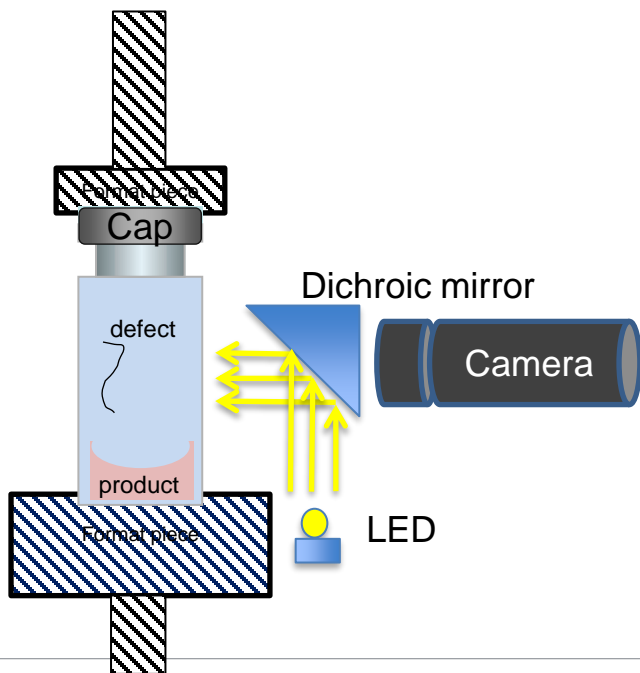
Critical Design Element:  
Dome take lo of space => mind stability of angle / position fixing

# Flat Dome light

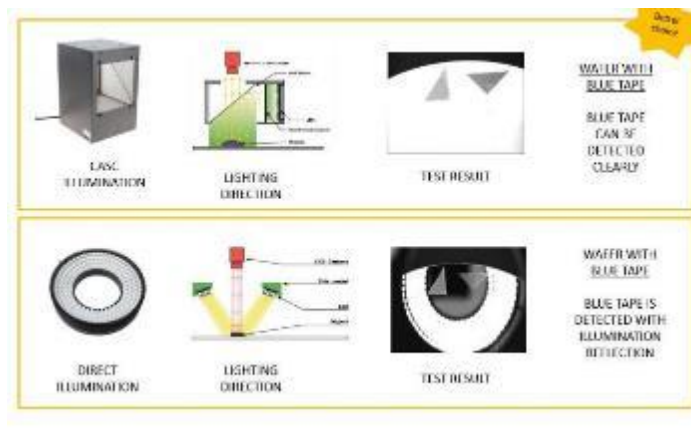


Critical Design  
Element:  
Flat Dome light can avoid  
reflects on shiny surfaces

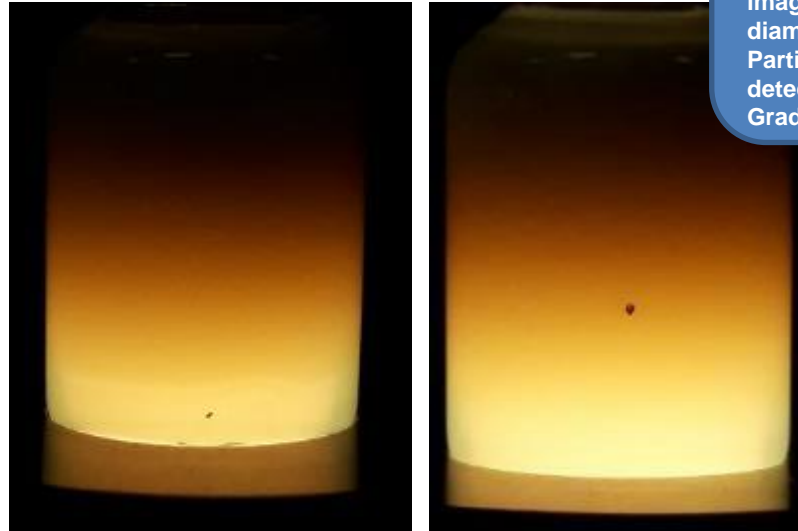
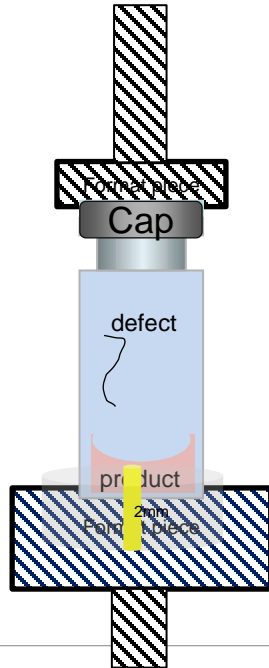
# On Axial Light



**Critical Design Element:**  
The mirror may be obstructed by dust => regular cleaning  
May lack power  
Takes more space



# Via product at 90°



Particle in heavy suspension/emulsion

## Critical Design Element:

Light from bottom vial may diffract light and burn the image, need to have a small diameter beam light  
 Particles at bottom may be detected  
 Gradiented light

# Dark field illumination




**Critical Design Element:**  
Dark field is over sensitive to powder on side walls => extra care in vial handling before AVI!  
Very efficient for crack



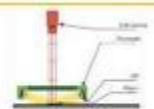
## EDGE INSPECTION APPLICATION




Inspection Object




Low Angle Illumination  
LIA-90-150-1-W-24V



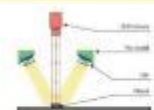
Lighting Layout




Clearer edge highlighted



Shower Illumination  
LSW-15-090-4-a-24V



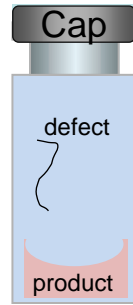
Lighting Layout



Edge is not highlighted clearly



# Combination of lights



Critical Design  
Element:  
Sequence of 4 lights  
+ subtractions

# LED risks

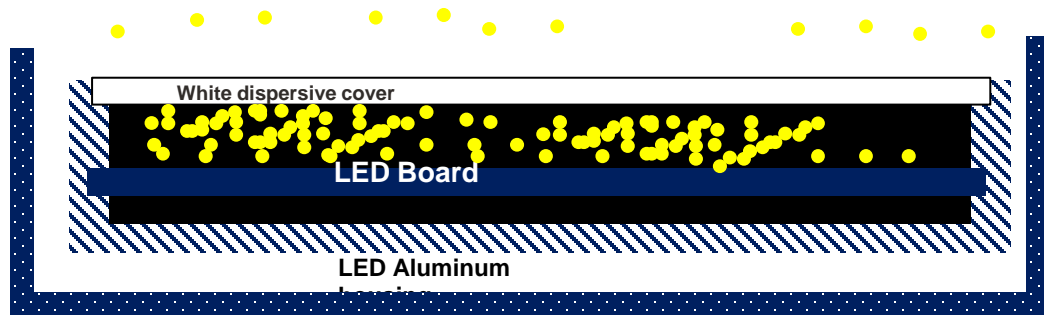
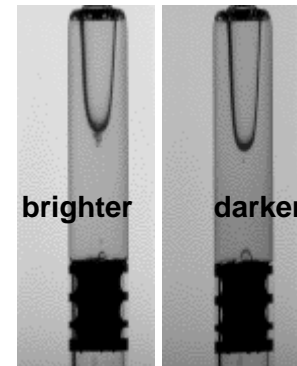


# Light stability

## Critical Design Element:

LED are not stable if no good heat dissipation  
Need a permanent ctrl

LED are more stable but .....  
beware of heat dissipation,  
when LED junction is heating it  
may loose power



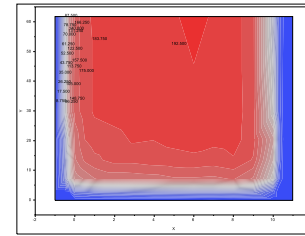
# Light spatial homogeneity

LED are more stable but .....beware of boarder effect

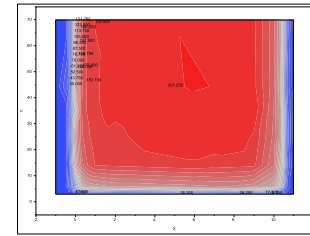
Practical Examples of key parameters ctrl:  
opportunity for knowledge improvement :  
spacial homogeneity of LED in 3D

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

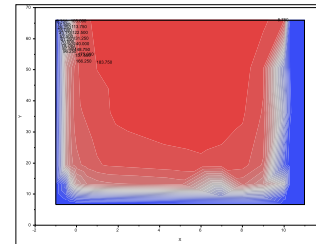
=> Very  
Homogeneous  
in area of use



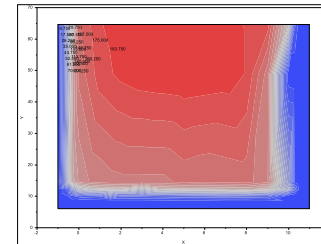
z =53.42mm



z =98.1mm



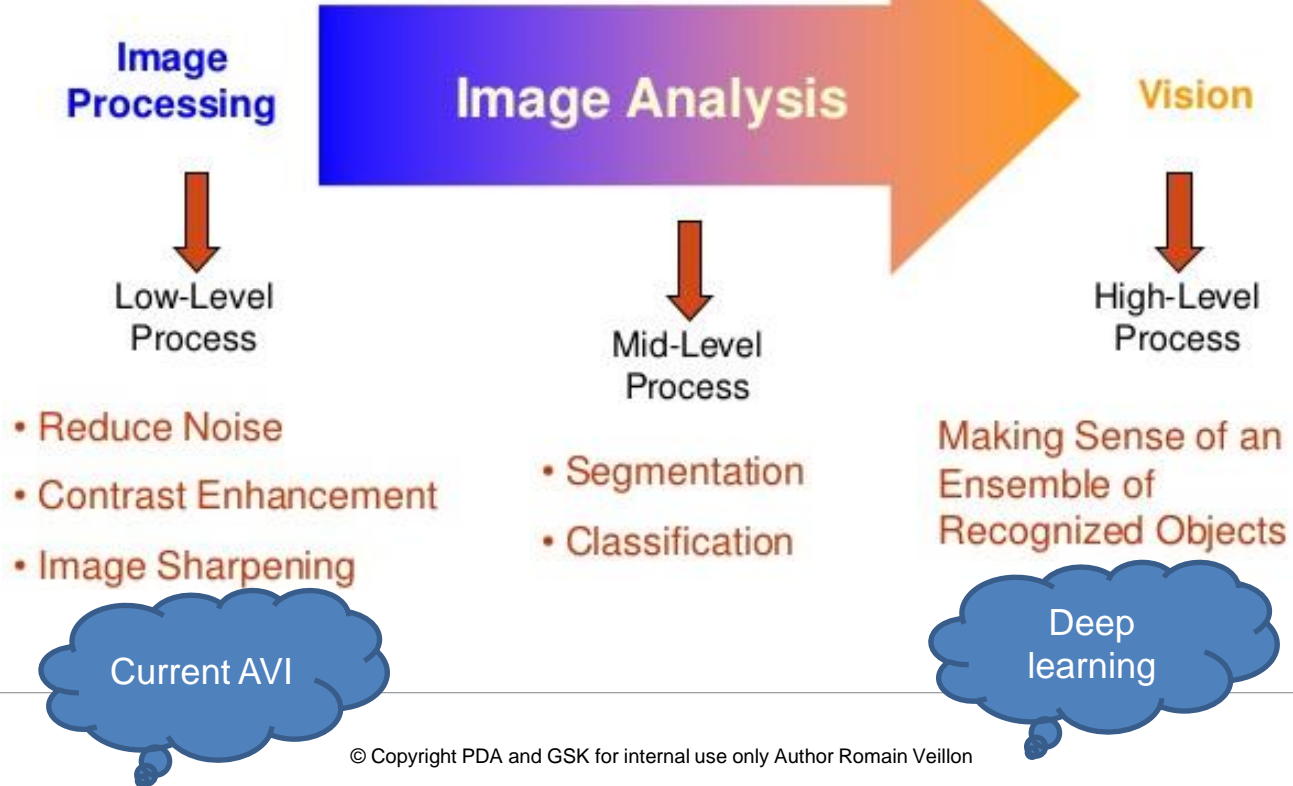
z =134.5mm



z =178mm

# Digital Image processing

# image processing level



# What is the goal of image processing ?

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

Image  
480x640 Pixels

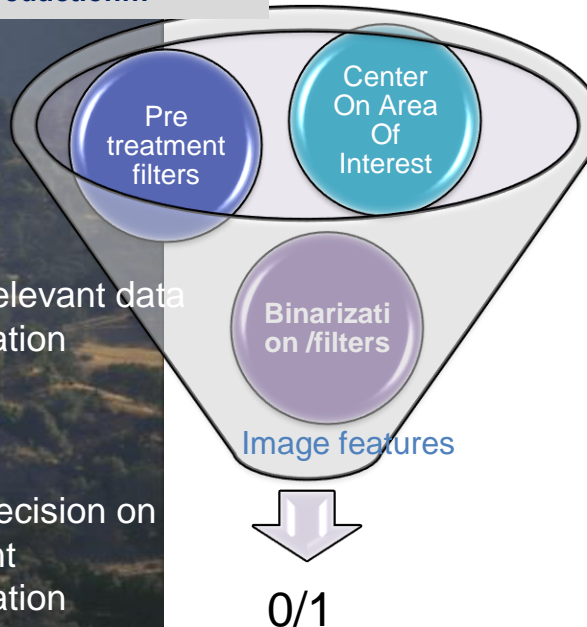
Why ? Image = too much information

Treatment = data reduction

Filter relevant data information

Take decision on relevant information

A car is very difficult to see first...image treatment will help



# Main steps in image processing

1 3D Object presented



2 2D image



3 Area Of Interest (=AOI)



4 Binarization



5 Object detection



6 Image feature

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

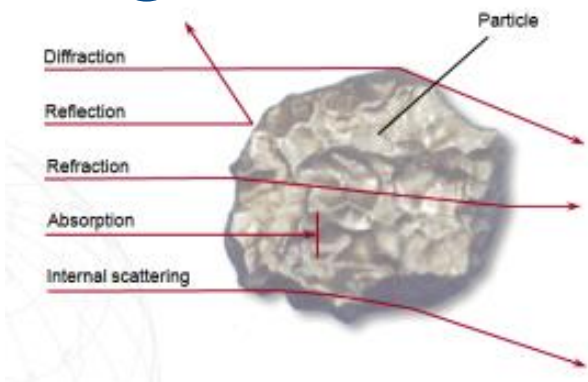
7 Image understanding

8 Pass / Fail

<10ms

**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

# Light scattering



**Key learning:** with transparent liquid solution Light obscuration techniques may be sensitive but more suitable for bench characterization purpose (PDA 2014)

3ml vial with Tape Water



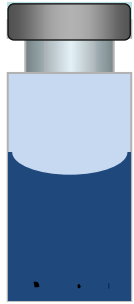
Red Laser beam

Visible and Sub visible particle are detected

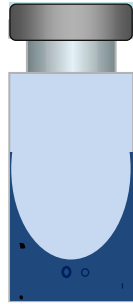


# Image subtraction

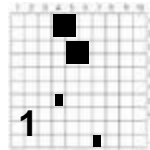
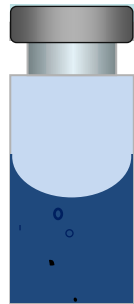
Vial with 3 particles



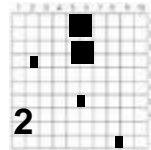
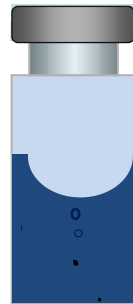
Rotation  
600t/min  
2 bubbles



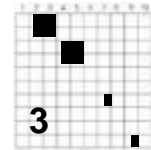
Stop  
1<sup>st</sup> Image



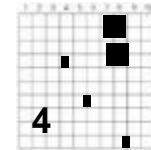
Stop  
2<sup>nd</sup>  
Image



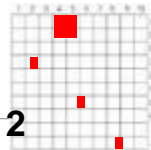
Stop  
3<sup>rd</sup>  
Image



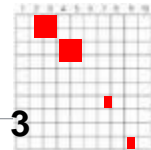
Stop  
4<sup>th</sup>  
Image



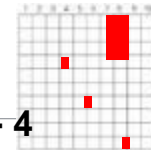
1-2



1-3



1-4

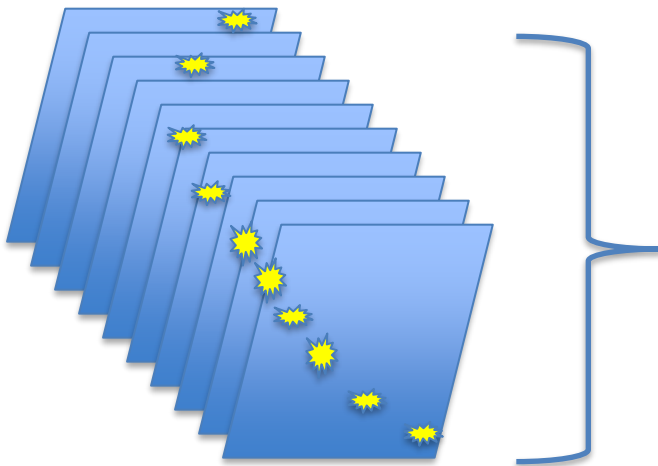


**Key learning:**  
Image Subtraction is not very sensitive for particle detection in small suspension unit + no detection above liquid + no detection of fixed particles

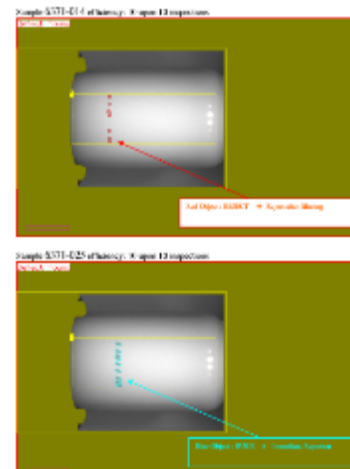


# Particle trajectories

- 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

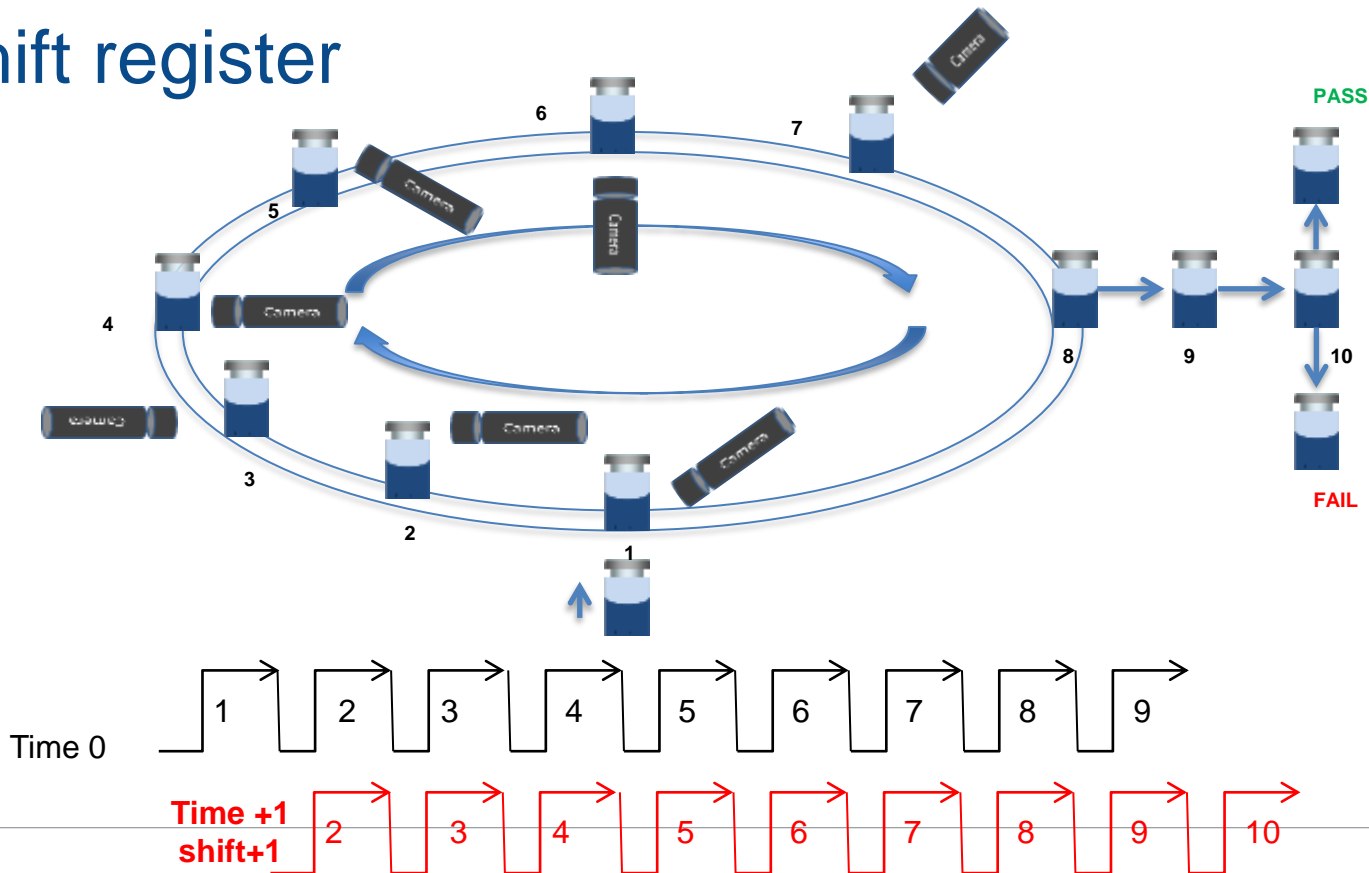


Analyze of 1  
stack of 10 to  
60 images all  
at once to  
track particle  
trajectories



# Shift register Automation principle

# Shift register



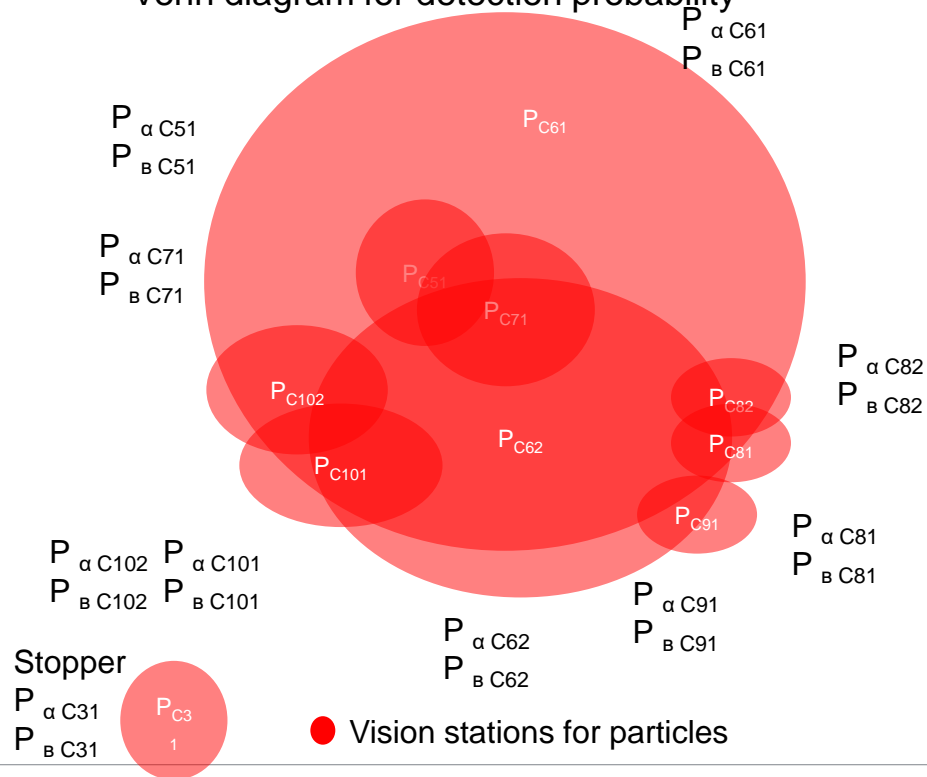
# Concept of collaborative cameras

# Multiple camera



**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

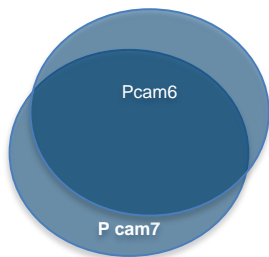
Venn diagram for detection probability



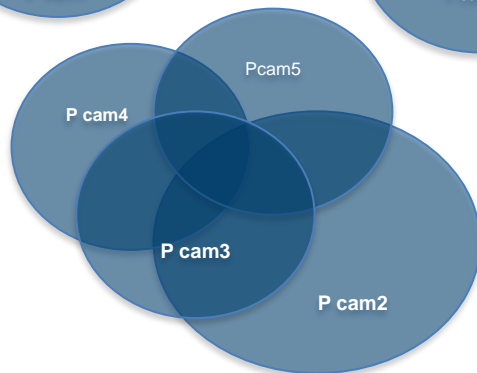
# Synergies of camera/images

- Multiple camera on AVI machines

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



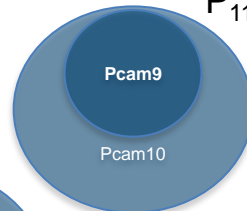
4 collaborative  
Cameras for a  
specific area  
i.e. = Syr. Body  
for particle or  
cracks



A & B mutually exclusive

$$P_{11+12} = P_{11} + P_{12}$$

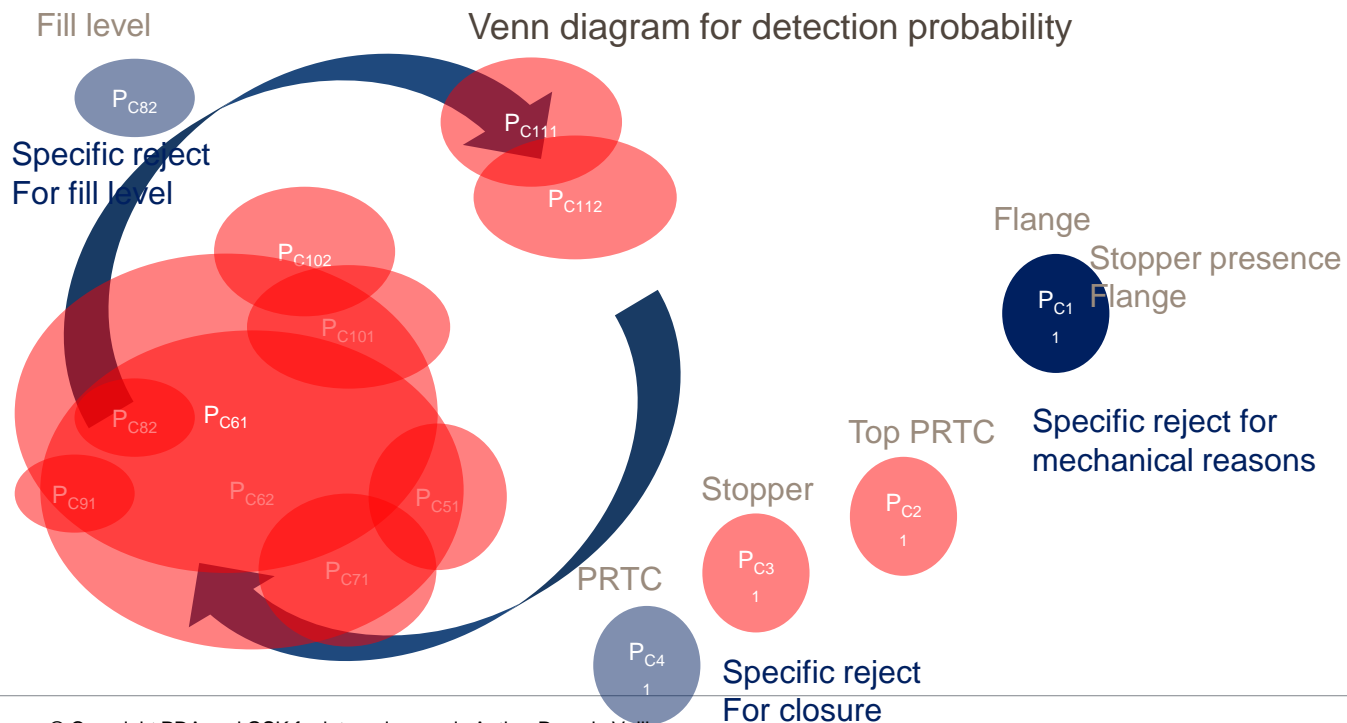
2 Camera specific  
for a defect area  
i.e. = Syr. closure



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



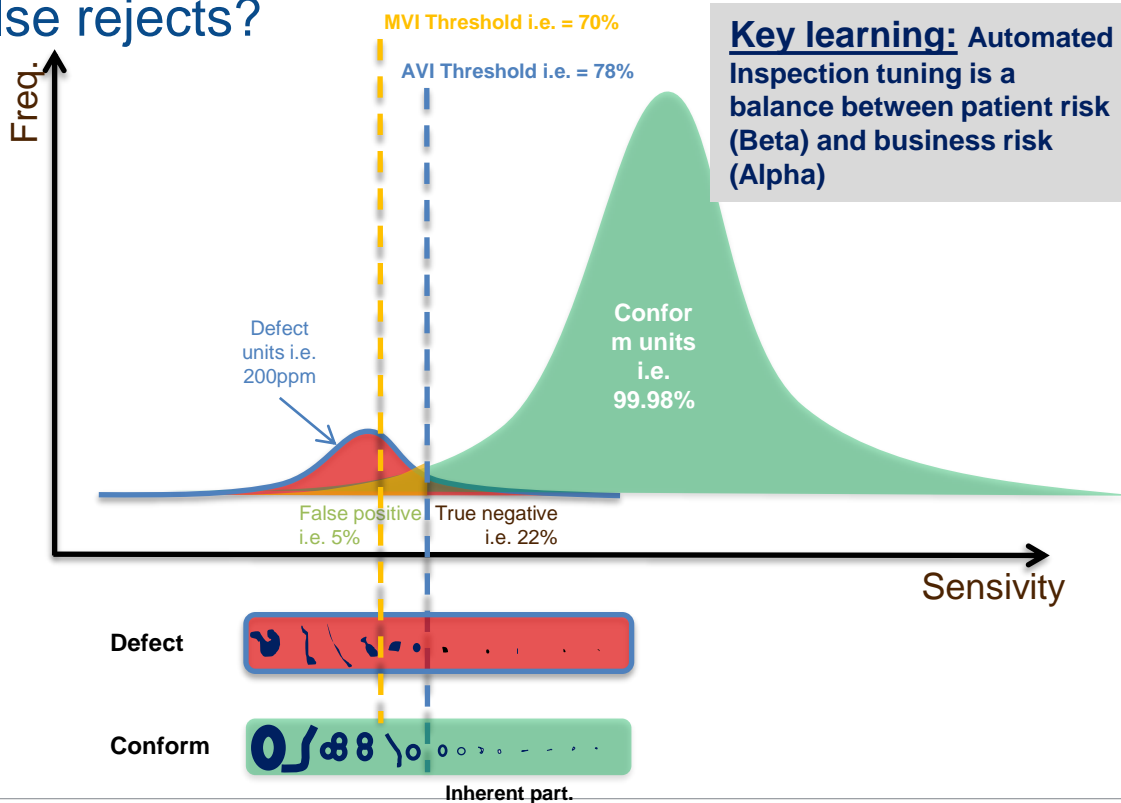
## Validation should test all collaborative camera at once



False reject  
True reject



# False rejects?



# Confusion matrix

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

# Key take away:

- In this section you have learnt:

## AVI

---

Long way

---

Equipment / Process / ctrl strategy design

---

Parts of AVI equipment: CDEs

---

Critical parameter  
Image processing steps

---

Illumination sources

---

X Cameras / Automation concept

---

False reject / true detection

---