YAG/OTR monitor for beam halo study

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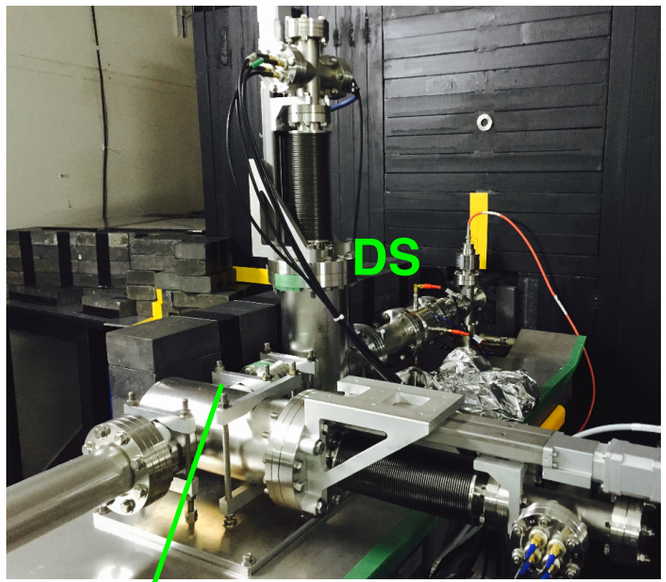
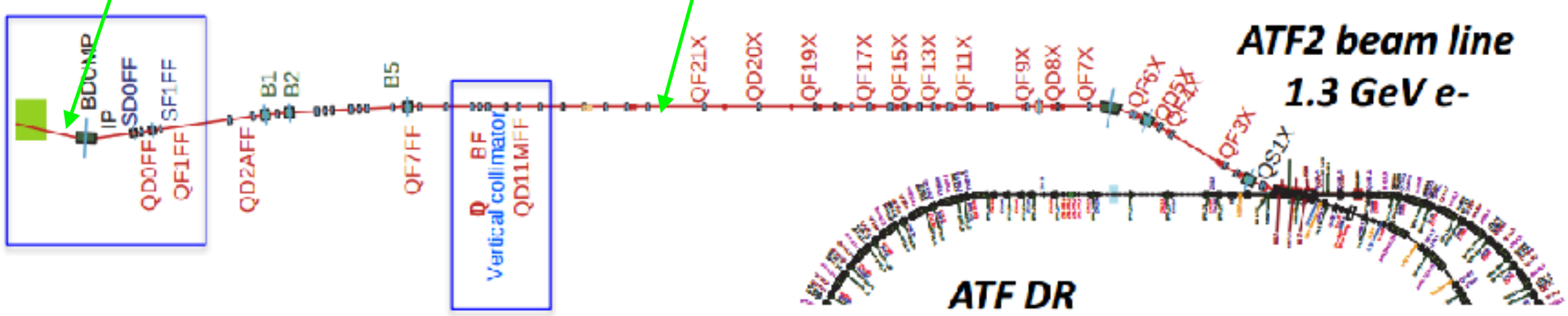
1. Introduction

Motivation of YAG/OTR monitor development

- Diagnostic of halo with dispersion-free or dispersion-domain
- Fast diagnostic
- Complementary measurement of beam halo
- Measurement using DS suffers more from chromaticity & aberration in FF



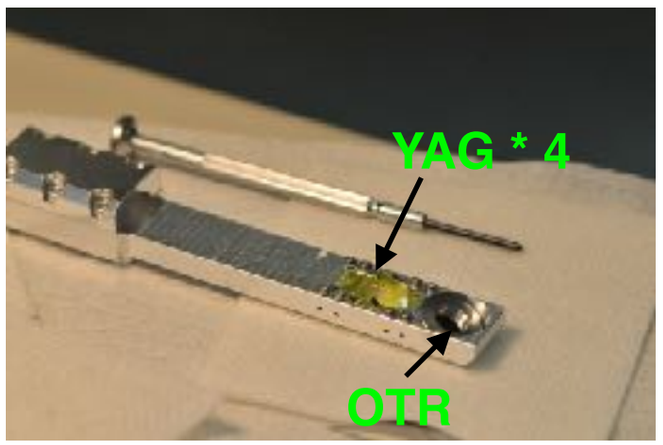
- Ver. beam halo **is** dominated by BGS
  —> PRAB submitted
- Formation of hor. beam halo?
  - EXT kicker
  - Touschek
  - Chromaticity in the DR



Design of YAG/OTR monitor

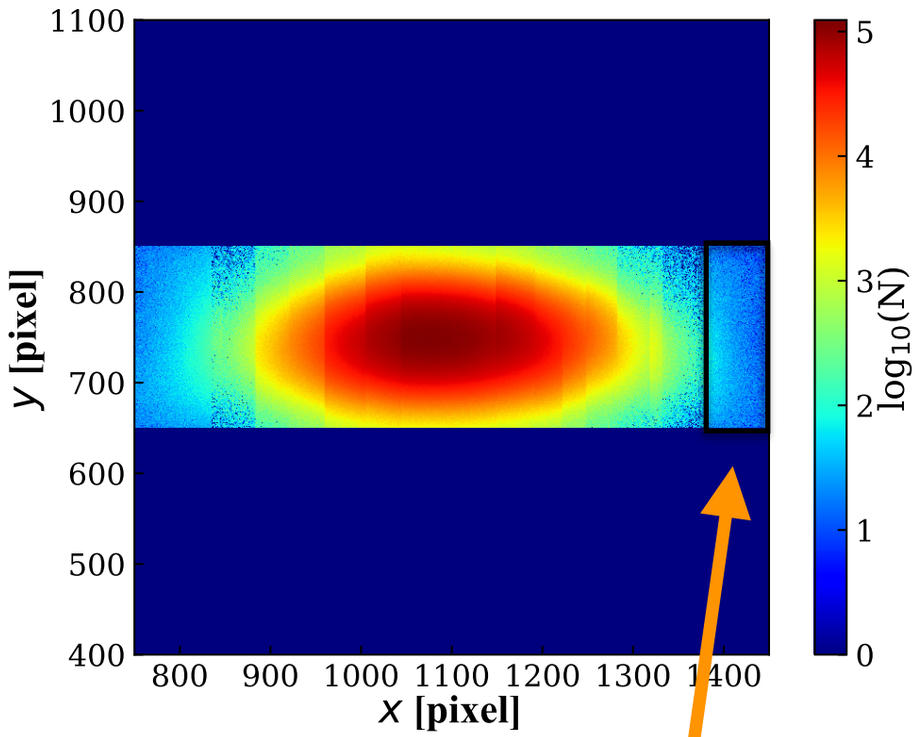
- Lens system — previous YAG monitor
- sCMOS camera — CERN ODR group
- Manipulator — Laser Wire (by A. Aryshev)
- Data acquirement
  - ODR group
  - Specialised for YAG/OTR monitor (by K. Tama)
- **Goal: DNR > 1e5 and resolution ~ 10 um**

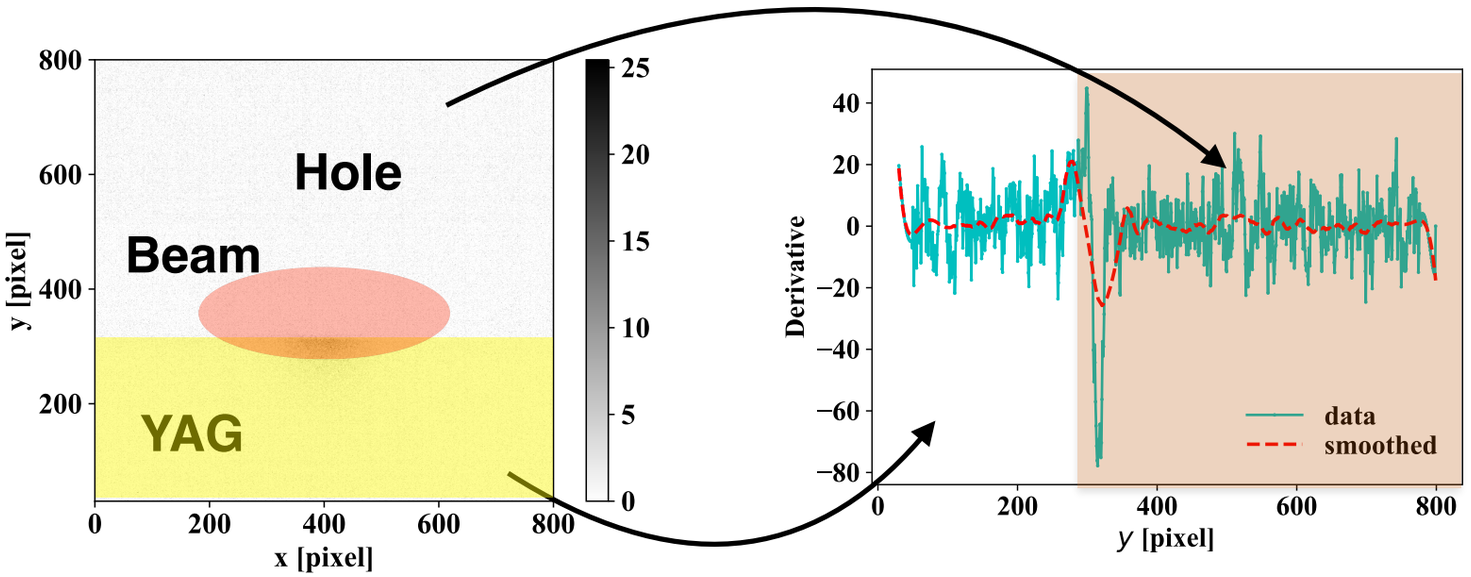
0.5 %mol Ce:YAG	Dimensions	4 * 6 * 0.1 mm
	Angle w. beam	45 deg
OTR	Dimensions	r = 4 mm
	Angle w. beam	67.5 deg
sCMOS camera	pixel size	6.5 um
	Digital DNR	16 bit
	Noise level	1.35 e (2 count)
Lens	Zoom	0.38 - 3

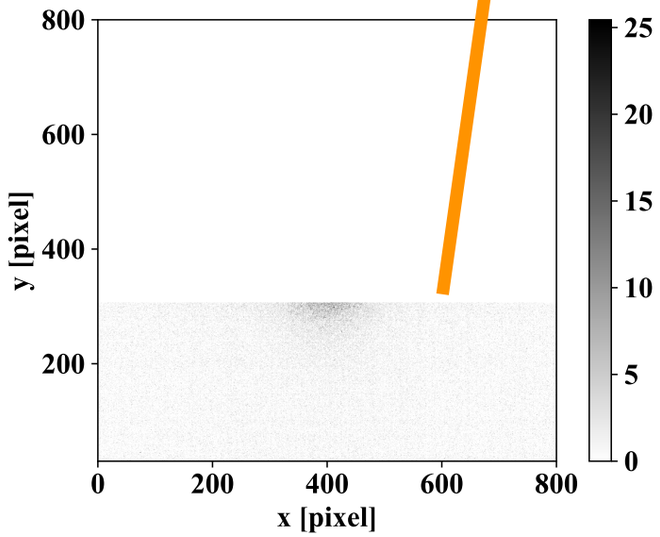


Scheme of beam halo imaging

- Halo particles has <10 e/pixel local density —> avoid blooming effect
- Scanning (x or y) using YAG + filter
- ND filters (10% and 1%) + BP filters
- Shot-by-shot beam instability is critical!!
  - 100 shots; σ_x~320 um, σ_y~74 um; 3e9/pulse
  - Hor./Ver. position jitter: < 5%/10% of σ_x/σ_y
  - Hor./Ver. beam size jitter: ~ 2%







2. Dynamic range of YAG/OTR monitor

Photon yield ability of ceramic 0.5 mol %Ce:YAG

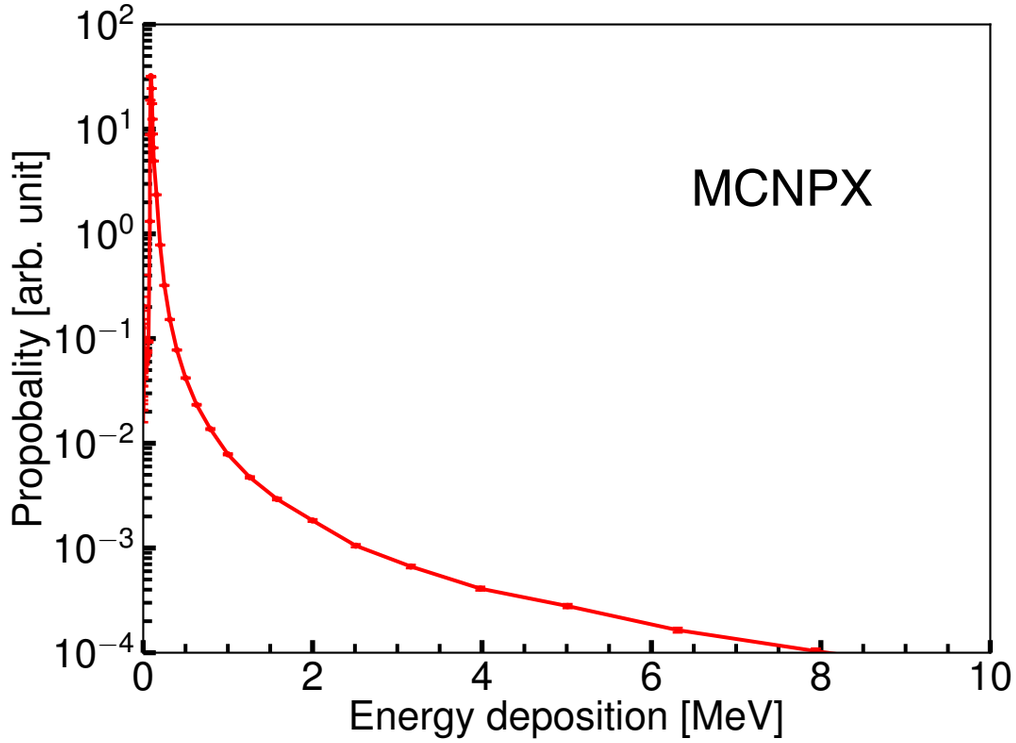
- PhY of scintillator

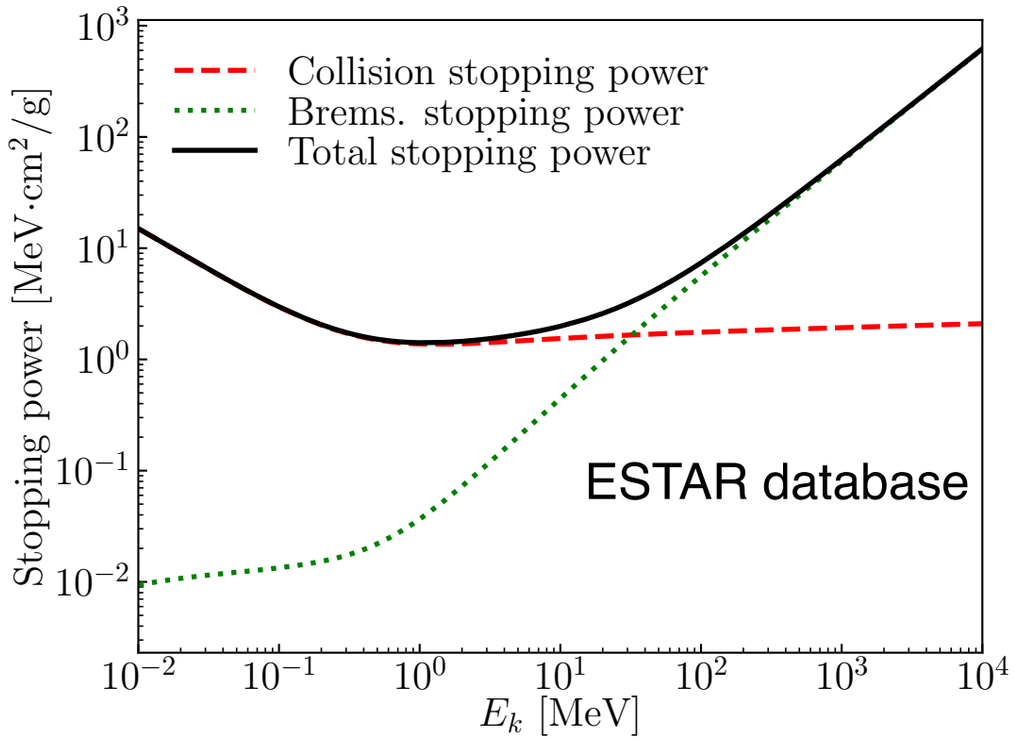
$$N_{ph} = \eta\, N_e = f(dE/dx)$$

η : efficiency of scintillating response
dE/dx: energy deposition

- Energy Deposition
  - **0.1 MeV**, by MCNPX (1.3 GeV, beam size 0.3 mm * 0.3 mm)
  - **0.13 MeV**, based on ESTAR database
- Nominal PhY: **1.92e4 ph/MeV**

PhY@ATF: 1900-2500 ph/e!

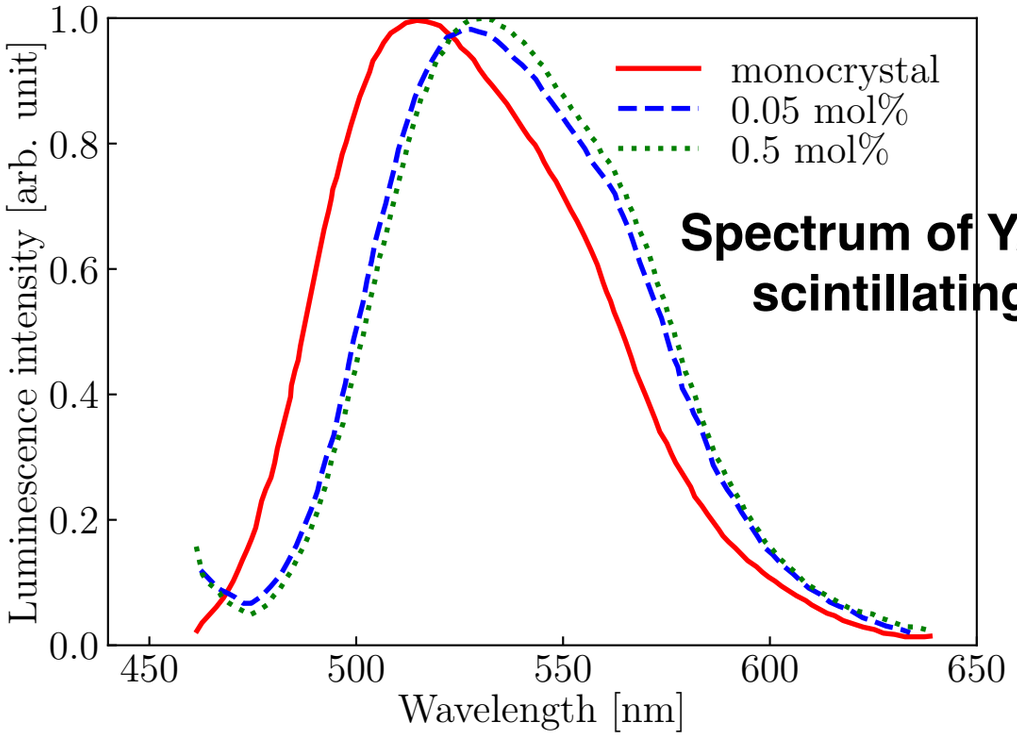




YAG photon collection by camera

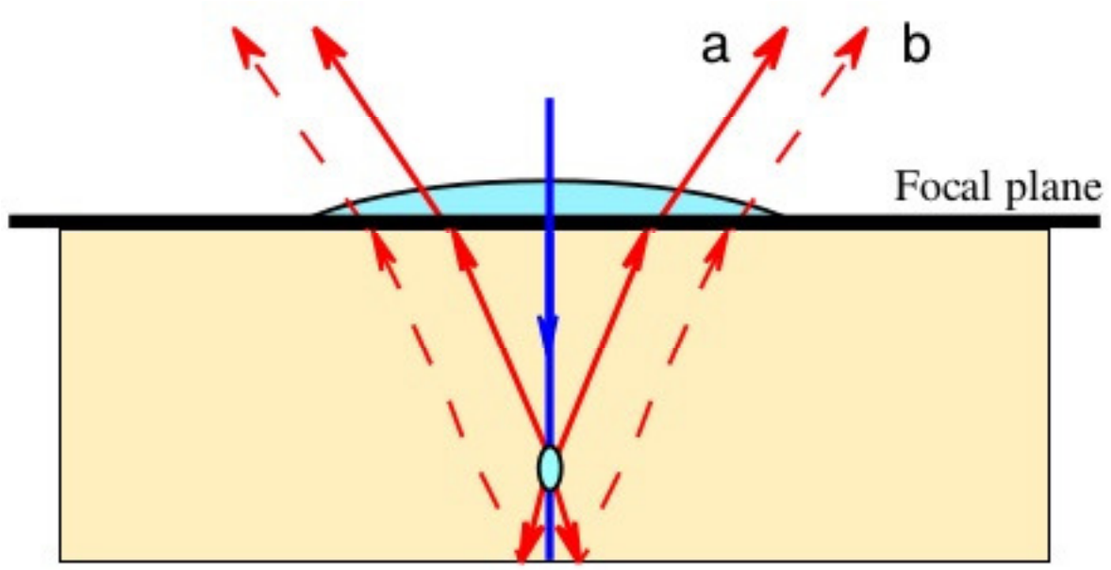
- The measured PhY of 0.5 mol% ceramic YAG: **1760 - 2200 ph/e**
  - Emission spectrum: [480 nm, 640 nm]
  - Transparency: 80%
  - Reflection: 20%
  - Transmission in lens/view window system: > 80%
- Quantum Efficiency of CMOS : 70%
- Reduction of the acceptance angle (YAG, refraction index 1.82)
  0.097 rad -> 0.062 rad (zoom = 2.8)
- Photon collection at sensor: **0.33 ph/e**

In agreement with estimation!



Spectrum of YAG scintillating

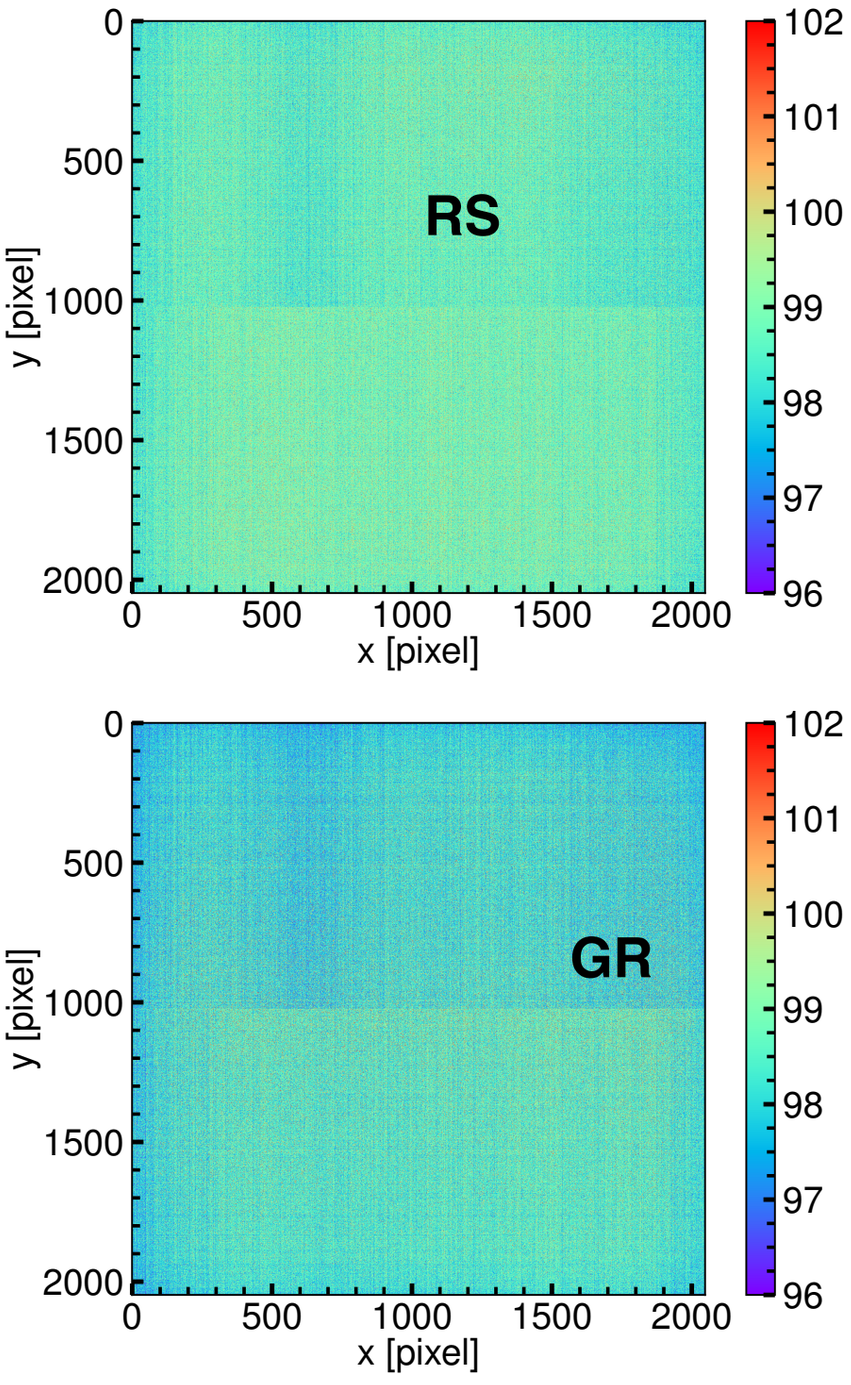
Reduction of efficient acceptance angle

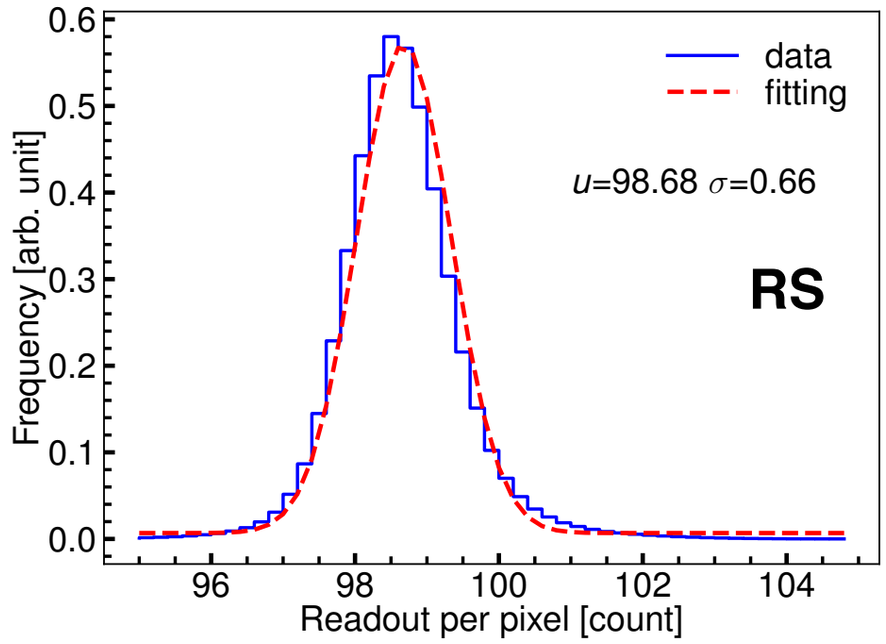


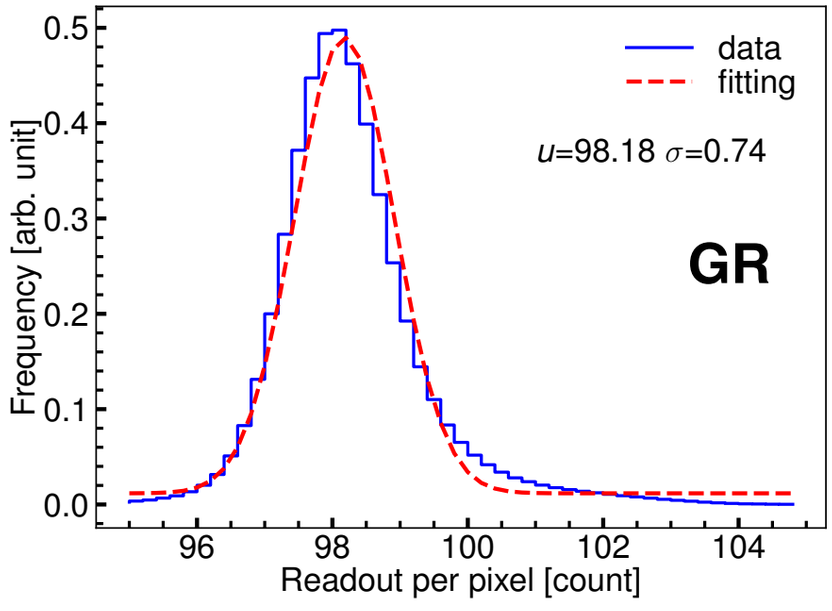
Noise level of sCMOS camera

- BG level with light: 98.x (σ=0.7) counts (t_{exp} = 10 ms)
- Non-uniform BG (<2 count)

wo. Beam

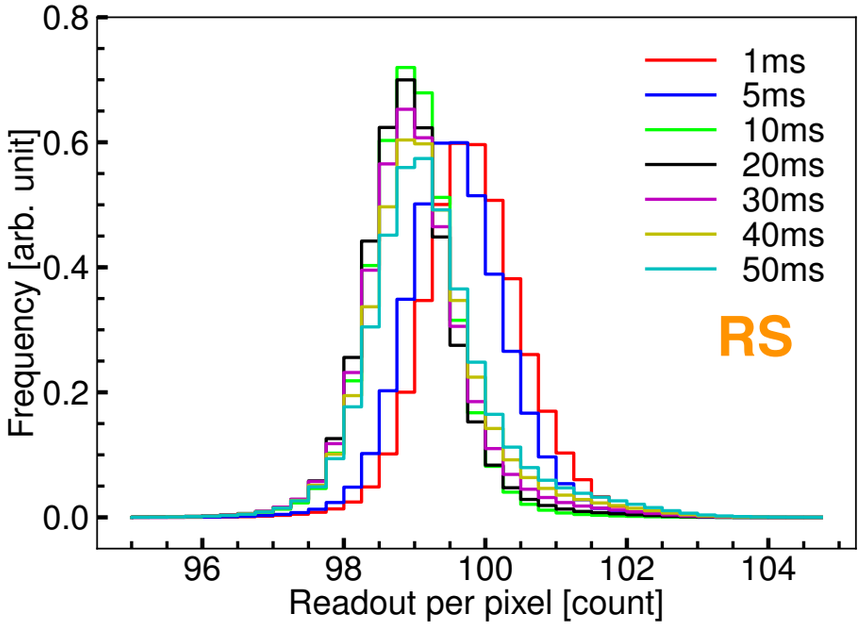


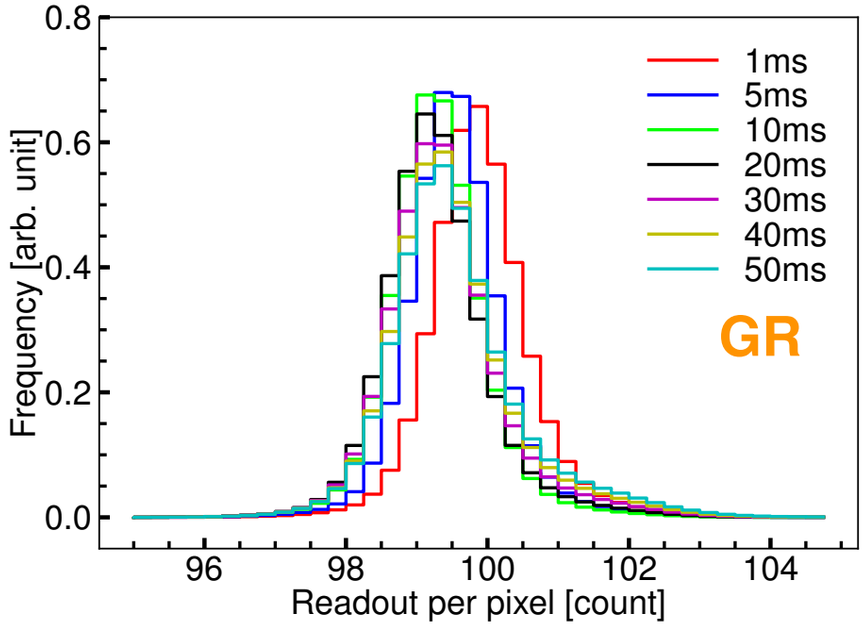


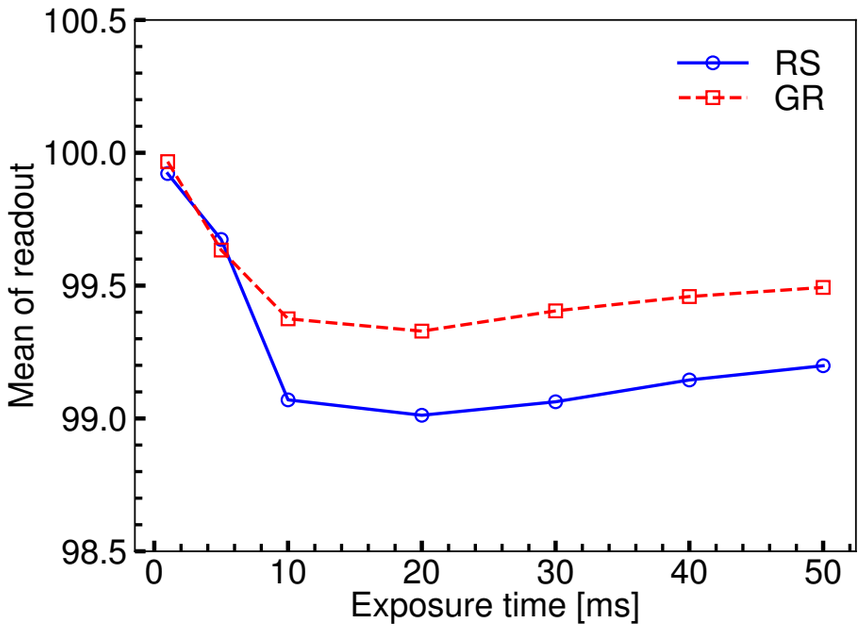


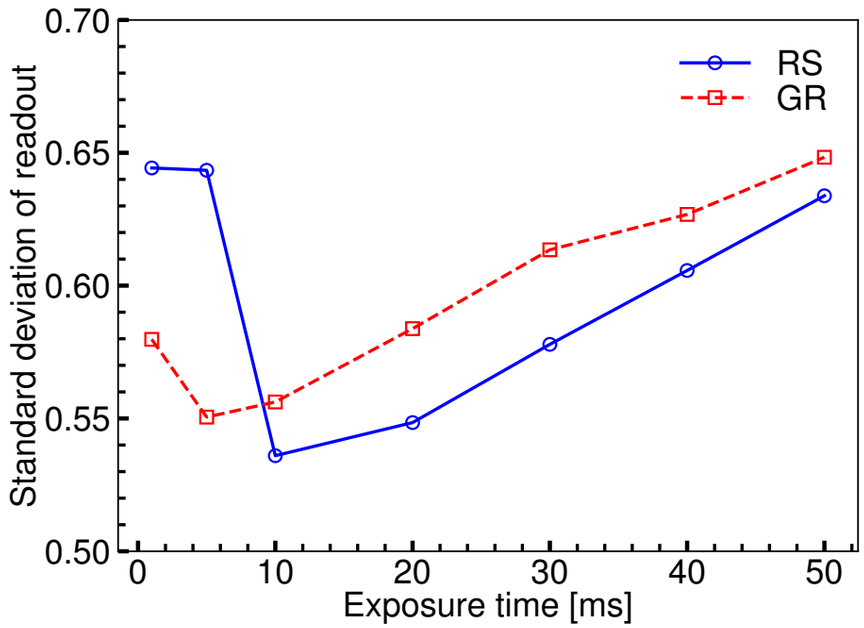
BG level of YAG system (w. beam)

- t_{exp} = 10 ms (5 ms) => least BG in the RS (GR) mode
- At least **3 count/pixel (6 e/pixel)** <— good SNR (>3)



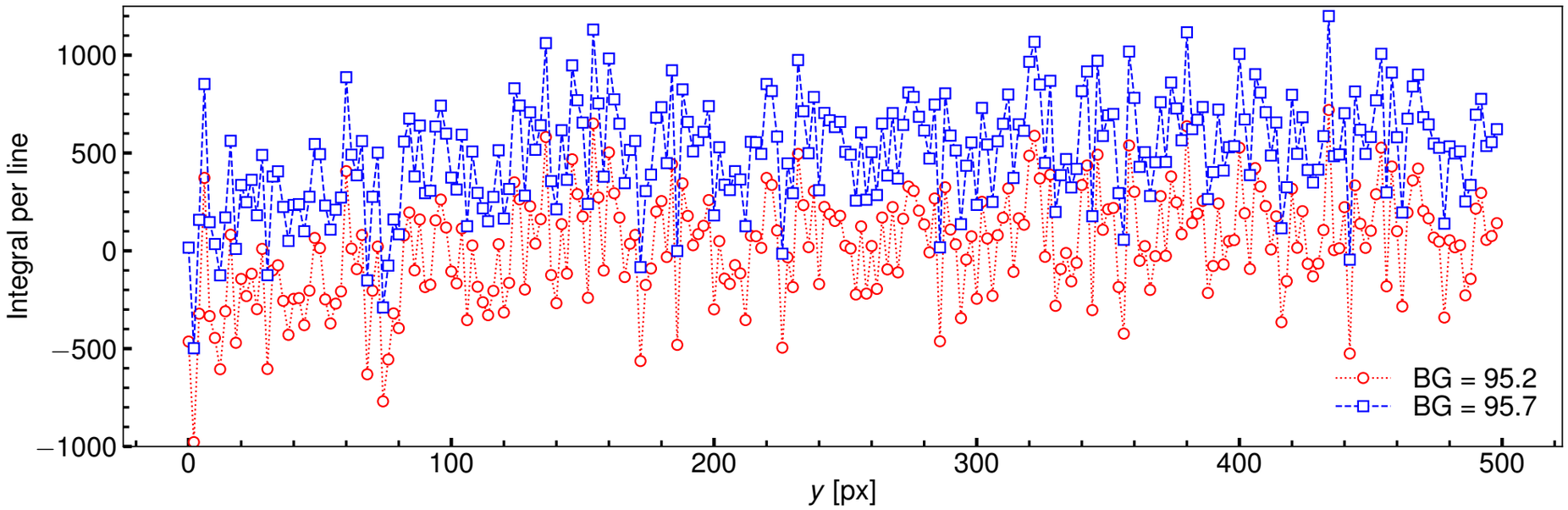


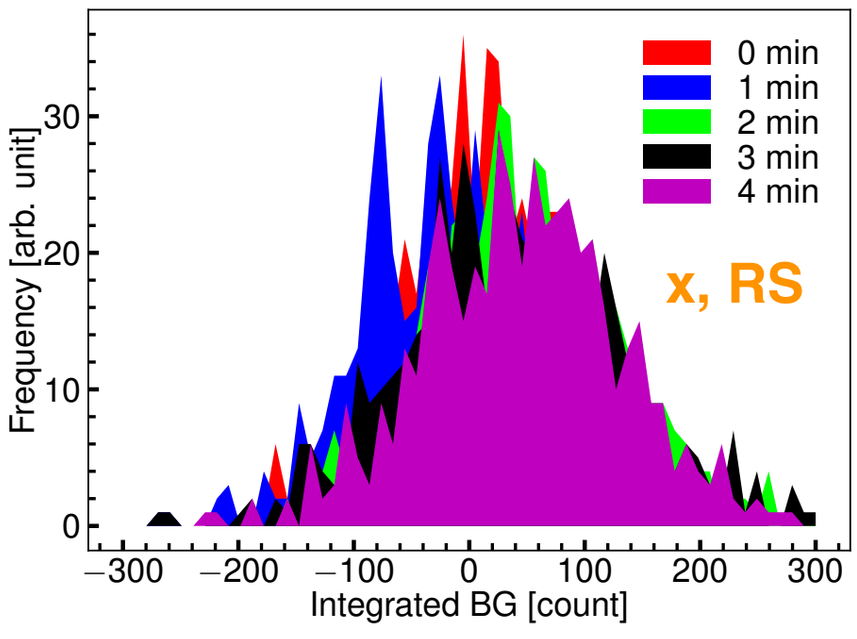


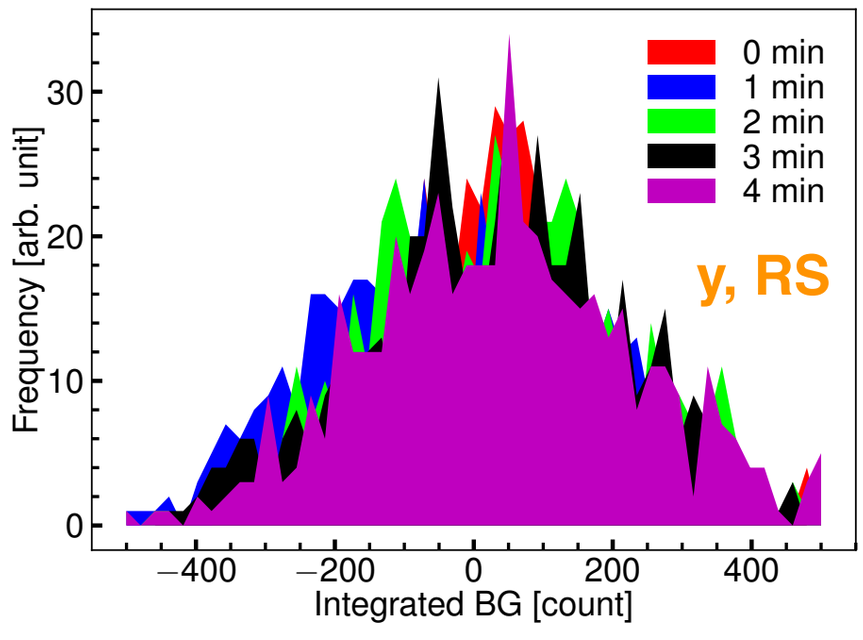


BG level of YAG system (w. beam)

- t_{exp} = 10-20 ms; RS mode
- The average of readout —> mean BG level
- BG for 1D projection ~ 300 counts (/600 pixels) -> 0.5 count/pixel

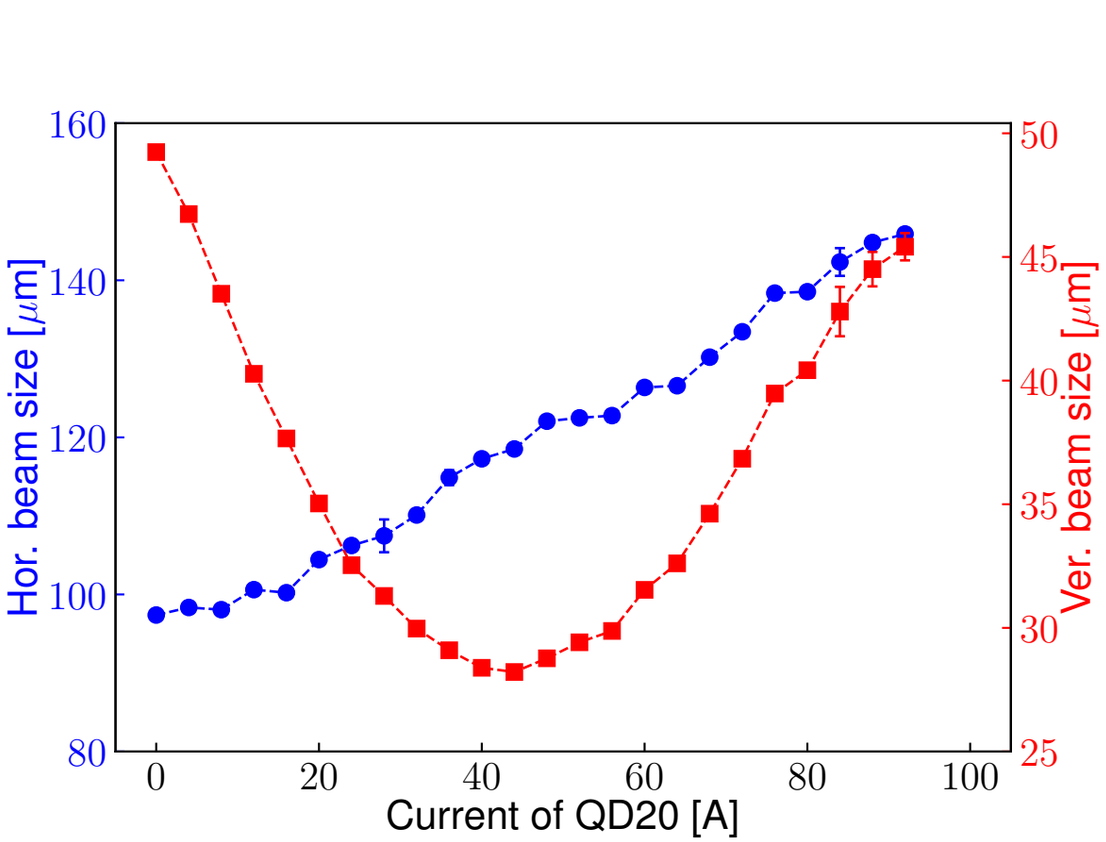




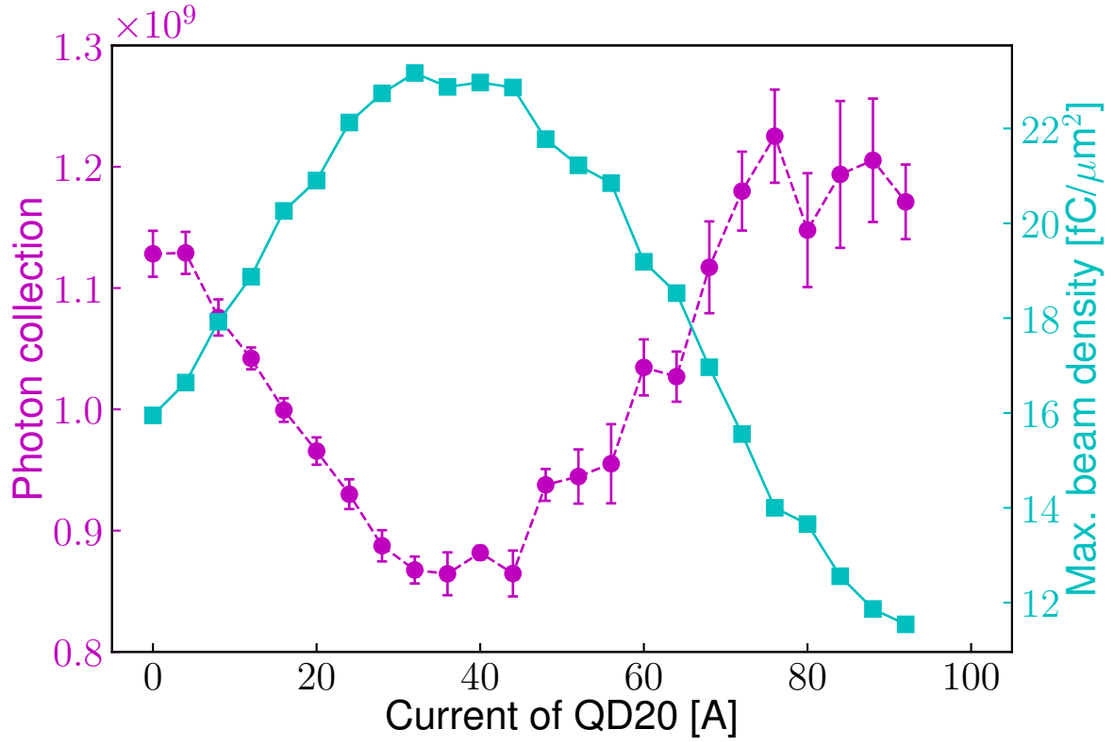


Saturation level of YAG scintillating

- Variation of photon collection vs. beam size on YAG (QD20 scan)
  => upper limit of saturation level
- Beam size => Max. local beam density/pixel
- Upper limit of saturation level: **16 fC/um²**



Expectation: <40 fC/um²



Upper limit of DNR: 16 fC/um² (7.5e5 electron/pixel, zoom = 2.8)

2D DNR > 1e5 using only YAG
YAG+OTR?

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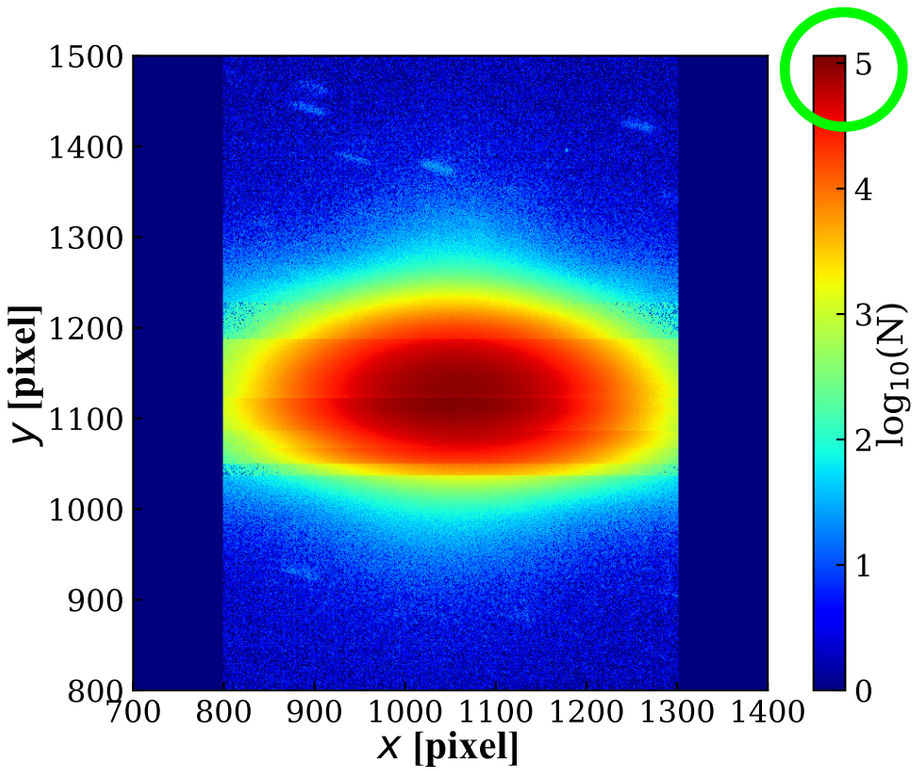

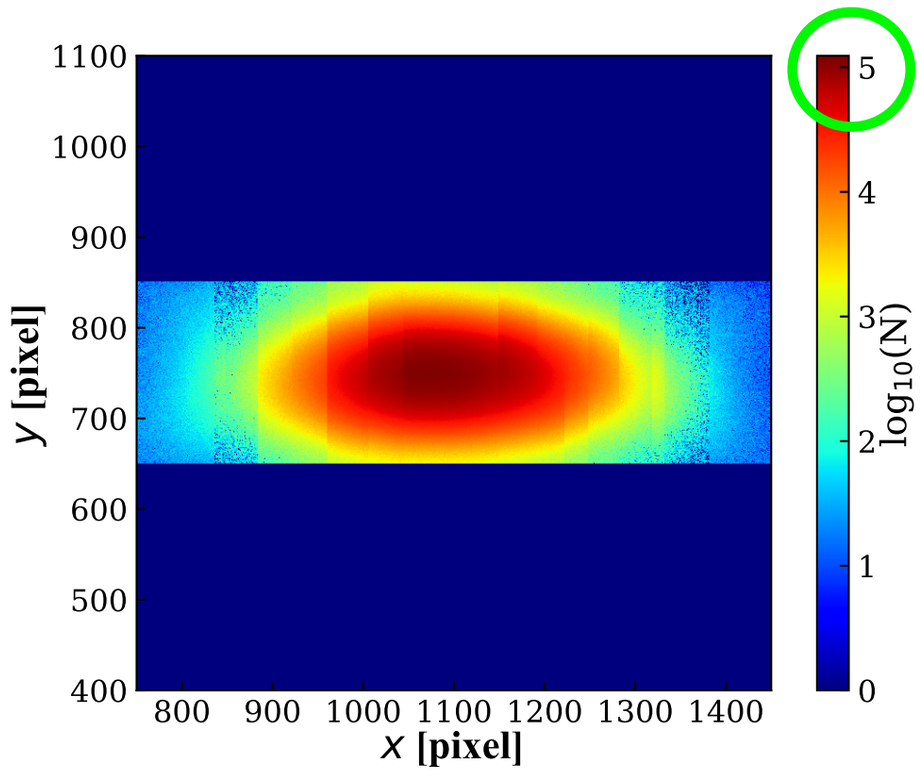

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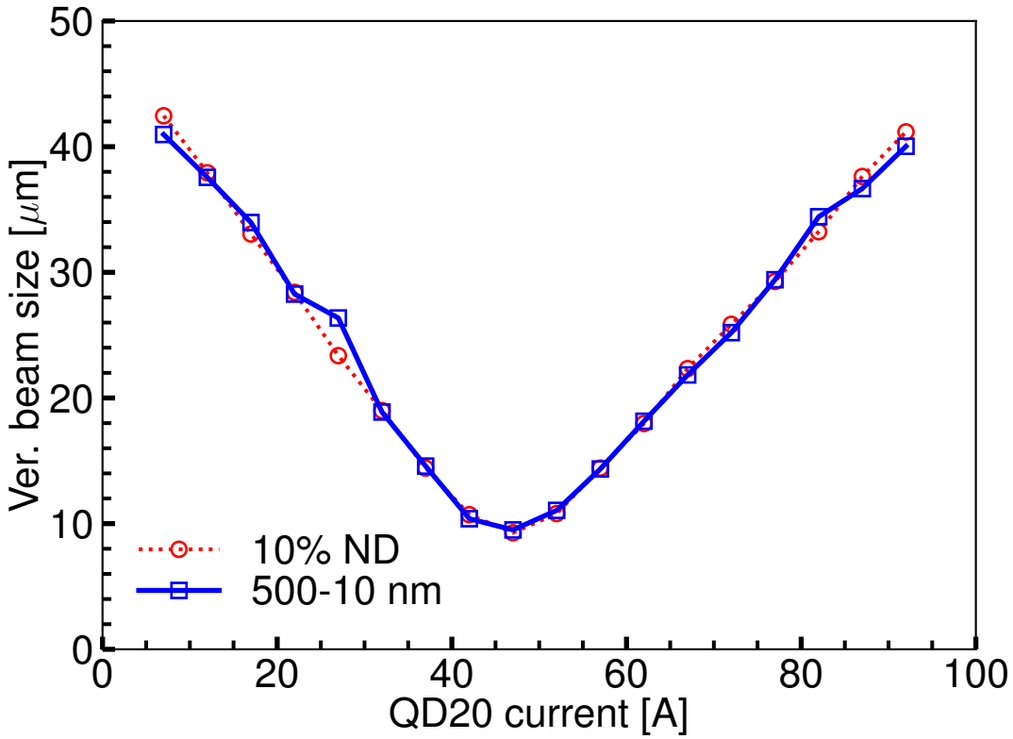
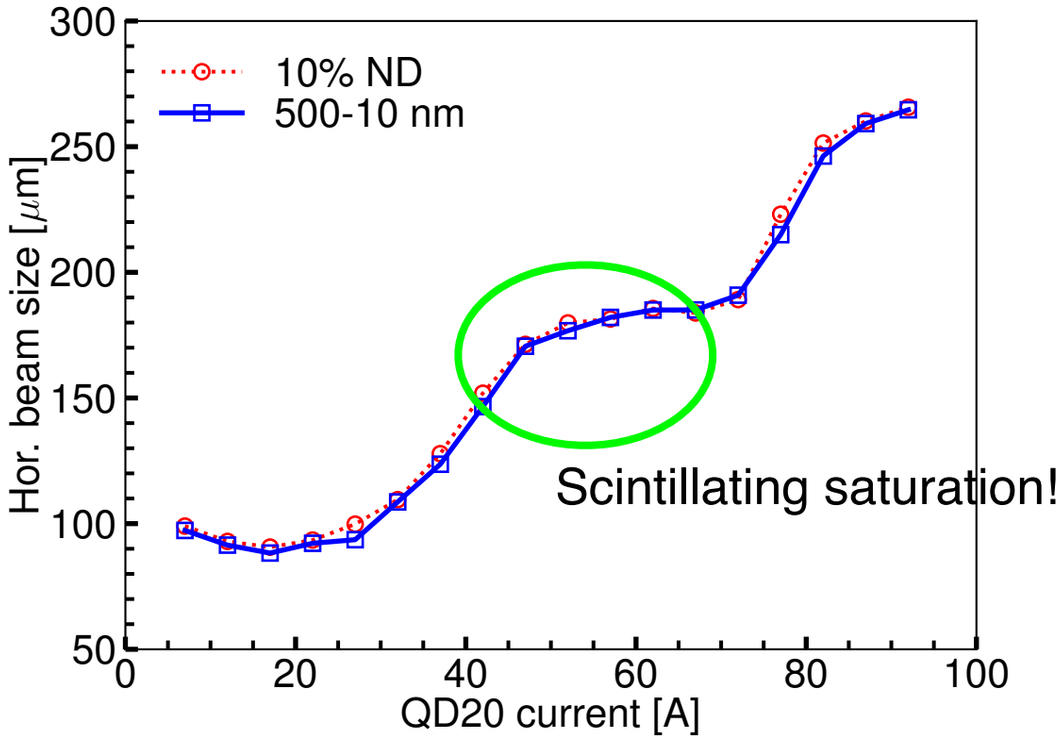
2D DNR > 1e5 using only YAG
YAG+OTR?

3. Resolution of YAG/OTR monitor

Resolution of YAG/OTR monitor

- Very flat beam at YAG for nominal ATF2 optics
  eg. $\sigma_x > 100$ um $\sigma_y > 10$ um
- YAG:
  - Resolution for hor. measurement: YAG thickness -> 26 um
    Normal hor. beam size at YAG > 100 um
  - Resolution for hor. measurement: pixel size and scintillating saturation (<10 um)
  - Measured min. ver. size: **9.5 um** (WD = 135 mm)



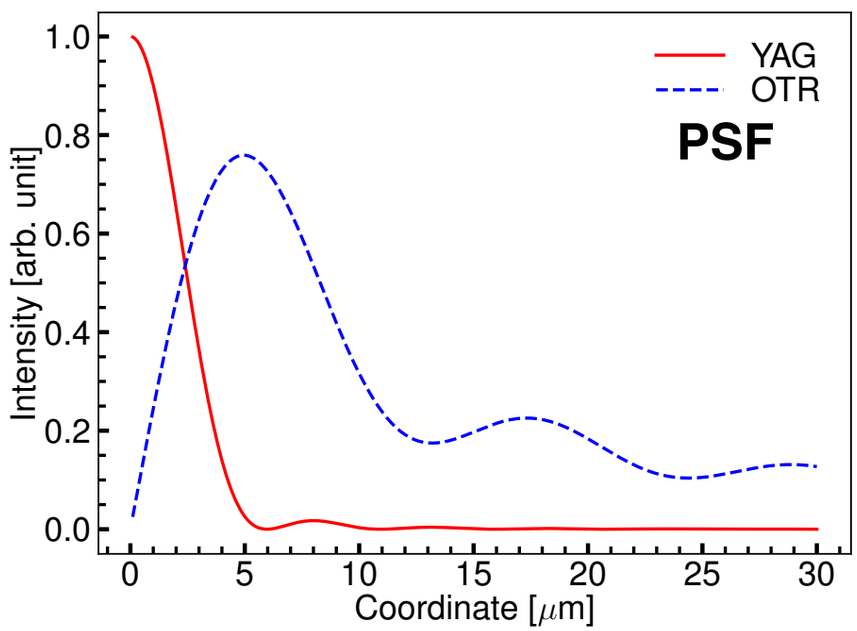


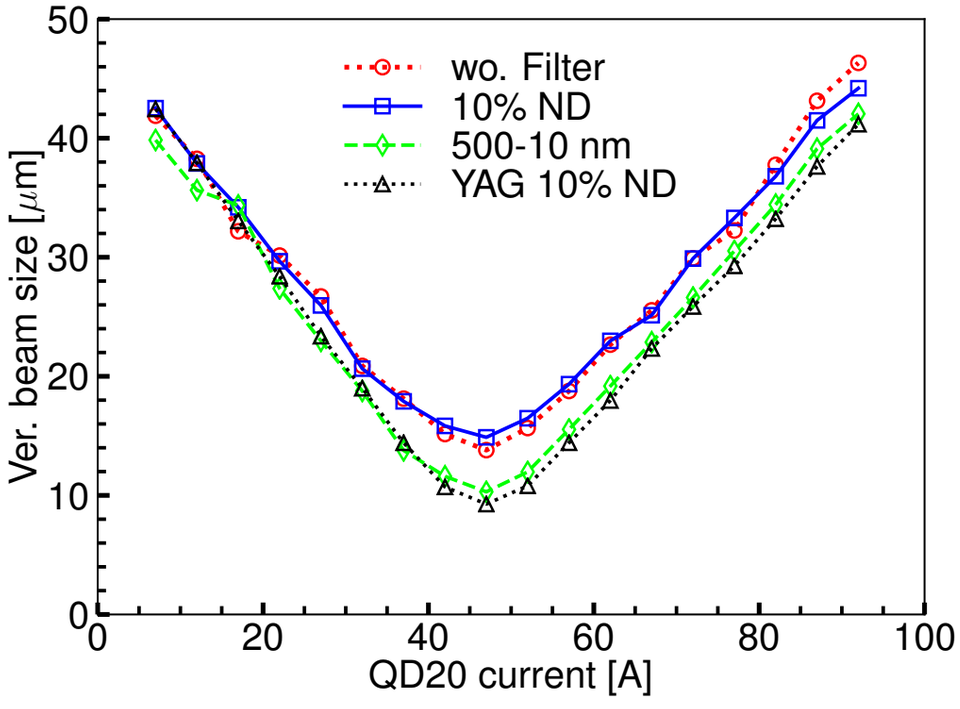
Resolution of YAG/OTR monitor

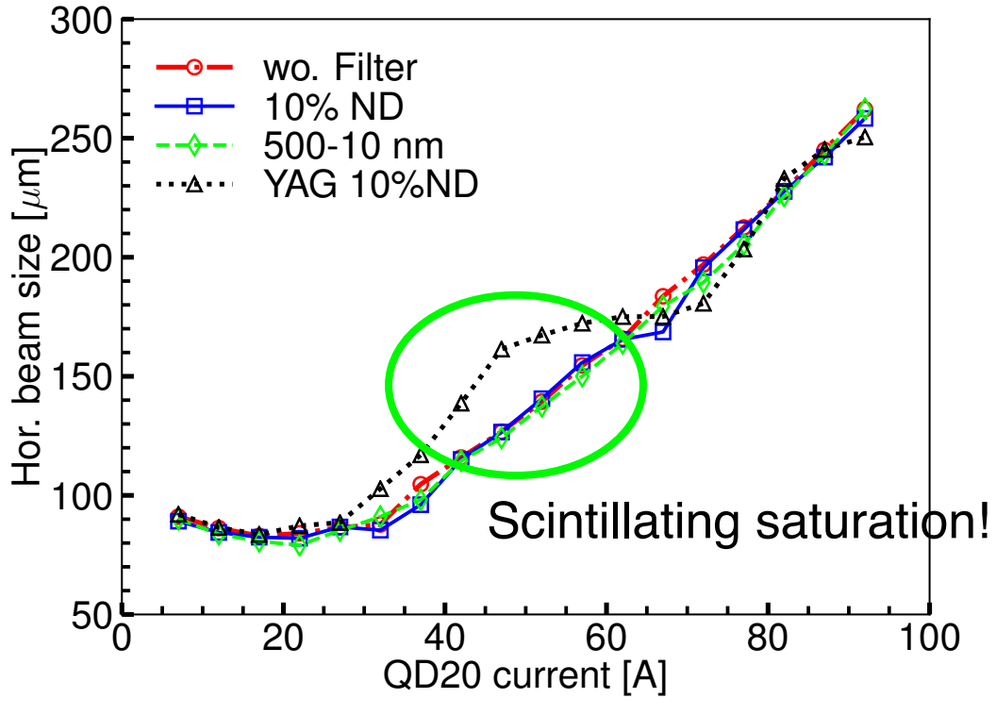
- Resolution of OTR is limited by optical diffraction
- Fitting PSF gives the diffraction limitation

$$\sigma_d = 4.2\,\lambda/\theta_{obs}$$

  - YAG, < 2 um; OTR, 5～8 um
- Min. ver. beam size by OTR: **10.2 um**
- Enlarged beam size for halo measurement
  —> saturation-free + less influence of diffraction







Summary

Summary and questions

- A YAG/OTR monitor for beam halo measurement has been designed and commissioned under the collaboration between KEK-CERN-LAL

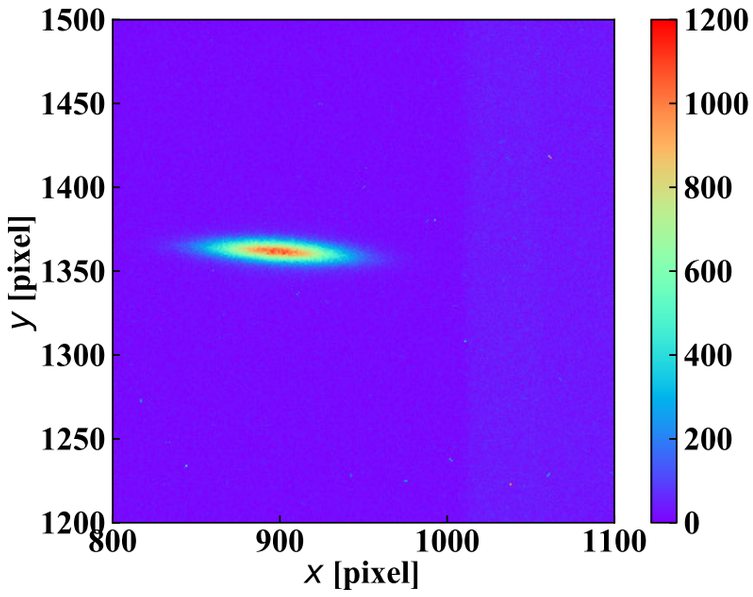
- The expected 2D DNR of **~1e5** (with good SNR) has been achieved
  - PhY of YAG and BG of sCMOS sensor —> the lower limit as 6 e/pixel
  - Scintillating saturation of YAG is estimated as 16 fC/um^2 -> Max. efficient local electron density of 7.5e5 e/pixel for the zoom of 2.8

- Resolution of YAG and OTR for ver. beam size measurement has been confirmed to be ~10 um with WD=135 mm lens system + BP filter

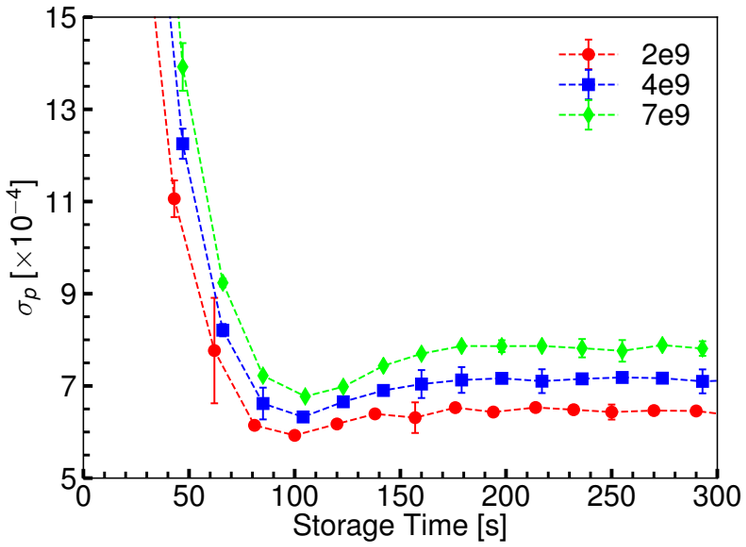
Thank you for your attention!

Side application of YAG/OTR monitor

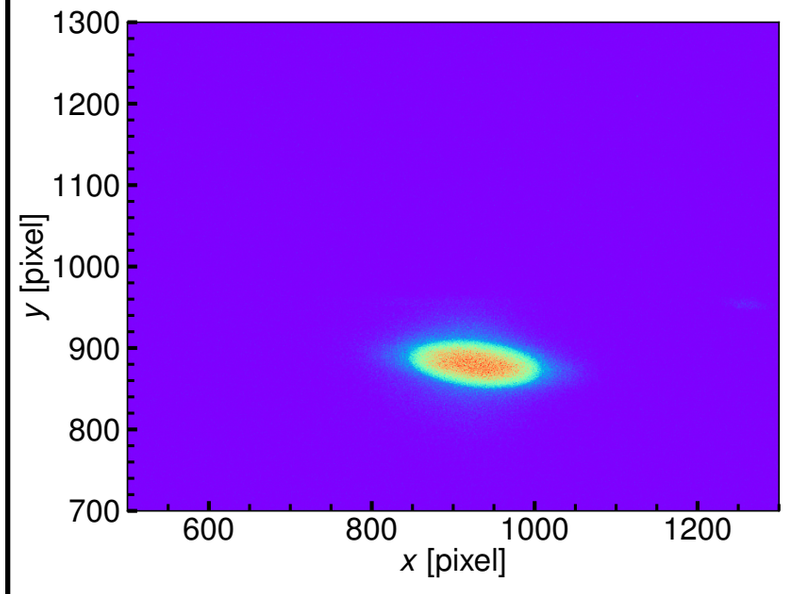
- Imaging of dark current from DR
  Intensity: 4.8e5 electrons (0.23 pA)
- The nature ver. emittance might be measured?

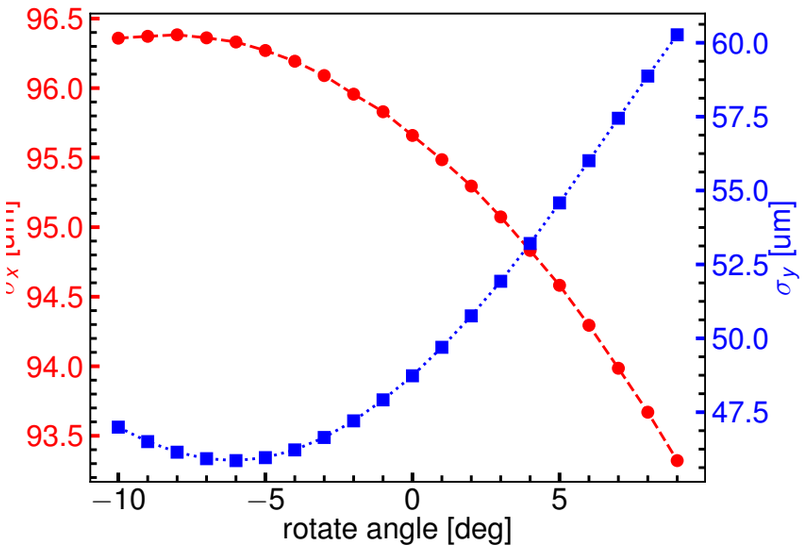


- Measurement of energy spread by proper adjustment of η_y



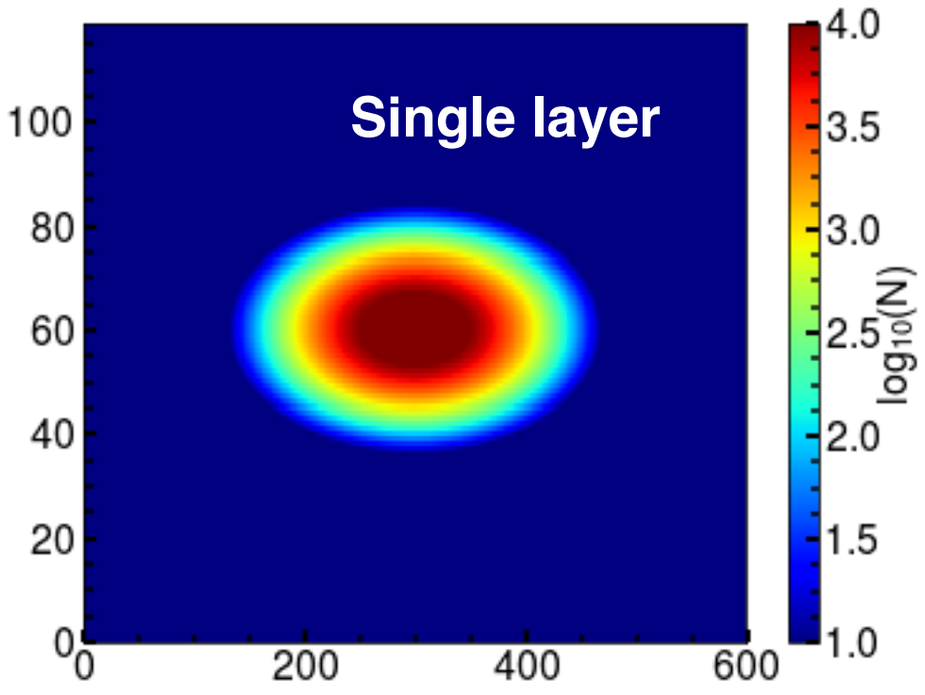
- Residual xy coupling at the entrance of QM16 can be checked

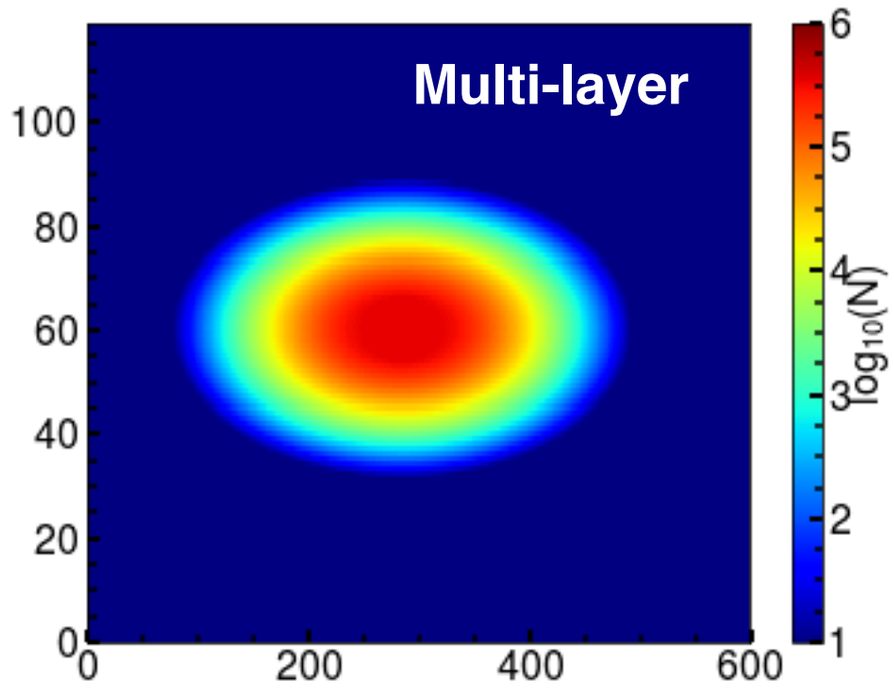




Evaluation of beam size for vertical focusing scan

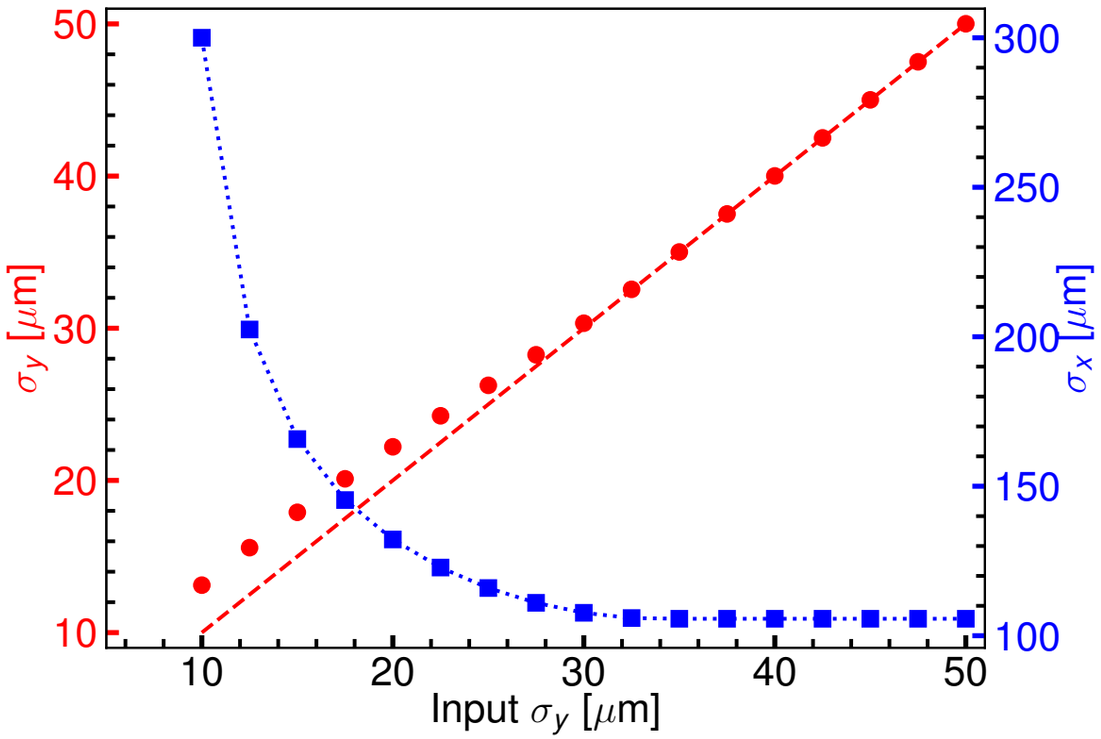
- Assuming transverse Gaussian distributed beam
- Image observed by camera is reproduced by multiple profiles at the different depth of YAG bulk (thickness 100 um)
- Prefect optical lens system
- Photon collection efficiency at CMOS sensor is 0.33 ph/e
- Saturation is considered when the local charge density is larger than 16 fC/um^2

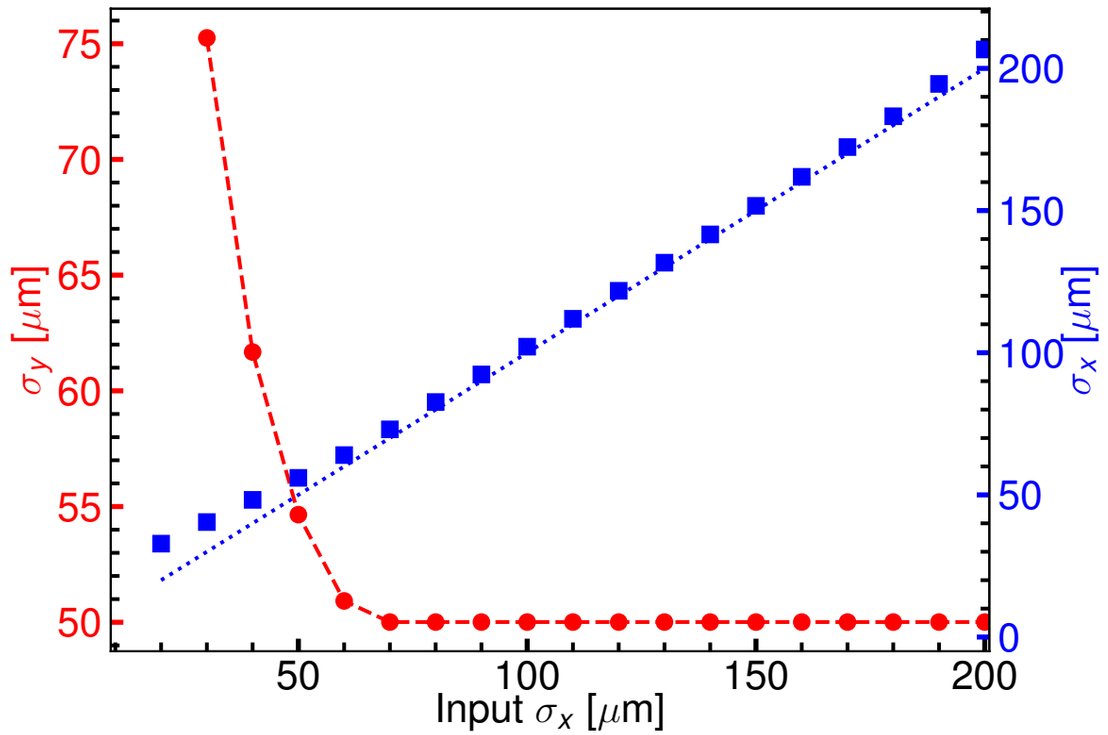




Evaluation of beam size for vertical focusing scan

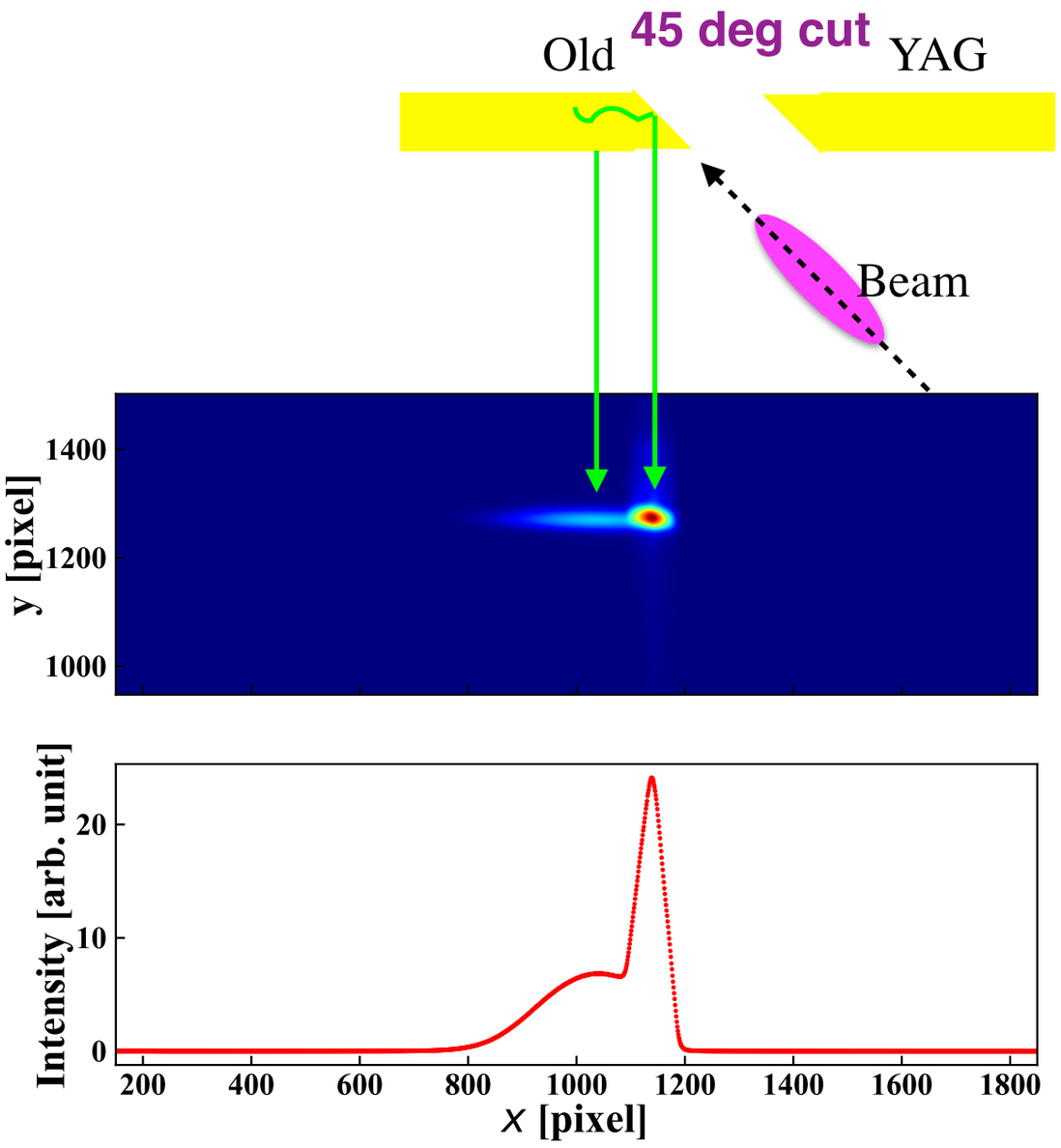
- Input vertical beam size is modulated from 10 um to 50 um while σ_x =100 um
  -> Hor. size is increased by more than 50% when $\sigma_y < 20$ um
- However, if we fixed σ_y = 50 um and reduced σ_x from 200 um to 30 um.
  Enhancement of ver. size is less than 50%
- σ_x is more sensitive to the scintillating saturation?

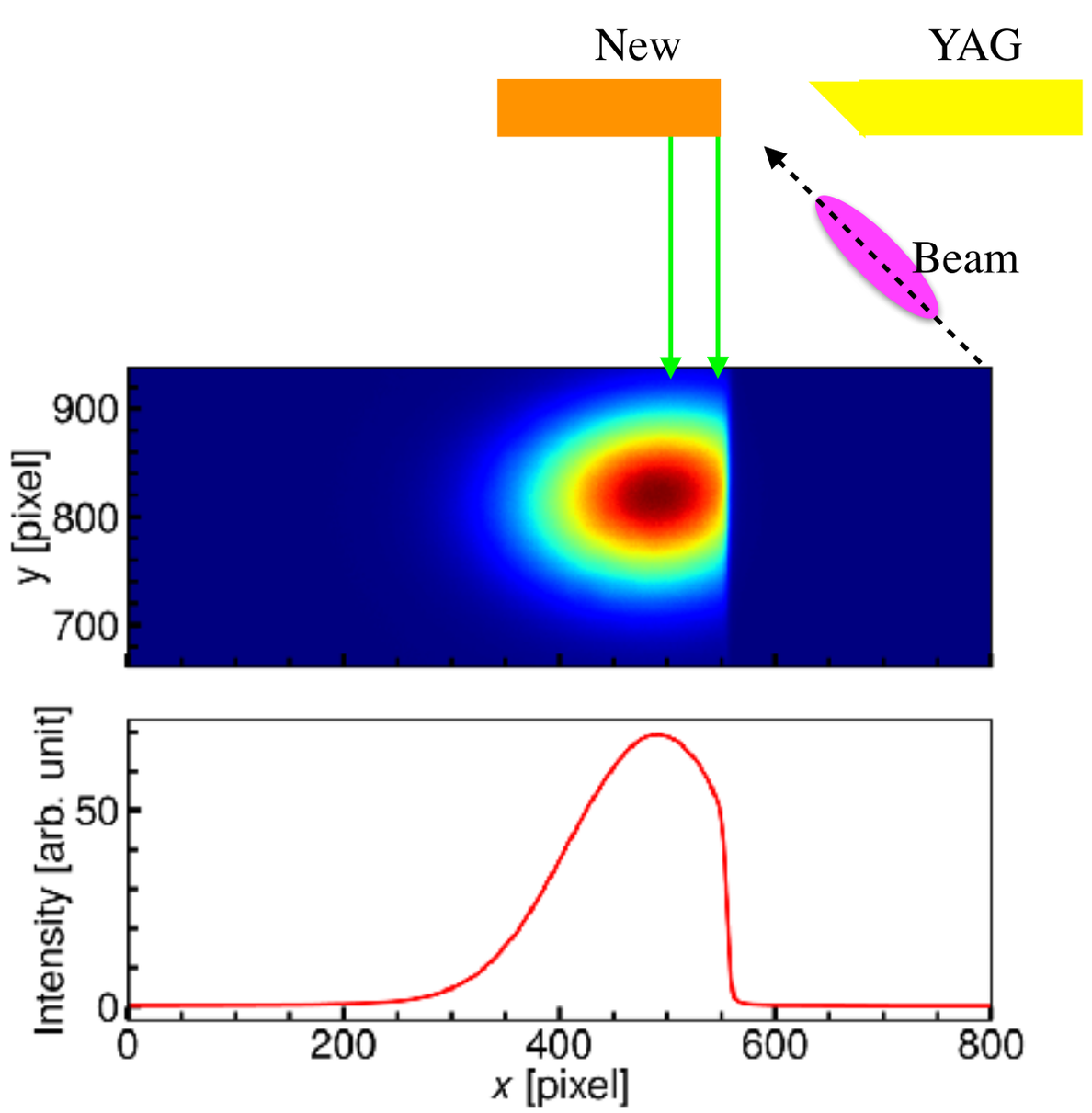




Brilliant light reflected by YAG cut edge

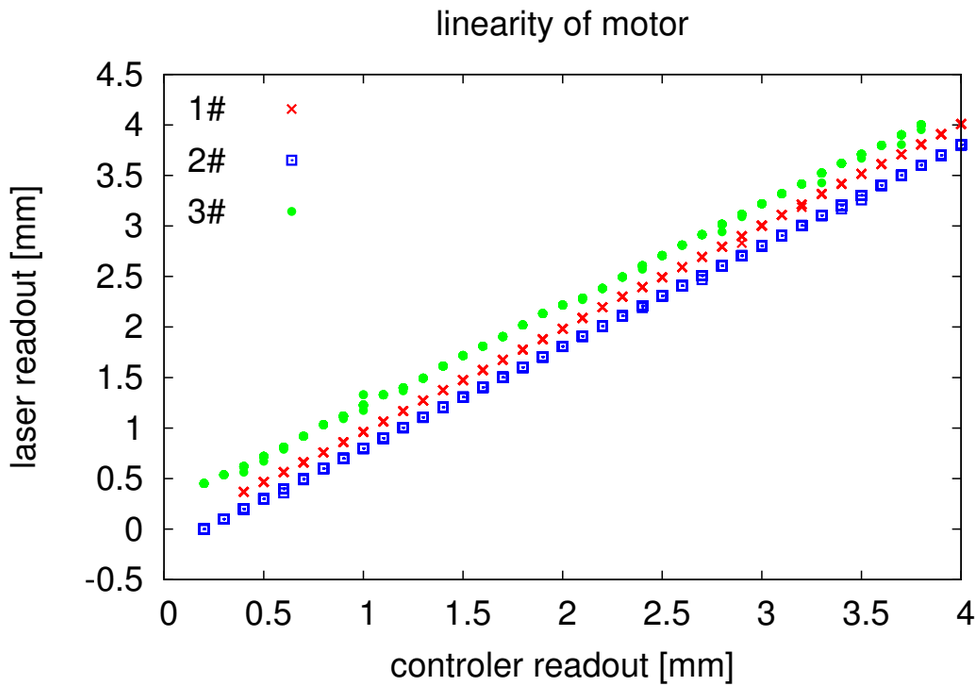
- Halo/tail could be “enhanced” due to blooming effect caused by reflection at 45 deg cut surface
- The inner edge of in parallel with the direction of light collection is superior!

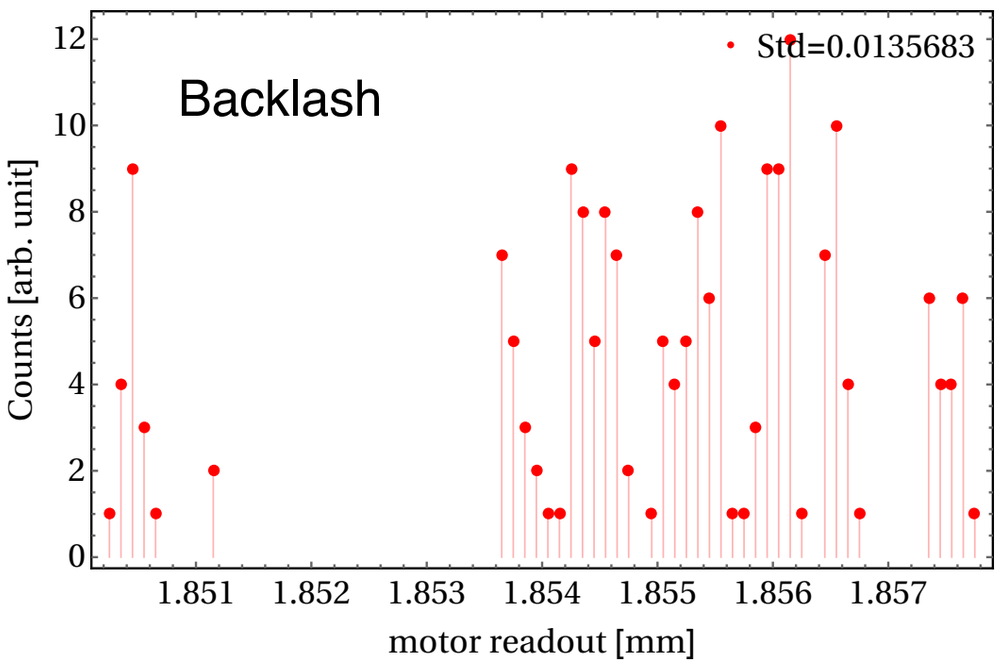


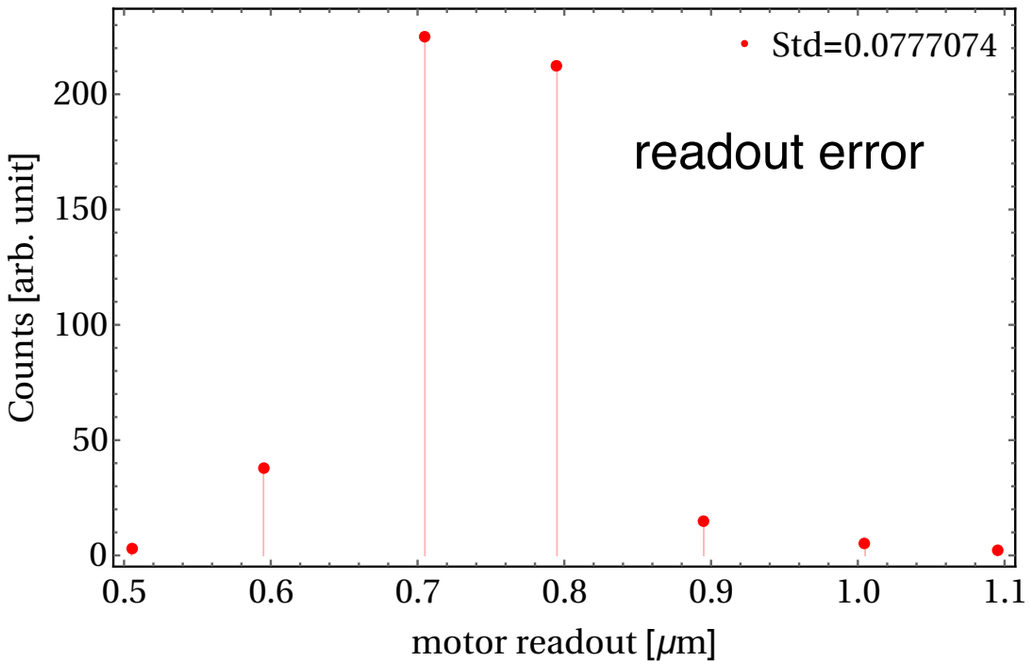


Performance of the manipulator

- Linearity, backlash and readout accuracy were measured in May 2017
- Backlash precise is 13.5 um and rms. readout error is less than 0.2 um
- Important to calibrate zoom of lens system!

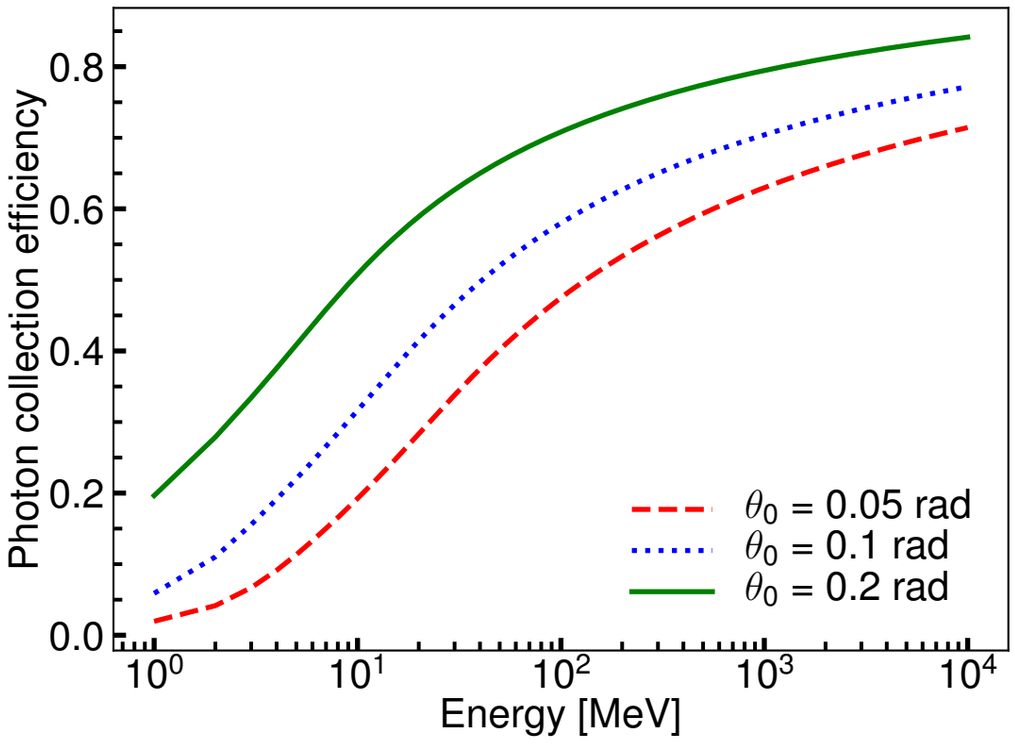


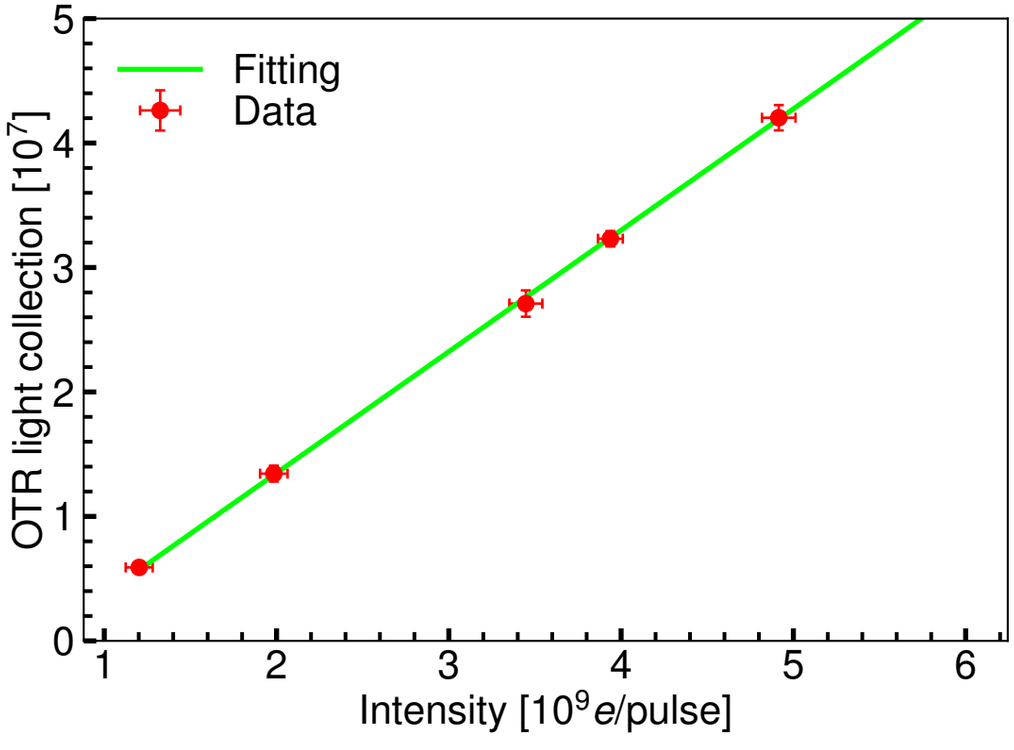




OTR photon collection by camera

- Theoretical estimation: 0.011 - 0.014 ph/e-
  1.3 GeV electron, visible region 400 nm - 700 nm and
  65% light collection efficiency (0.112 rad observation angle)
  Transmission efficiency in lens/view window system is > 80%
- Measured PhY of OTR is 0.01 ph/e-

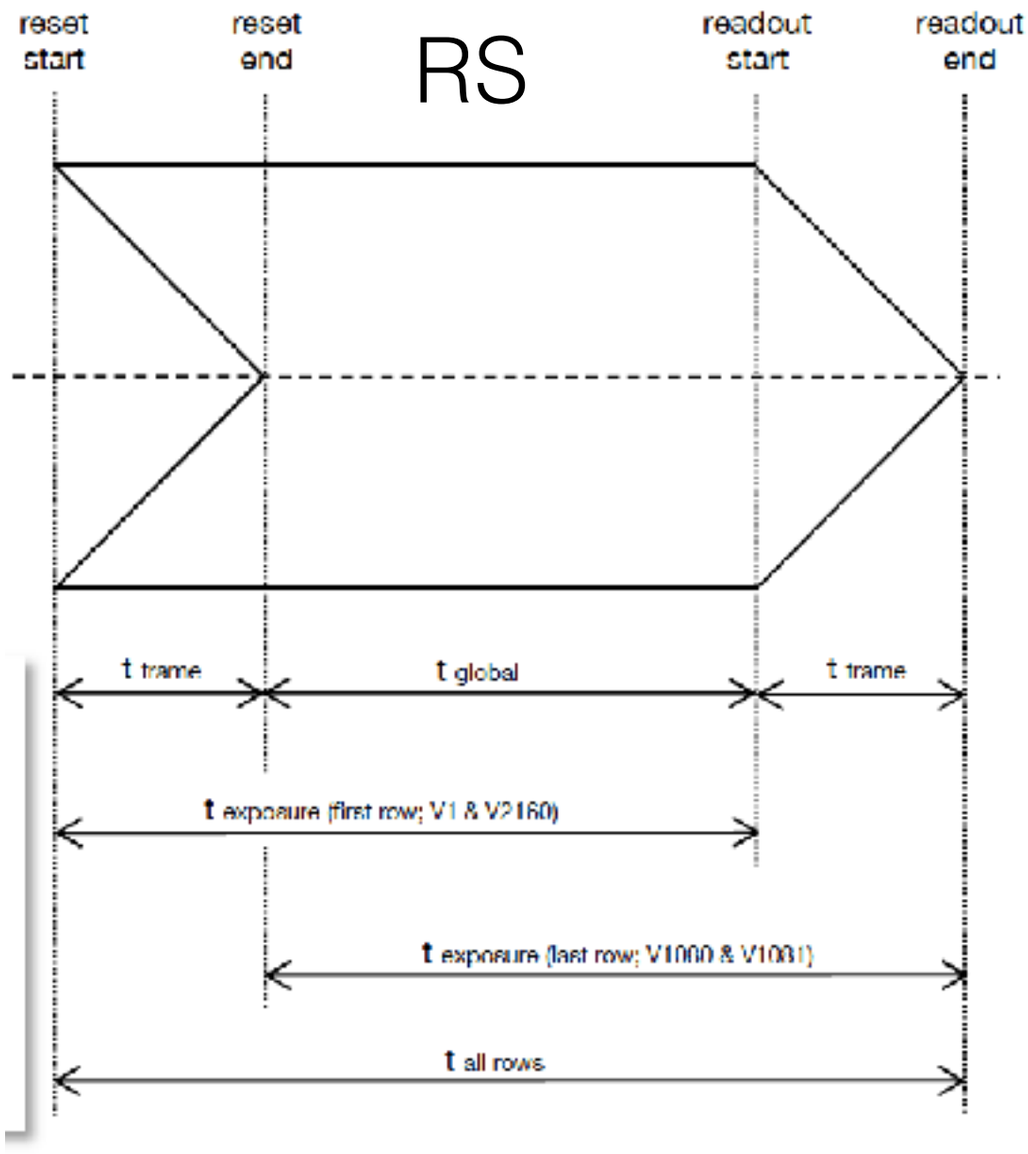


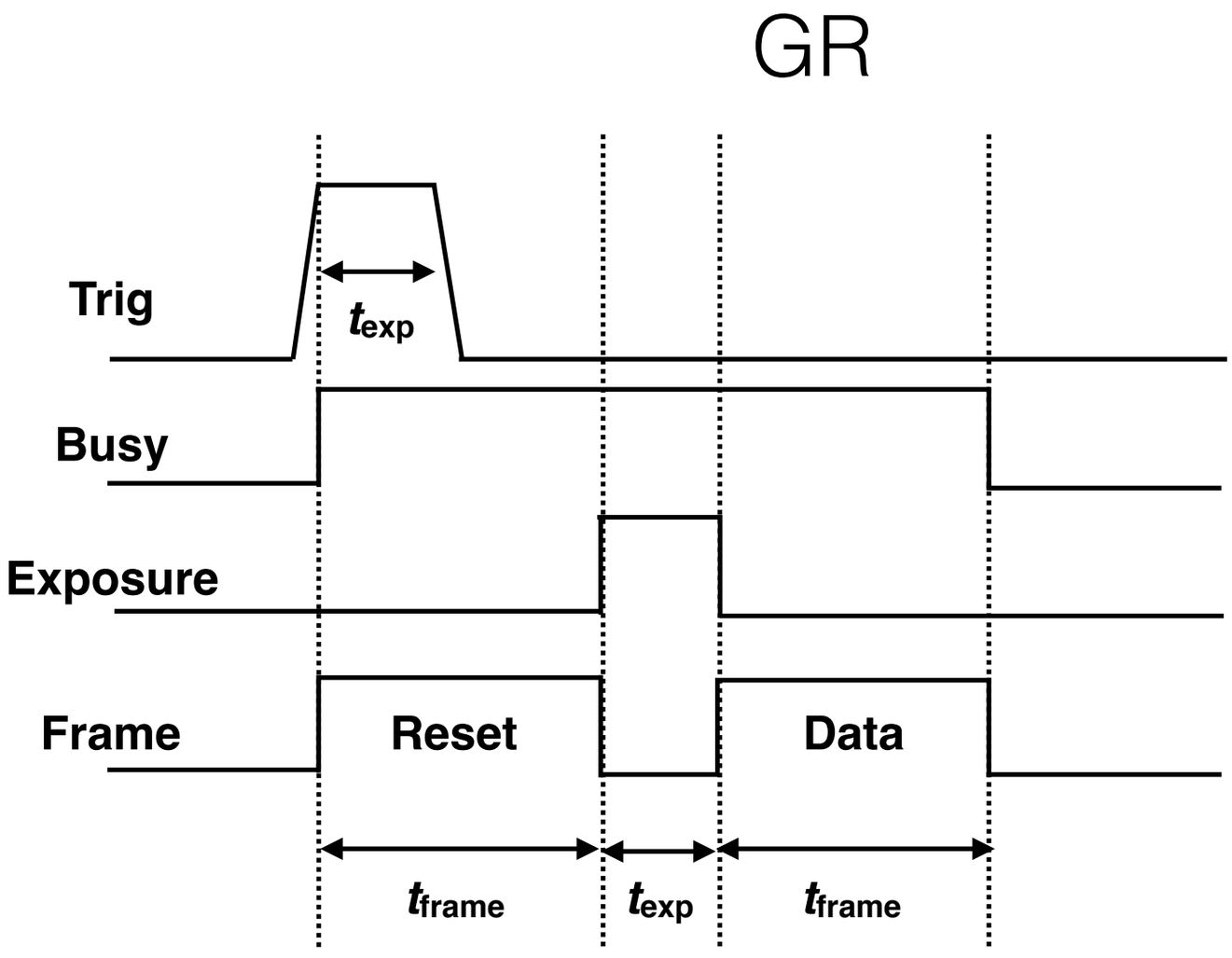


Rolling shutter & global reset

- RS: excellent low noise level
- GR: fast exposure time, might with higher noise level

  Output image = Exposure - Reset dark image





Beam size/position stability

- 100 shots; $\sigma_x \sim 320$ um, $\sigma_y \sim 74$ um; 3e9/pulse
- Hor./Ver. position jitter: < 5%/10% of rms beam size
- Hor./Ver. beam size jitter: ~ 2%

Enable multi-shot halo measurement!