Beam Size Measurement With Synchrotron Radiation Monitor Along the Booster Energy Ramp

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Visible Synchrotron Radiation Monitor (MRSV)

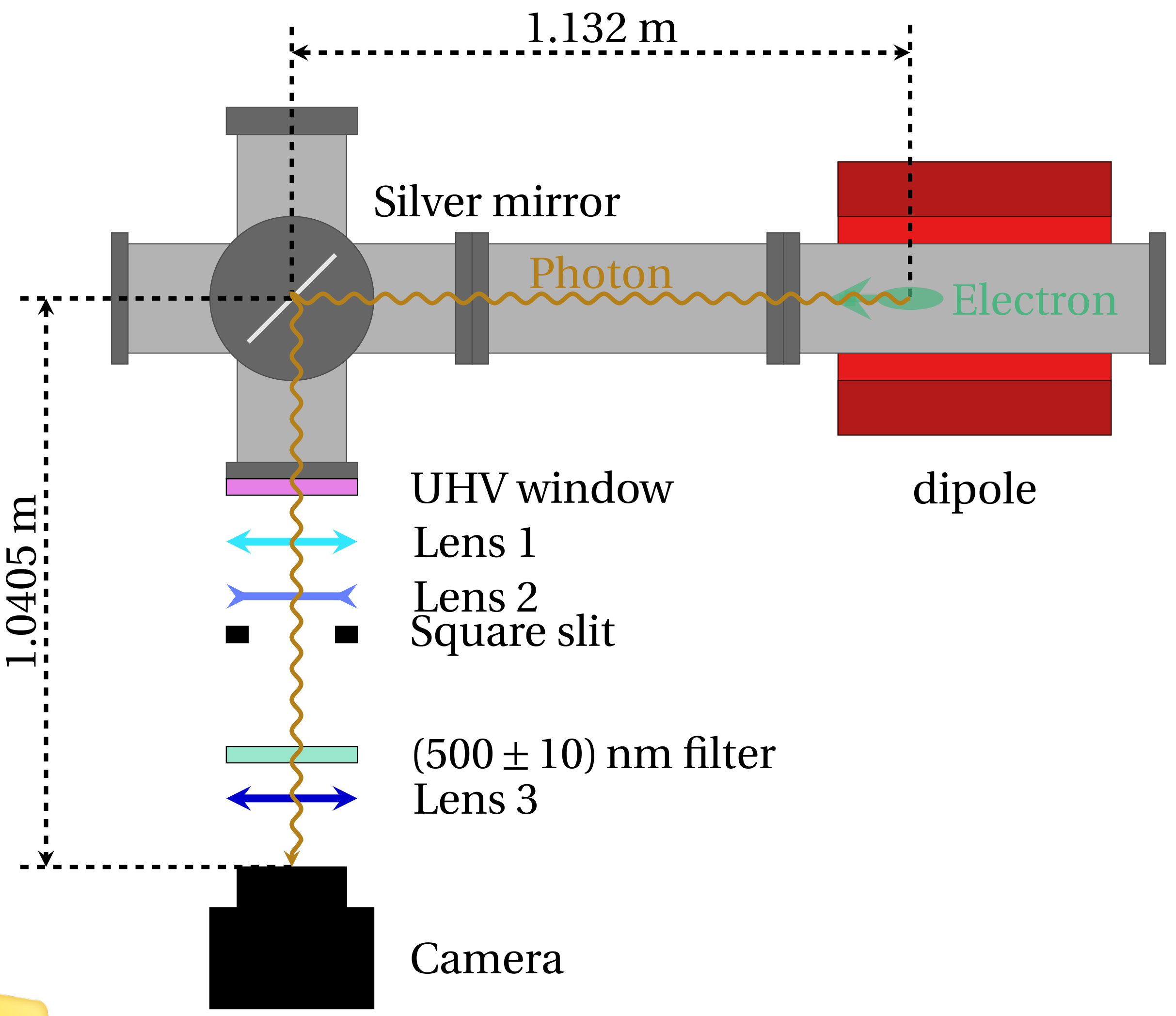

Figure: Setup of Booster MRSV

- Initial goal :
  - Check beam presence
- Goal for SOLEIL II :
  - Measure beam emittance evolution during booster ramp using beam size measurement and theoretical Twiss parameters
  - Check the efficiency of H/V transfer emittance before extraction
  - Essential to reach emittance goal for SOLEIL II at booster extraction :
    - 60-170 nm.rad → 0.5-5 pm.rad in x plan
    - 2-60 nm.rad → 0.2-5 pm.rad in y plan

⇒ On-going work :
  - Upgrade of the diagnostics
  - Beam size measurement along booster ramp and comparison with theory

MRSV image analysis for beam size retrieval

- Image analysis steps :
  - 2D Gaussian fit on the image:

$$G = Ae^{-(a(x-x_0)^2+2b(x-x_0)(y-y_0)+c(y-y_0)^2)} + cst$$

$$a = \frac{\cos^2(\alpha)}{2\sigma_x^2} + \frac{\sin^2(\alpha)}{2\sigma_y^2}$$

$$b = \frac{\sin(2\times\alpha)}{4\sigma_x^2} - \frac{\sin(2\times\alpha)}{4\sigma_y^2}$$

$$c = \frac{\sin^2(\alpha)}{2\sigma_x^2} + \frac{\cos^2(\alpha)}{2\sigma_y^2}$$

  - Projection on horizontal axes:

$$\sigma_{H,exp} = 2\sigma_x\sigma_y\sqrt{\frac{c}{2}}$$

  - Remove PSF (simulated with SRW):

$$\sigma_{H,real} = \sqrt{\sigma_{H,exp}^2 - \sigma_{PSF}^2}$$

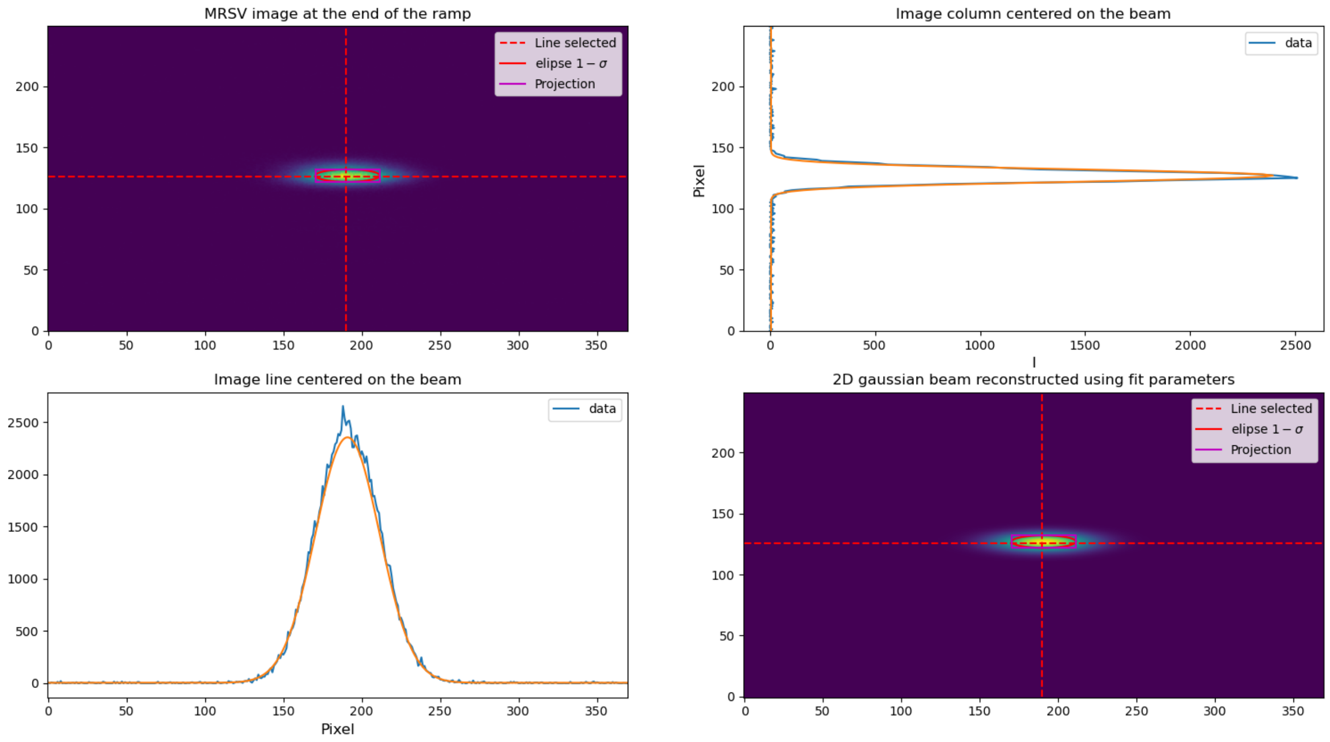

Figure: Example of 2D Gaussian fit on a beam image at the end of the booster ramp

Horizontal beam size along booster ramp

- Scan along booster ramp by changing camera trigger delay
- Comparison experiment/simulation:
  - Relative comparison:
    - Good agreement on the global shape
  - Absolute comparison:
    - Drop around 117 ms due to fluctuation in linac injection
    - 10 to $40\,\%$ oversized beam measured
  - Conclusion:
    - Larger measured than simulated beam size

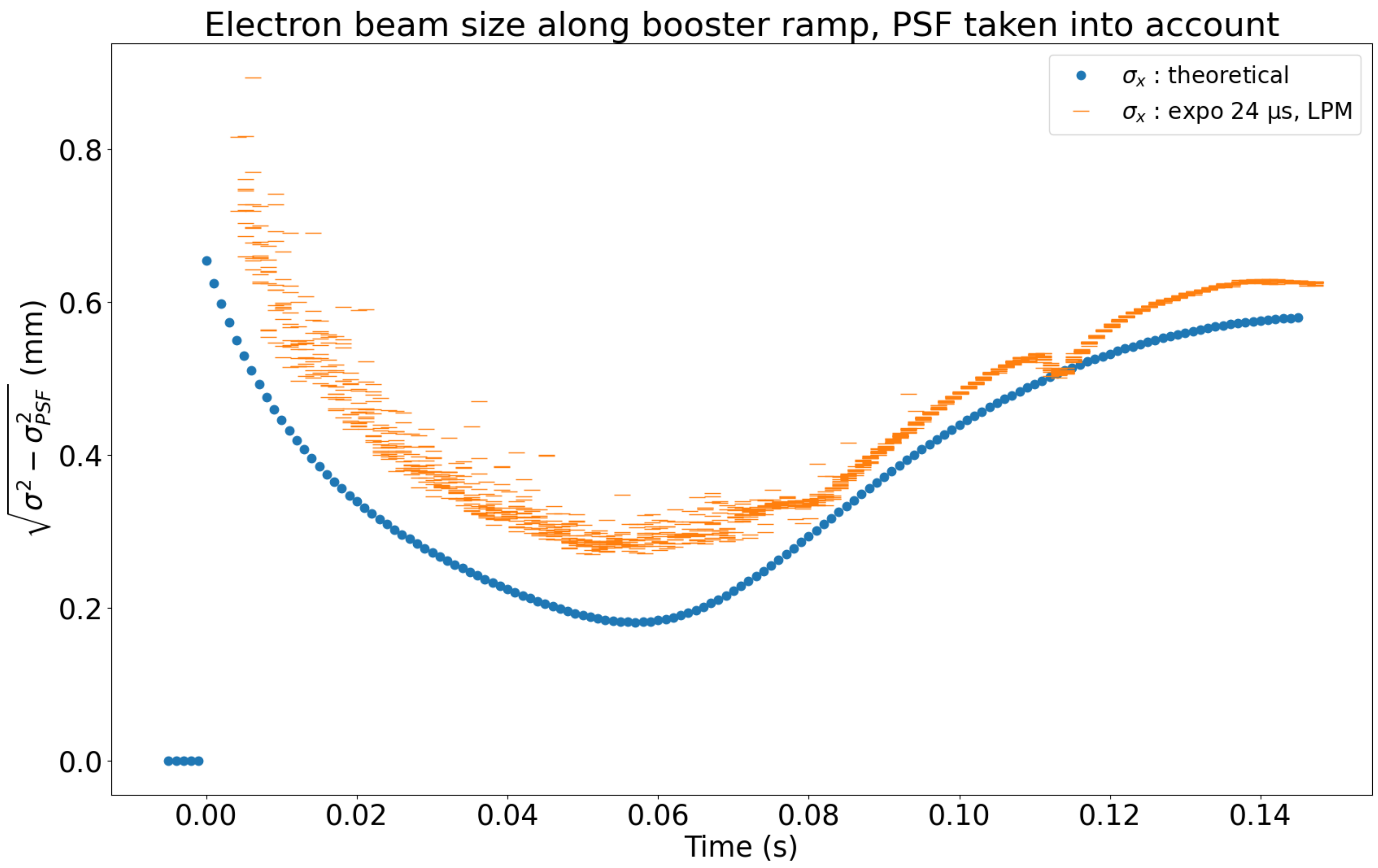

Figure: Horizontal beam size along the booster ramp

Horizontal beam size along booster ramp

- Possible causes for exp/sim discrepancy:
  - Beam oscillation integrated by exposure time: $24\,\mu s$ (≈ 50 turns)
    - ⇒ Increasing artificially the measured beam size
    - Minimum camera exposure time : $24\,\mu s$

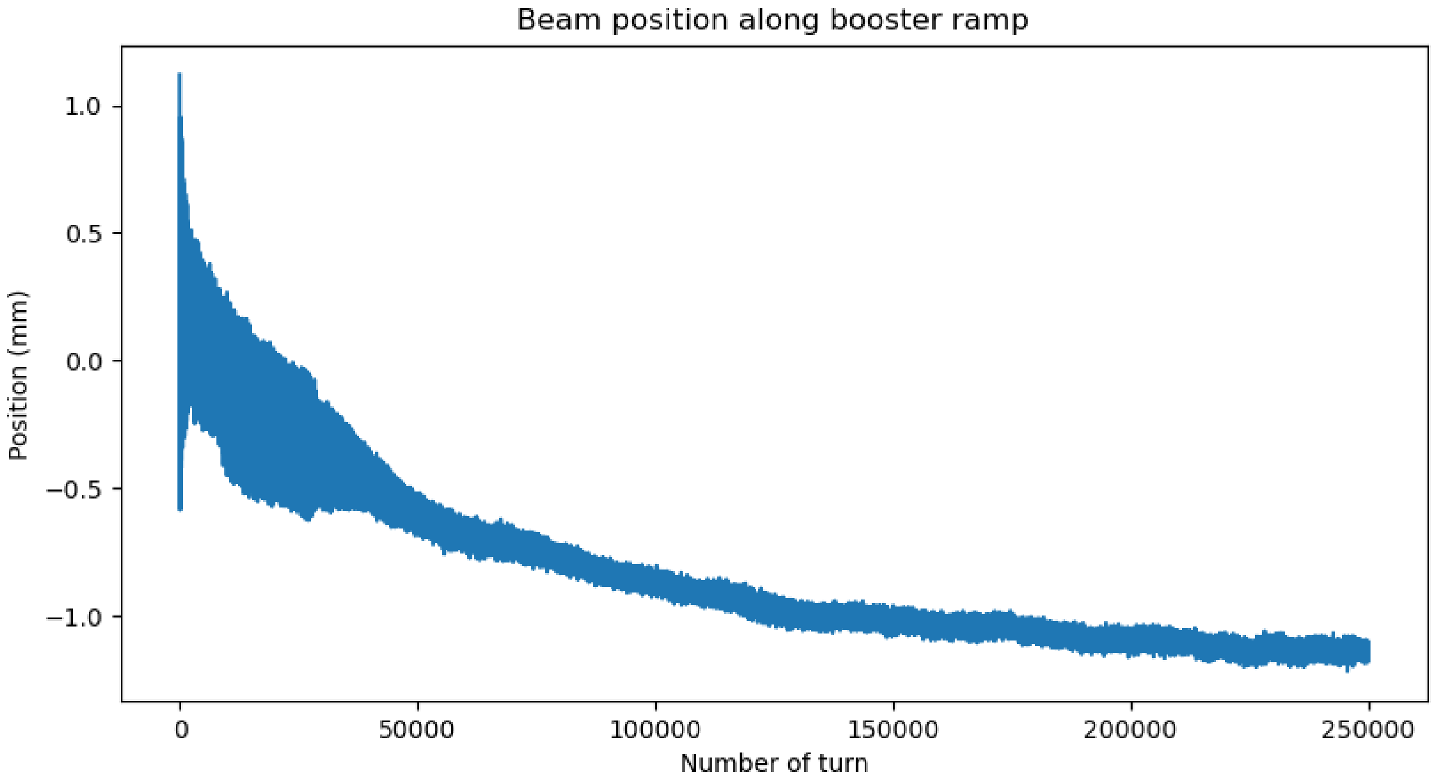

Figure: Beam centroid oscillation measured with one BPM close by the MRSV

⇒ Change the camera for a new one with a smaller minimum exposure time ($1\,\mu s$)

Horizontal beam size along booster ramp

- Reference camera parameters:
  - Camera model: acA1920-40gm
  - Sensor Type: **Mono**
  - Minimum exposure time: 24 µs i.e. ≈**50 turns**
  - Pixel size: **5.86 µm**
  - Pixel number : 1920 × 1200
- New camera parameters:
  - Camera model: a2A1920-51gcPRO
  - Sensor Type: **Colour**
  - Minimum exposure time: 1 µs i.e. **1-2 turns**
  - Pixel size: **3.45 µm**
  - Pixel number : 1920 × 1200

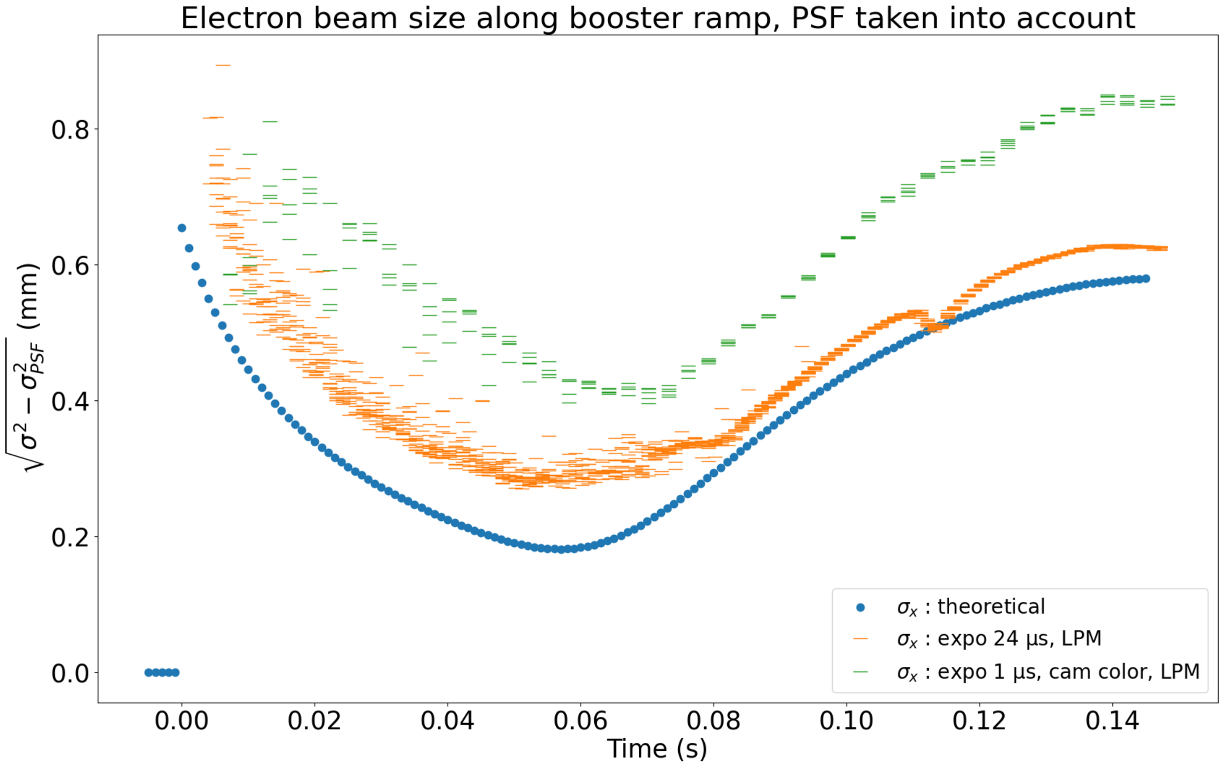

Figure: Horizontal beam size along the booster ramp

Measured beam size larger with smaller exposure time: Something went wrong!
⇒ We uninstall the camera and perform some tests on the lab

Lab test on the 1 μs colour camera

- Bench test #1 :
  - Imaging of an USAF target with both cameras
    - Same magnification measured
  - Test of the 1 μs colour camera's parameters
    - Mono vs. RGB
    - Gain
    - Exposure time
    - Gamma factor
    - White balance

  → Measured target size unchanged

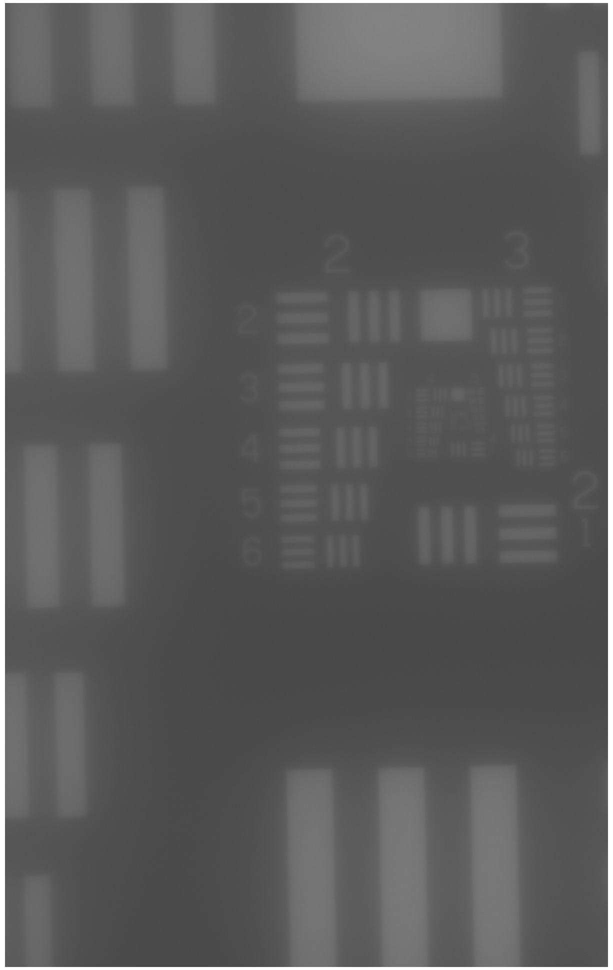

Figure: USAF 1952 calibration target with reference camera

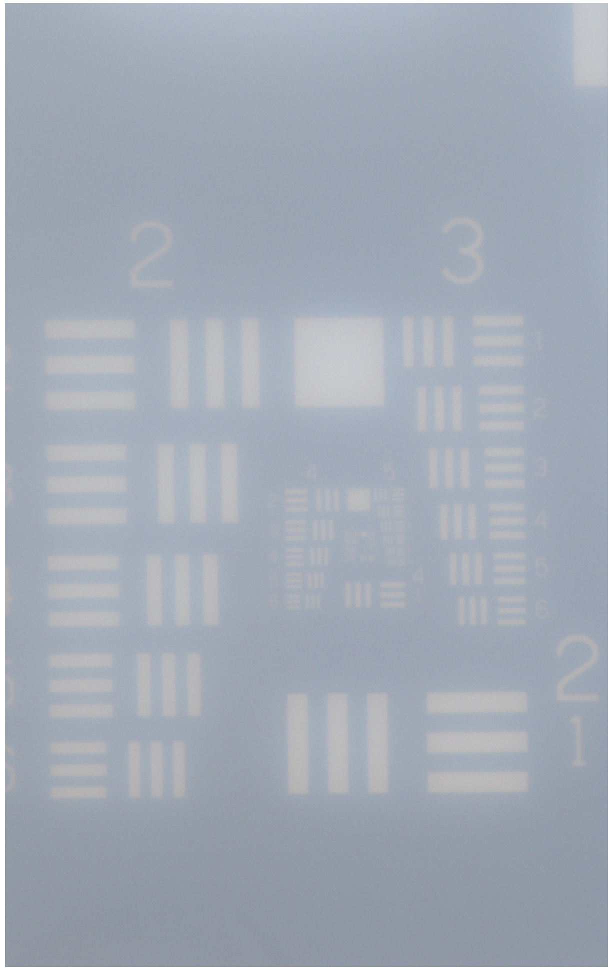

Figure: USAF 1952 calibration target with 1 μs colour camera

Lab test on the $1\,\mu s$ colour camera

- Bench test #2:
  - Imaging of the ring MRSV with both cameras
- One error spotted :
  - Camera used in mono mode for MRSV measurement
  - Good exposure = Pixel intensity close to maximum
  - (500 ± 10) nm filter used
  - ⇒ Blue pixels completely saturated, hence beam size overestimated

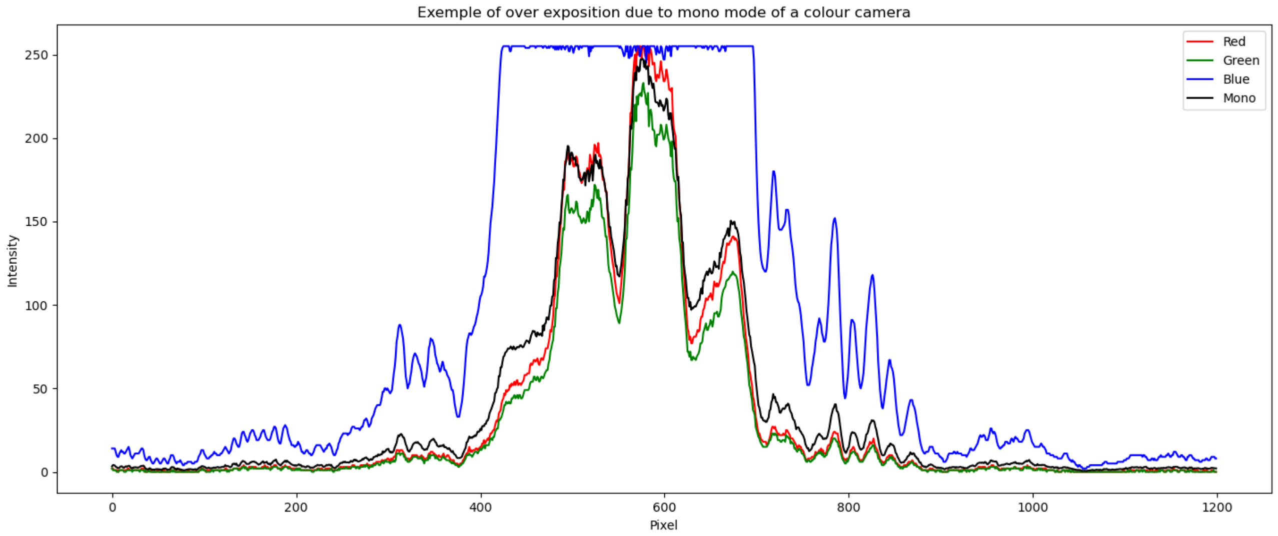

Figure: Plot of pixel intensity of one column in an image taken in RGB mode (red, green, blue line respectively) and the same column on an image taken in mono mode of the $1\,\mu s$ camera. In blue there is a clear over exposition in colour mode that is not clearly visible in mono mode.

Error corrected by setting exposure in RGB mode and not in mono mode

Lab test on the $1\,\mu s$ colour camera

- Bench test #3:
  - Imaging of the ring MRSV with both cameras at different positions along the optical line
    - 1 motor step $= 0.6\,\text{mm}$
    - Closer results $\approx 2\,\%$ difference
    - Smallest size measured with the $1\,\mu s$ colour camera

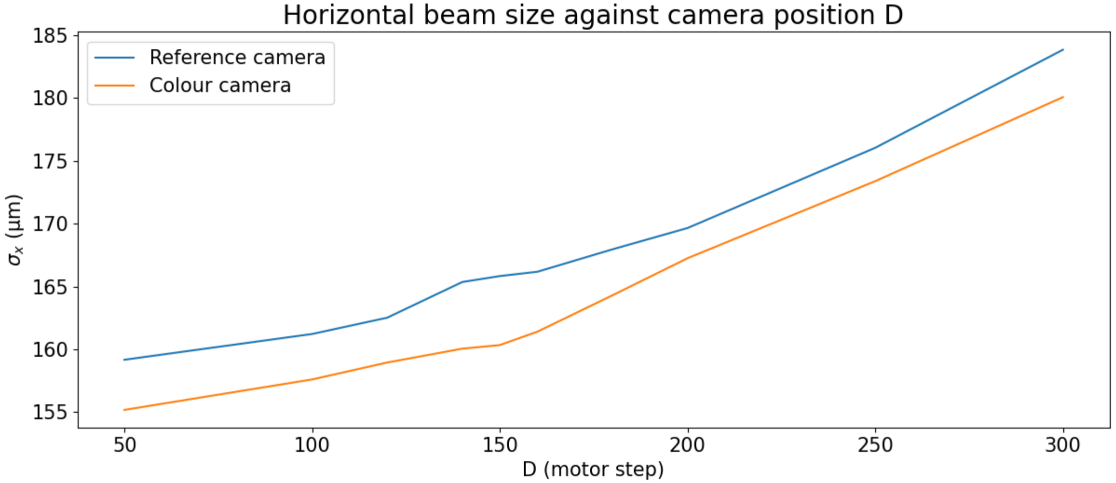

Figure: Horizontal beam size vs. camera position along optical line

- Possible explanations :
  - Difference in sensor position according to the camera frame
    - A few millimetres of difference at most, cannot explain everything
  - Difference due to depth of field variation and beam rotation in dipoles

    $\Rightarrow$ Close study of depth of field

Study of the depth of field as function of camera parameters

Depth of field (DoF): defined as the distance where one light point focuses on one pixel only

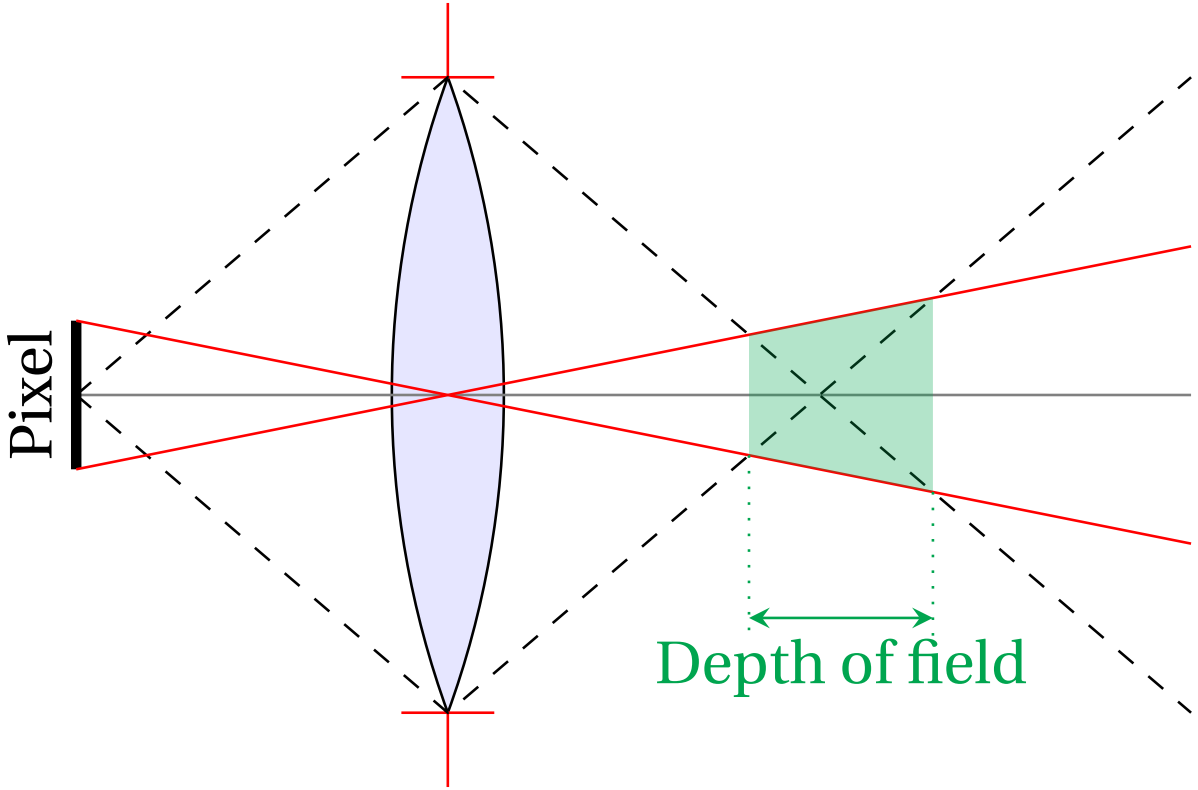

Figure: Simplified diagram of depth of field

Study of the depth of field as function of camera parameters

Parameters studied :

- Aperture :
  - Only light going straight through the lens reaches the pixel, which lowers blurriness
  - **Decrease** aperture ⇒ **Increase** DoF

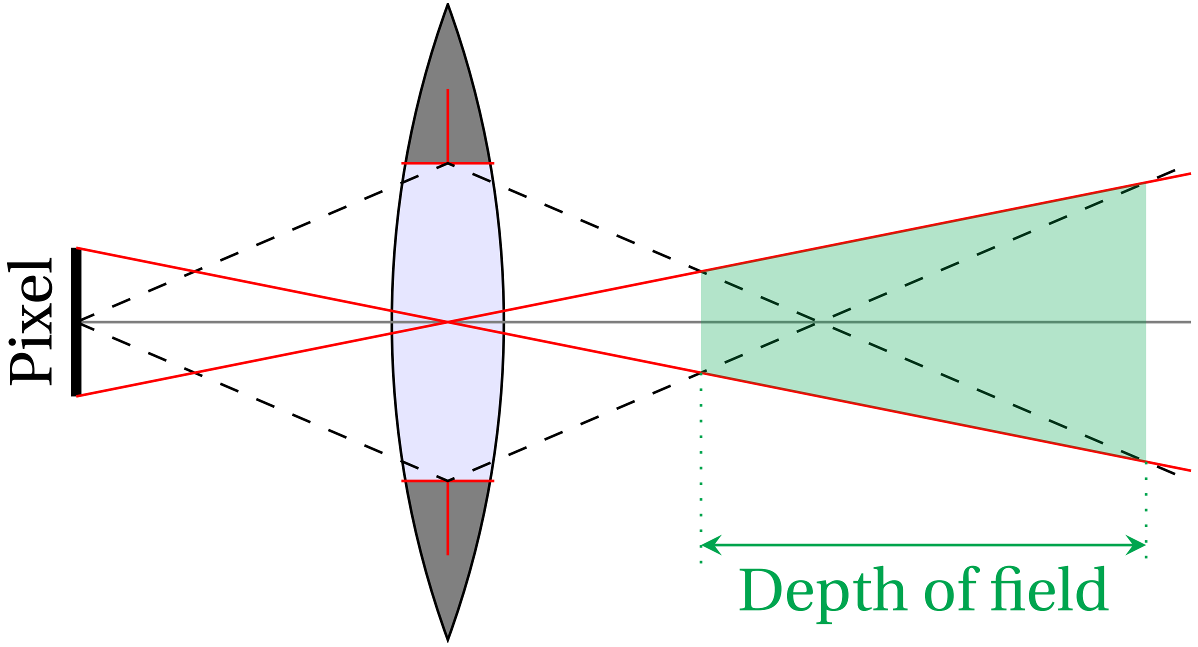

Figure: Simplified diagram of depth of field

Study of the depth of field as function of camera parameters

Parameters studied :

- Aperture :
  - **Decrease** aperture ⇒ **Increase** DoF
- Pixel size :
  - Change the pixel size does not change the blurriness of the image point; Hence, maximum acceptable blurriness on a large pixel already spread out on a smaller pixel
  - **Decrease** pixel size ⇒ **Decrease** DoF

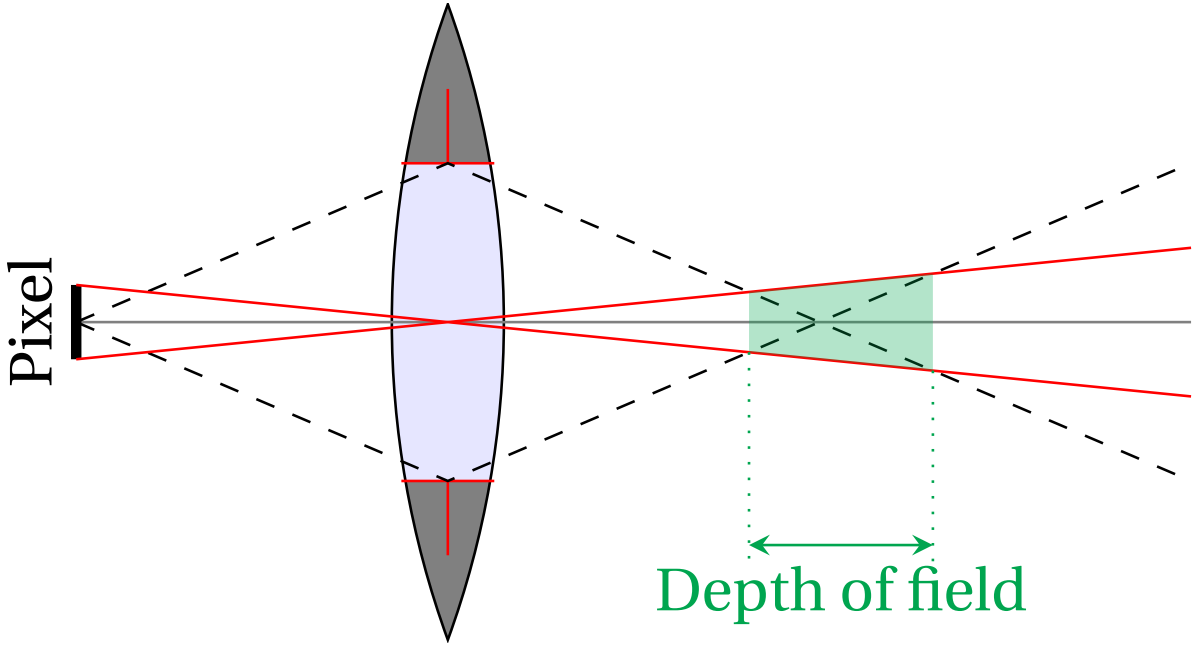

Figure: Simplified diagram of depth of field

Study of the depth of field as function of camera parameters

Parameters studied :

- Aperture :
  - **Decrease** aperture ⇒ **Increase** DoF
- Pixel size :
  - **Decrease** pixel size ⇒ **Decrease** DoF
- Sensor type (mono/colour) :
  - Because of fitters before each pixel, a blue light point source won't reach nearby red pixels; Hence, larger blurriness will still be visible only on one pixel.
  - It acts like an artificial increase in pixel size
  - **Colour camera** ⇒ **Increase** DoF comparing to mono camera

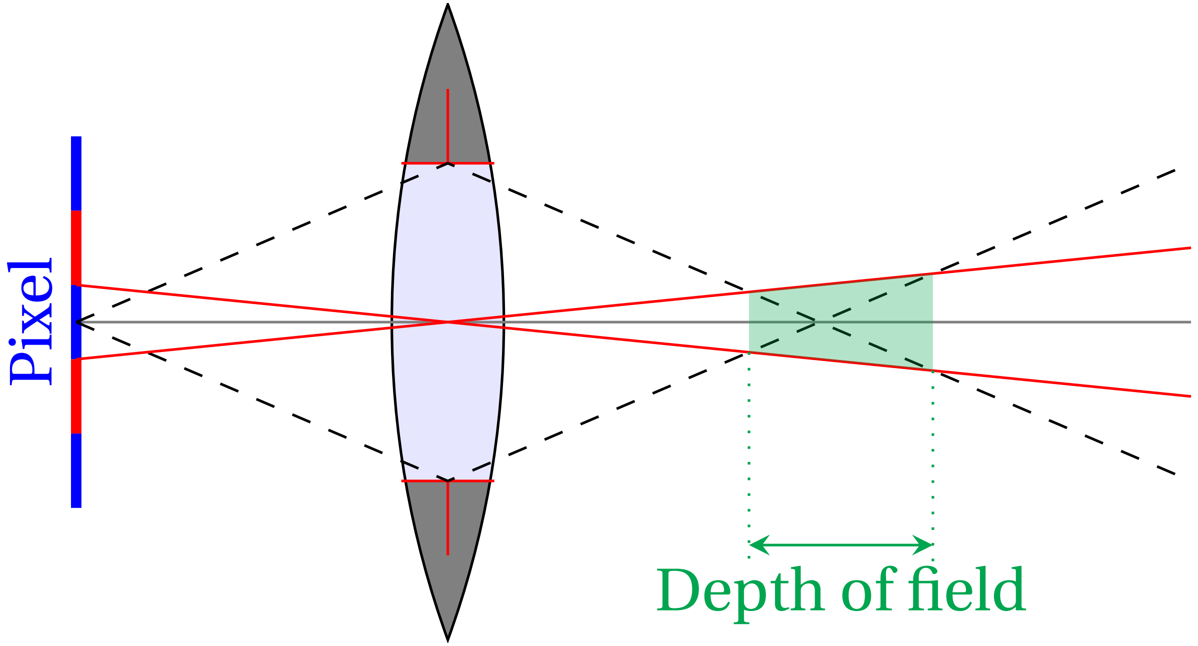

Figure: Simplified diagram of depth of field

Study of the depth of field as function of camera parameters

Parameters studied :

- Aperture :
  - **Decrease** aperture ⇒ **Increase** DoF
- Pixel size :
  - **Decrease** pixel size ⇒ **Decrease** DoF
- Sensor type (mono/colour) :
  - **Colour camera** ⇒ **Increase** DoF comparing to mono camera

- Parameters to compute DoF :
  - f: lens focal [m]
  - d: Aperture diameter [m]
  - $N = f/d$: Optical aperture
  - WD: Work distance [m]
  - P: Pixel size [m]
  - $S = \begin{cases} 1.4 & \text{Mono} \\ 2 & \text{Colour} \end{cases}$: Correcting factor according to sensor type

- DoF calculator : https://www.framos.com/en/depth-of-field-calculator
  - $CoC = P \times S$: Cercle of confusion [m]
  - $Dhyper = \frac{f^2}{N \times CoC + f}$: Hyperfocal distance [m]
  - $Dnear = \frac{WD}{1 + ((WD - f) \times N \times CoC)/f^2}$: Near limit of DoF[m]
  - $Dfar = \begin{cases} \infty & \text{if} WD > Dhyper \\ \frac{WD}{1 - ((WD - f) \times N \times CoC)/f^2} & \text{else} \end{cases}$: far limit on DoF [m]
  - $DoF = Dfar - Dnear$: Depth of field [m]

Test of a 1 µm mono camera on ring MRSV

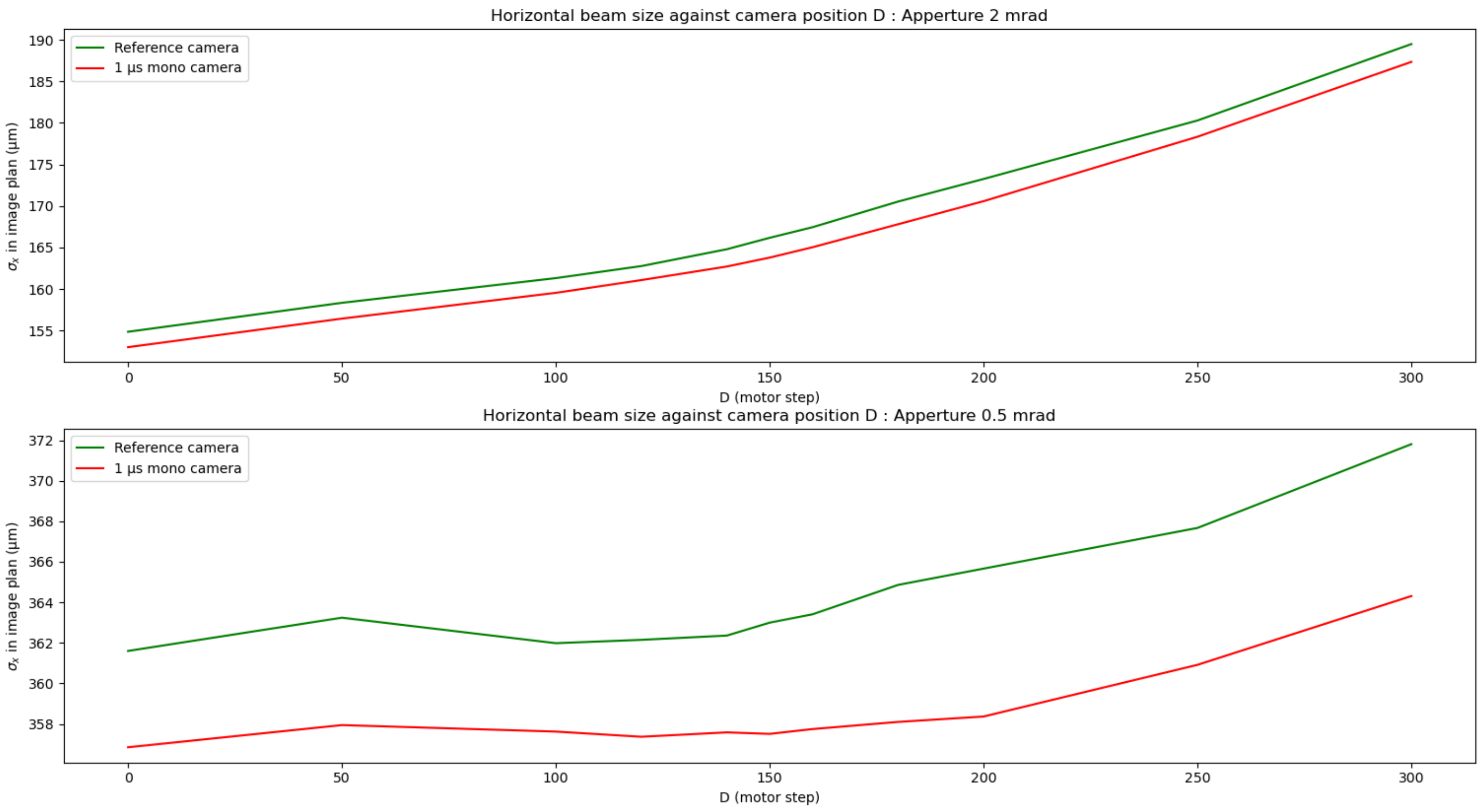

Figure: Horizontal beam size along the booster ramp

- Beam size measurement : 1-2 % difference between cameras
- Smaller pixel ⇒ Smaller beam size measured
- Larger aperture ⇒ Smaller beam size measured
- Coherent with depth of field modification
  - Larger depth of field = Longer integrated curved trajectory

  ⇒ Larger beam measured
- Impact of pixel size modification much smaller than aperture modification

Horizontal beam size measurement at $1\,\mu s$ along the ramp

- Coherent results between cameras
- More stable measurement with $1\,\mu s$ camera (to be confirmed)
- But beam fluctuation finally plays no impact on beam size
- And still 10 to $40\,\%$ discrepancy exp./sim.

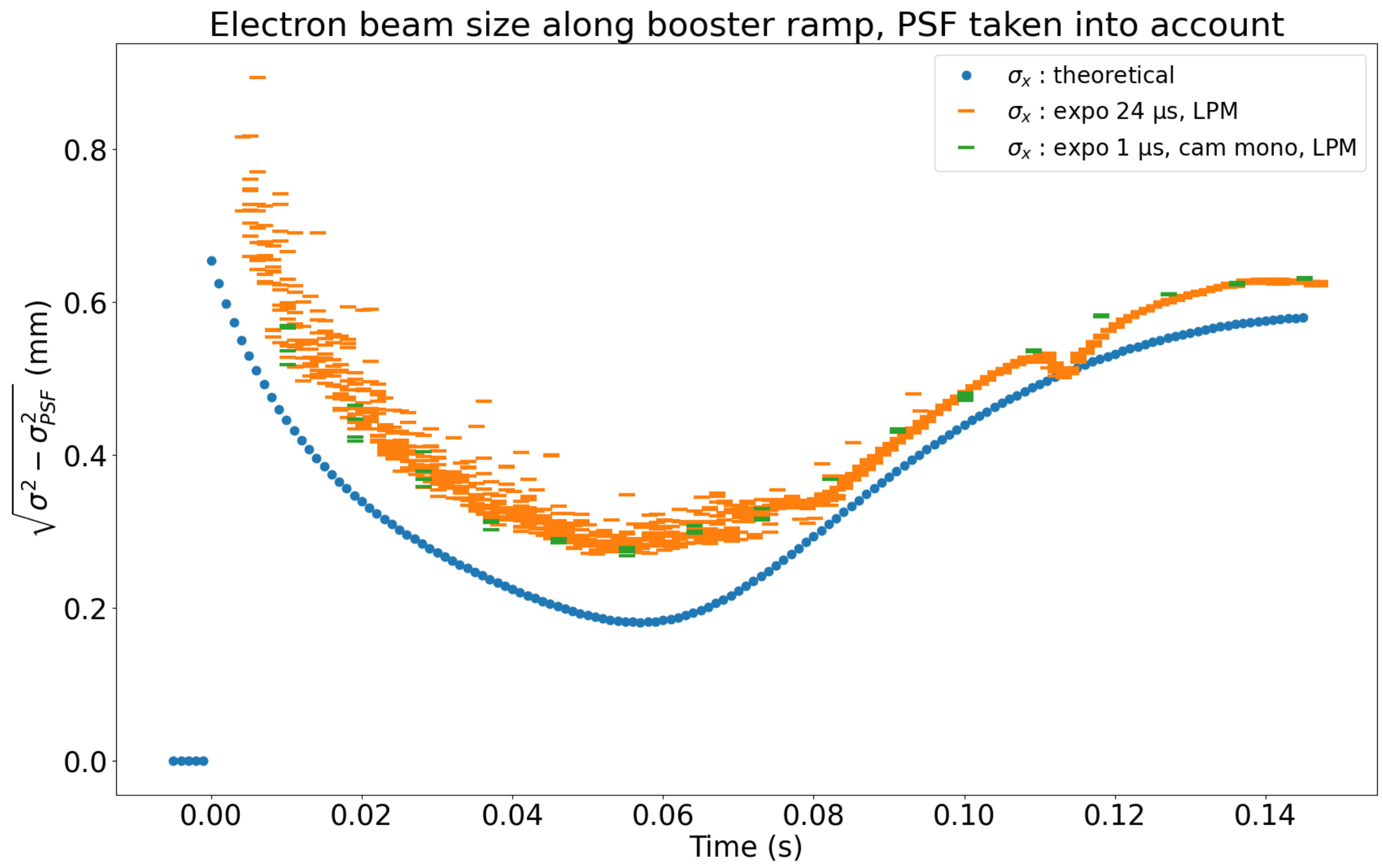

Figure: Horizontal beam size along the booster ramp

Conclusion

- The MRSV has been upgraded
- Some tests have been made with a colour camera, but it creates more drawbacks and risk of mistakes than advantages
- Beam size measurement along the booster ramp shows similar behaviours as the theoretical model
  - Larger experimental than simulated beam size
  - The exposure time does not seem to explain this difference
- In parallel, we are improving emittance and Twiss parameters measurement before and after the booster to check the theoretical model

Thanks for your attention !

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