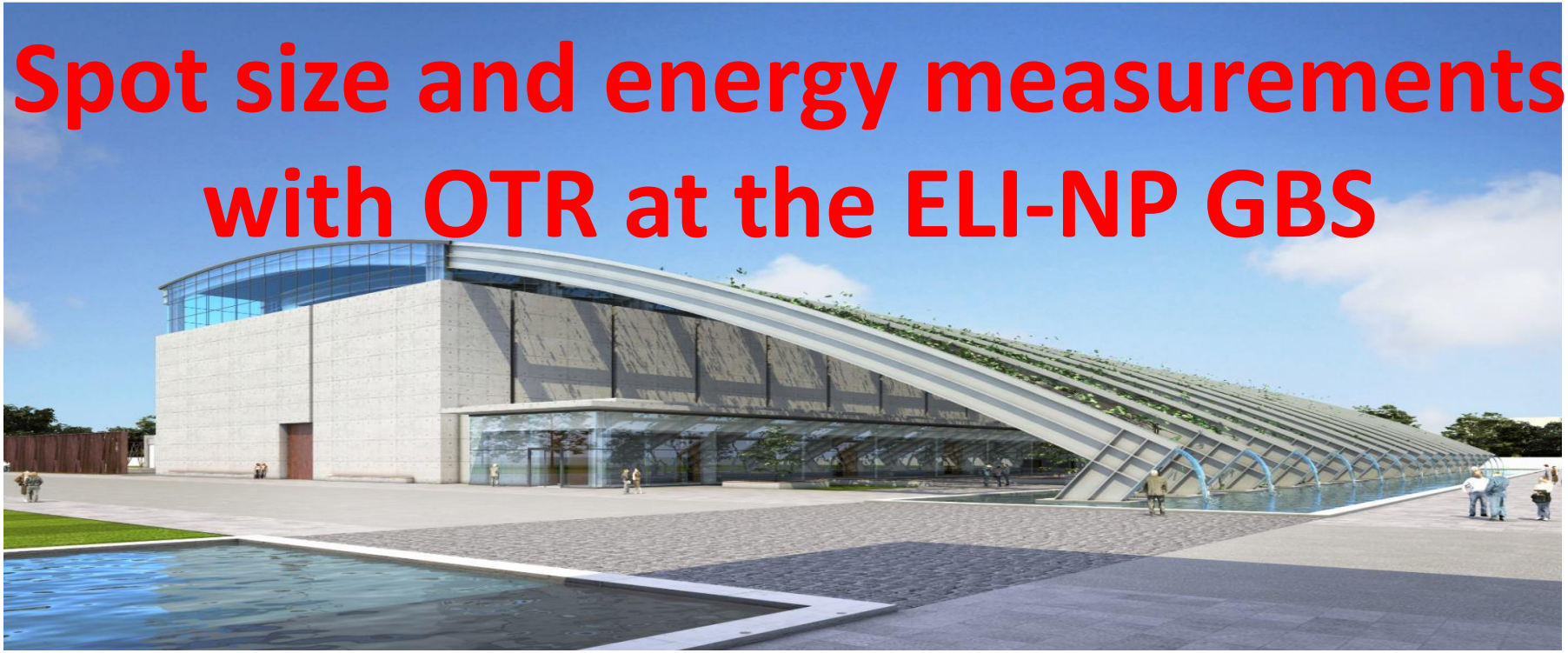
EuroGammaS

European Consortium for the delivery of a Gamma Beam System to ELI-NP

Spot size and energy measurements with OTR at the ELI-NP GBS

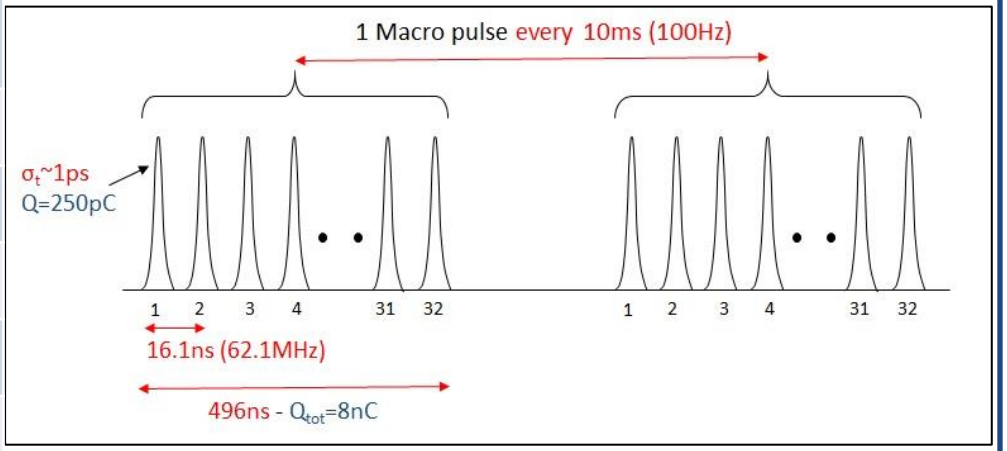


Contributions:
A. Mostacci, F. Cioeta, A. Stella, G. Franzini, M. Pompili, M. Castellano, E. Chiadroni, A. Cianchi, V. Shpakov, interaction with other WPs

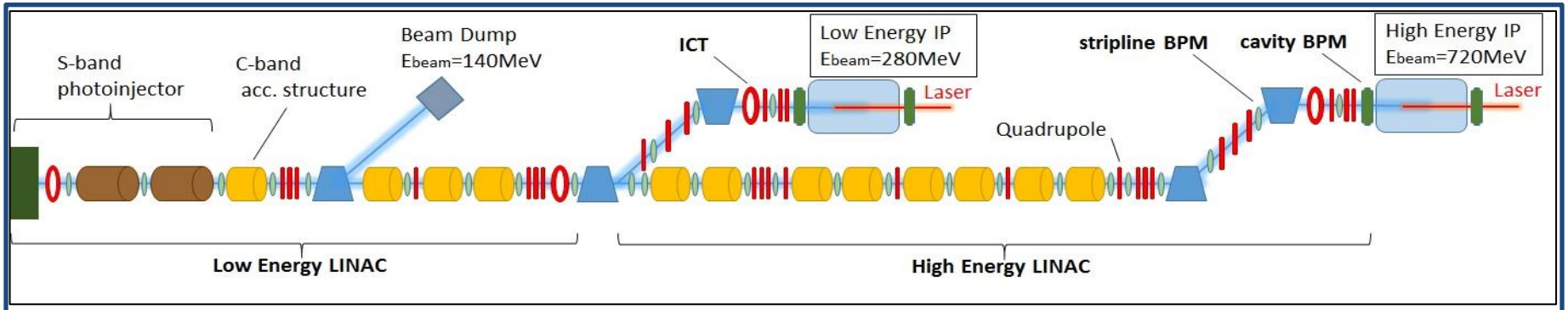
- **ELI main parameters**
- **OTR Screens**
  - Thermal issues
  - Fatigue Stress
  - Photons Evaluation
- **Beam Imaging**
  - Magnification
  - Resolution
- **Energy Measurements**
  - Angular Distribution

Electron Beam Parameters @ IP

Electron Beam Specifications	
Max. Energy at IP [MeV]	280 – 720
Macro Pulse rep. Rate [Hz]	100
Number of bunches	up to 32
Bunch spacing [ns]	16.1
Bunch length [ps]	0.91
Bunch charge [pC]	25-250
$\varepsilon_{n\_x,y}$ [mm·mrad]	0.2-0.6
Bunch Energy Spread	< 0.1%



Linac diagnostics



Non-intercepting diagnostics:

Charge measurements:

- 4 Integrating Current Transformers (bunch by bunch)

Position measurements:

- 29 stripline BPMs (Macro pulse)
- 4 cavity BPMs (bunch by bunch)

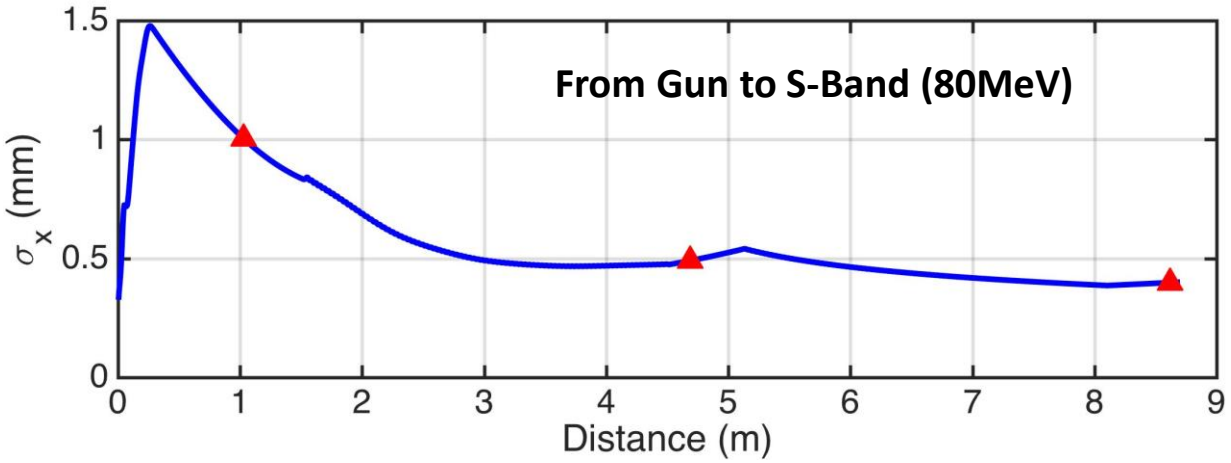
- Beam Loss Monitor System

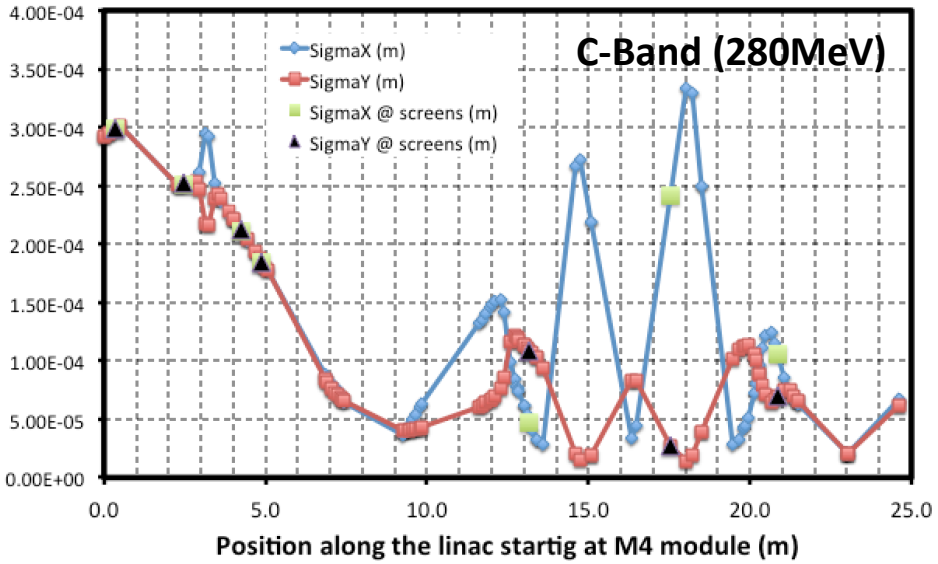
Intercepting diagnostics:

Position and spot size measurements:

- 23 Beam Screens (YAG and OTR)

Beam envelope along the Linac



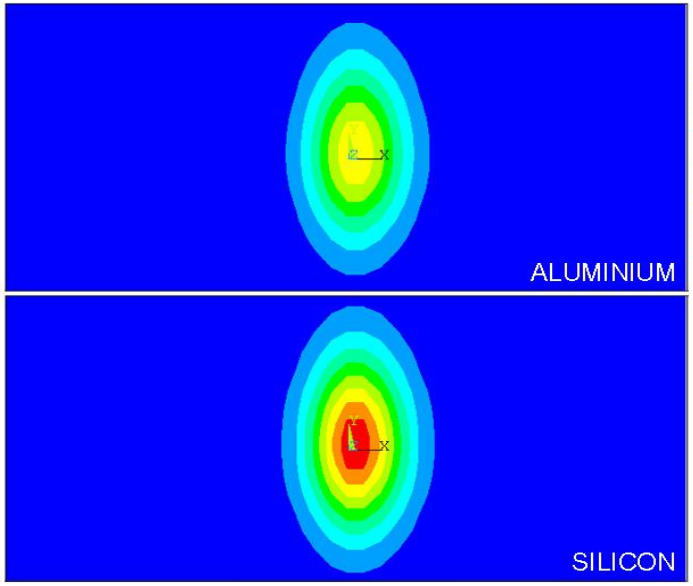


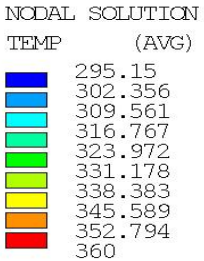
A. Bacci, A. Giribono, C. Vaccarezza

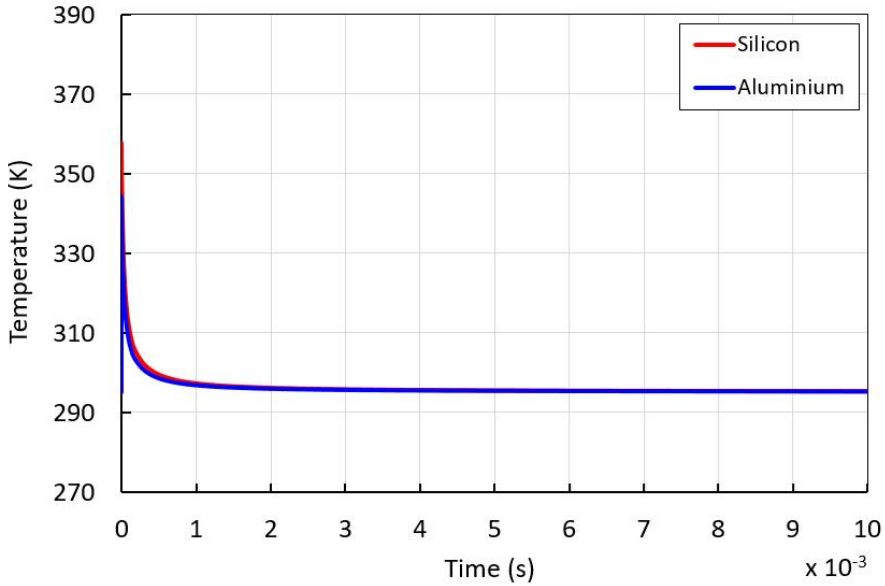
Thermal Analysis OTR

32 bunches, 250pC each

Beam dimension	ΔT^+ Al	ΔT^+ Si
σ_x =298 µm σ_y =298 µm	3 K	4 K
σ_x =251 µm σ_y =252 µm	5 K	6 K
σ_x =211 µm σ_y =213 µm	6 K	8 K
σ_x =184 µm σ_y =184 µm	9 K	11 K
σ_x = 48 µm σ_y = 109 µm	57 K	71 K
σ_x =241 µm σ_y =27 µm	43 K	55 K
σ_x =106 µm σ_y =70 µm	38 K	50 K







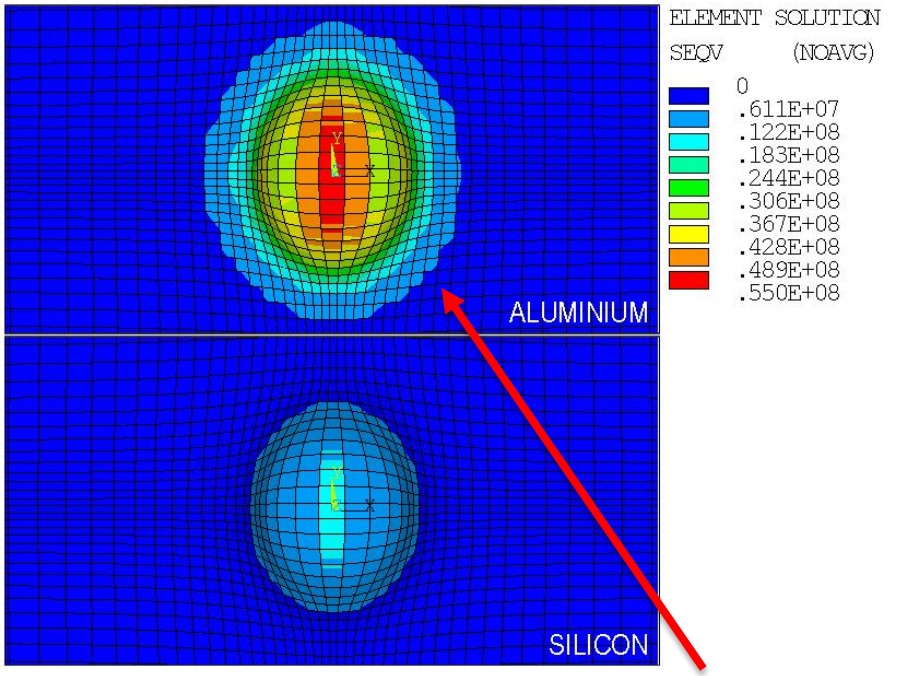
F. Cioeta, M. Ciambrella,, V. Pettinacci, D. Cortis

Fatigue Stress

	Al	Si
Young's Modulus [GPa]	69	150
Poisson	0.33	0.17
Density $[\mathrm{kg} * \mathrm{m}^{-3}]$	2700	2330
Coeff. Thermal Expansion $[\mathrm{K}^{-1}]$	23×10^{-6}	2.5×10^{-6}
Thermal Conductibility $[\mathrm{W} * \mathrm{m}^{-1} * \mathrm{K}^{-1}]$	209	14.5
Specific Heat Capacity $[\mathrm{J} * \mathrm{kg}^{-1} * \mathrm{K}^{-1}]$	890	700

	Al	Si
Alternative Stress [MPa]	30.2	7.74
# Cycles to failure	610	∞
Cumulative fatigue damage after 1h	0.59	0

6 seconds

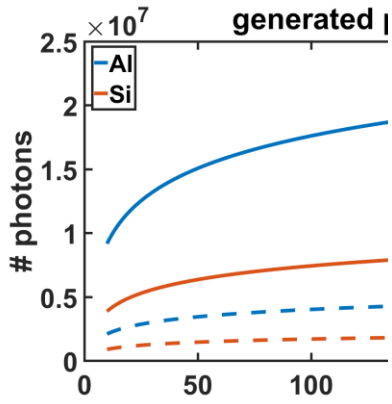


Equivalent Von Mises Stress (Pa)

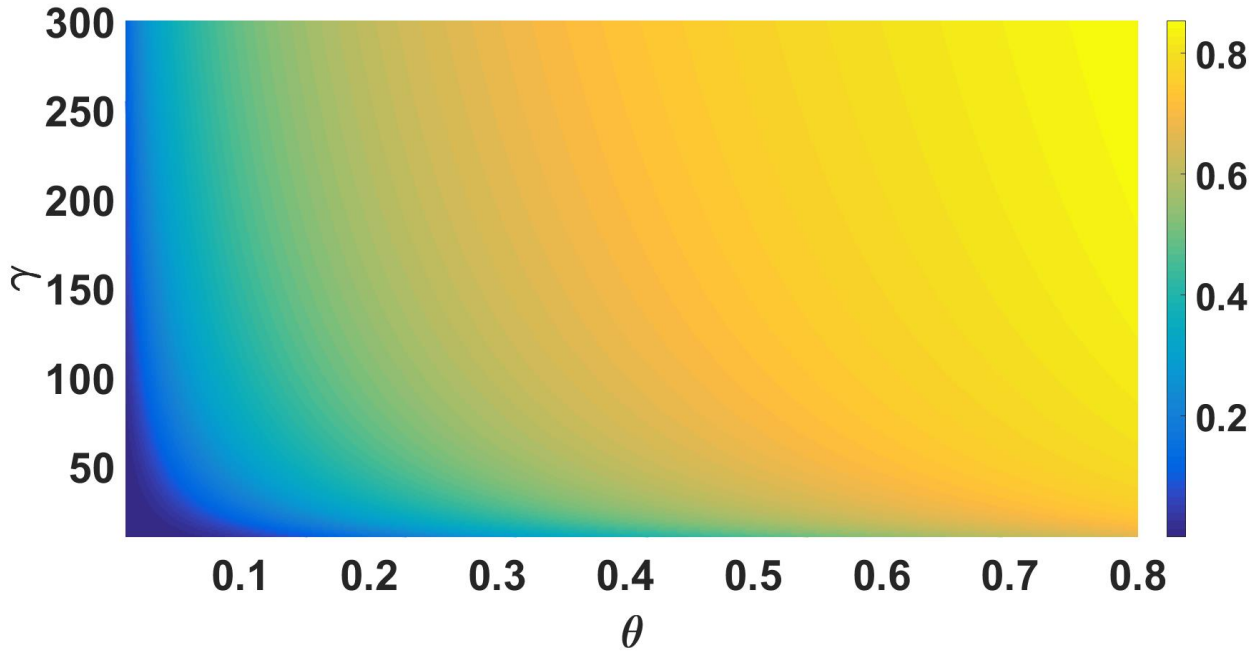
# Bunches	Max. Temp. [K]	Alternate Stress [MPa]	# Cycles to failure
32	344.4	30.2	610
16	320.2	15.2	∞
8	307.7	n.a.	∞
4	301.4	n.a.	∞
2	298.3	n.a.	∞
1	296.7	n.a.	∞

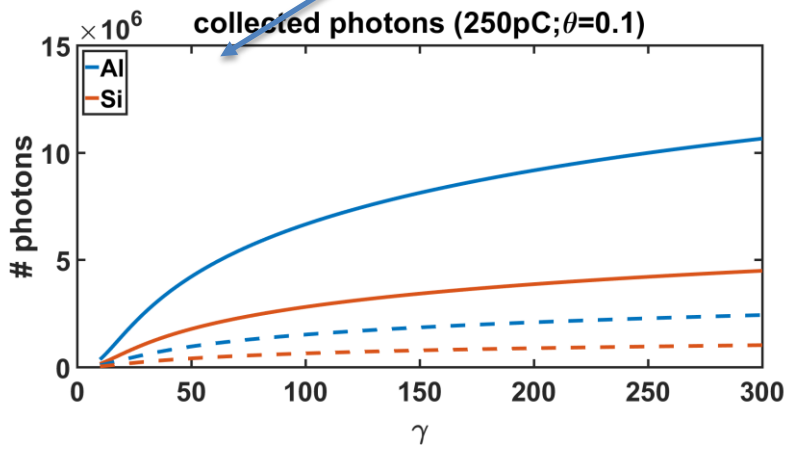
F. Cioeta, M. Ciambrella,, V. Pettinacci, D. Cortis

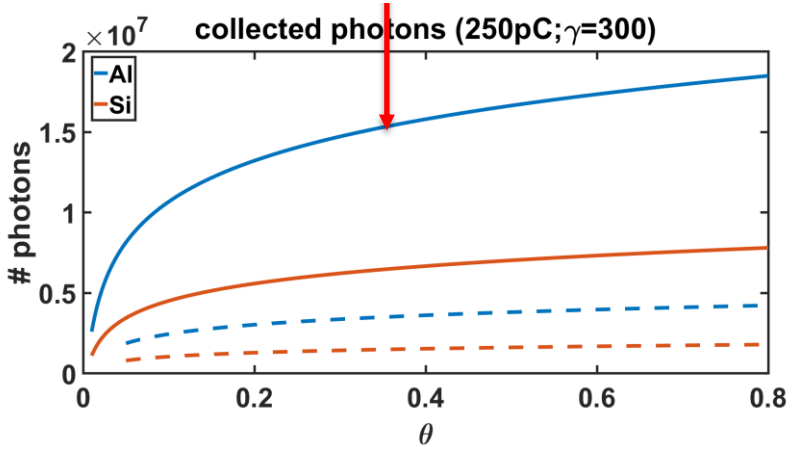
Photons Evaluation



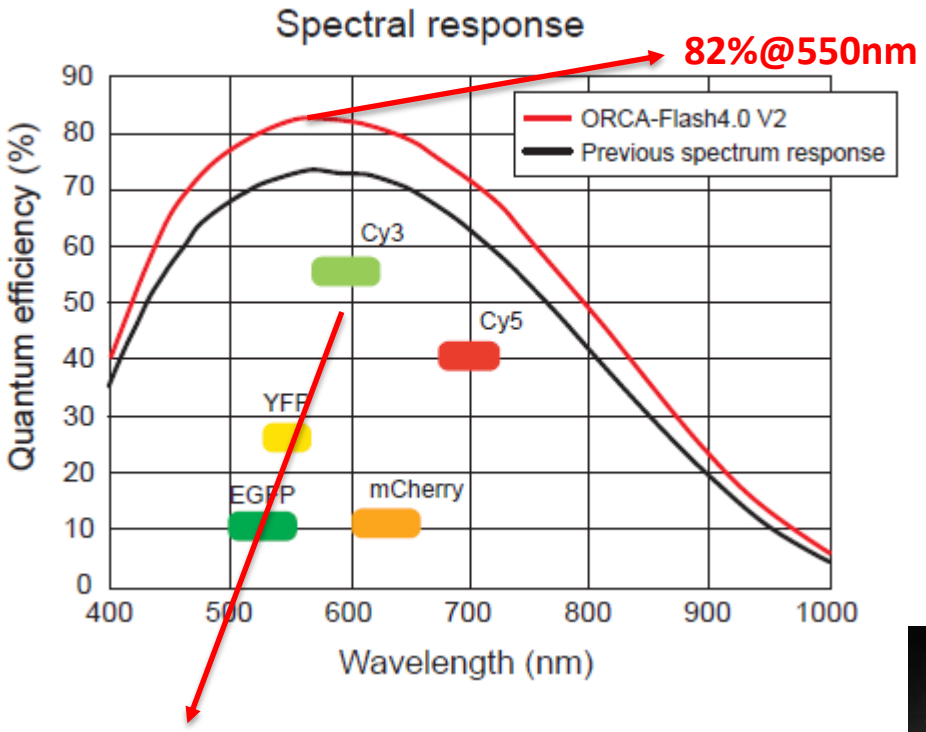
$$n_c(Q, \theta, \lambda_1, \lambda_2) =$$



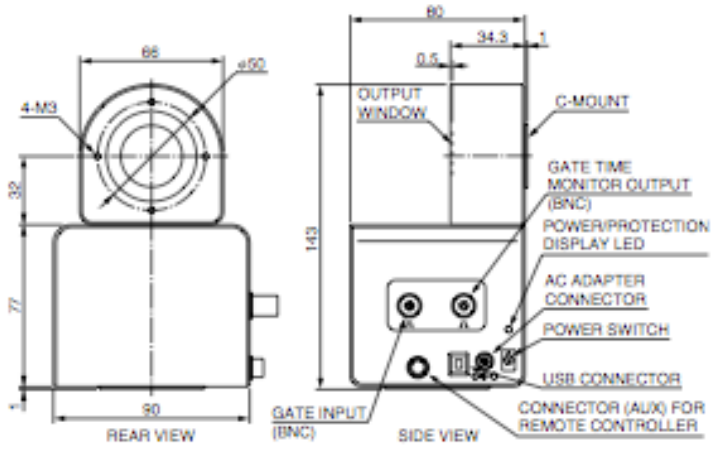




Gated intensified camera

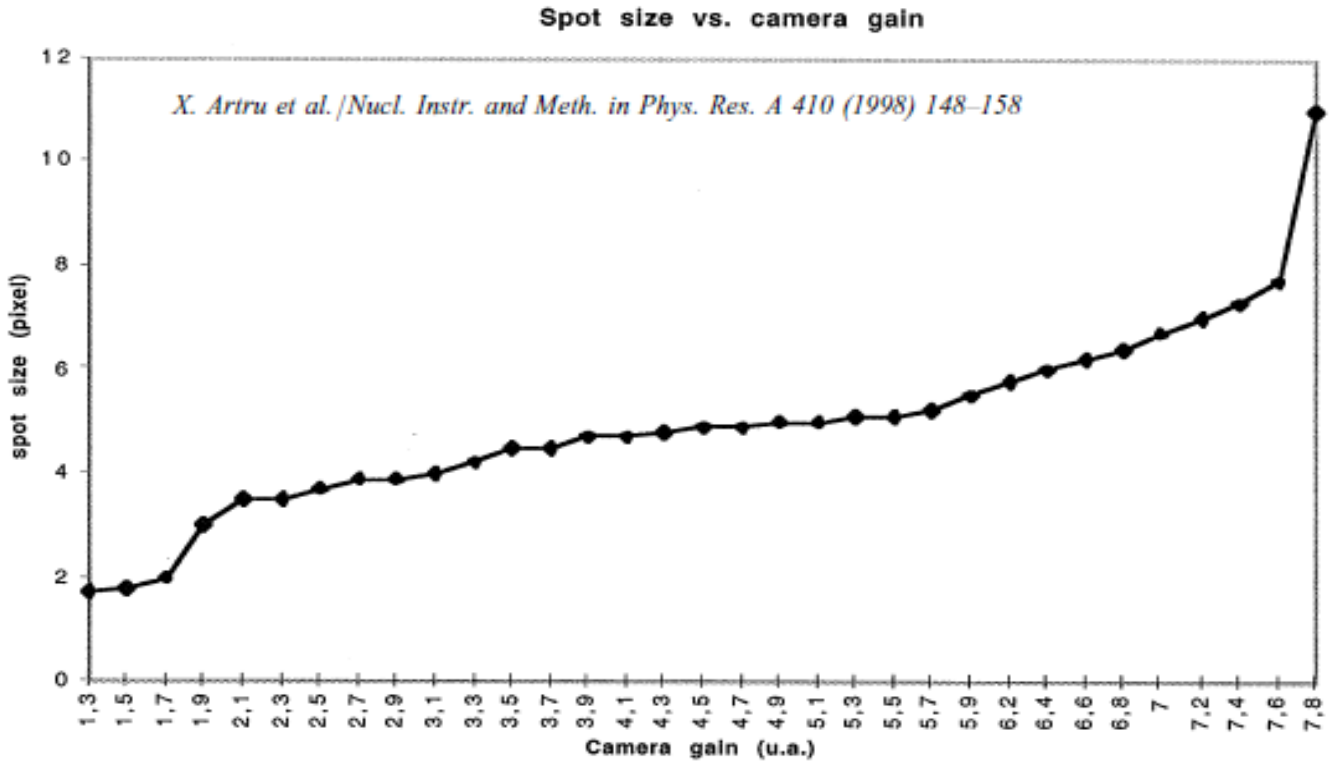


$$n_{pixel} = n_c \frac{\Delta_x \Delta_y}{2\pi\sigma_x\sigma_y}$$



Hamamatsu Datasheet

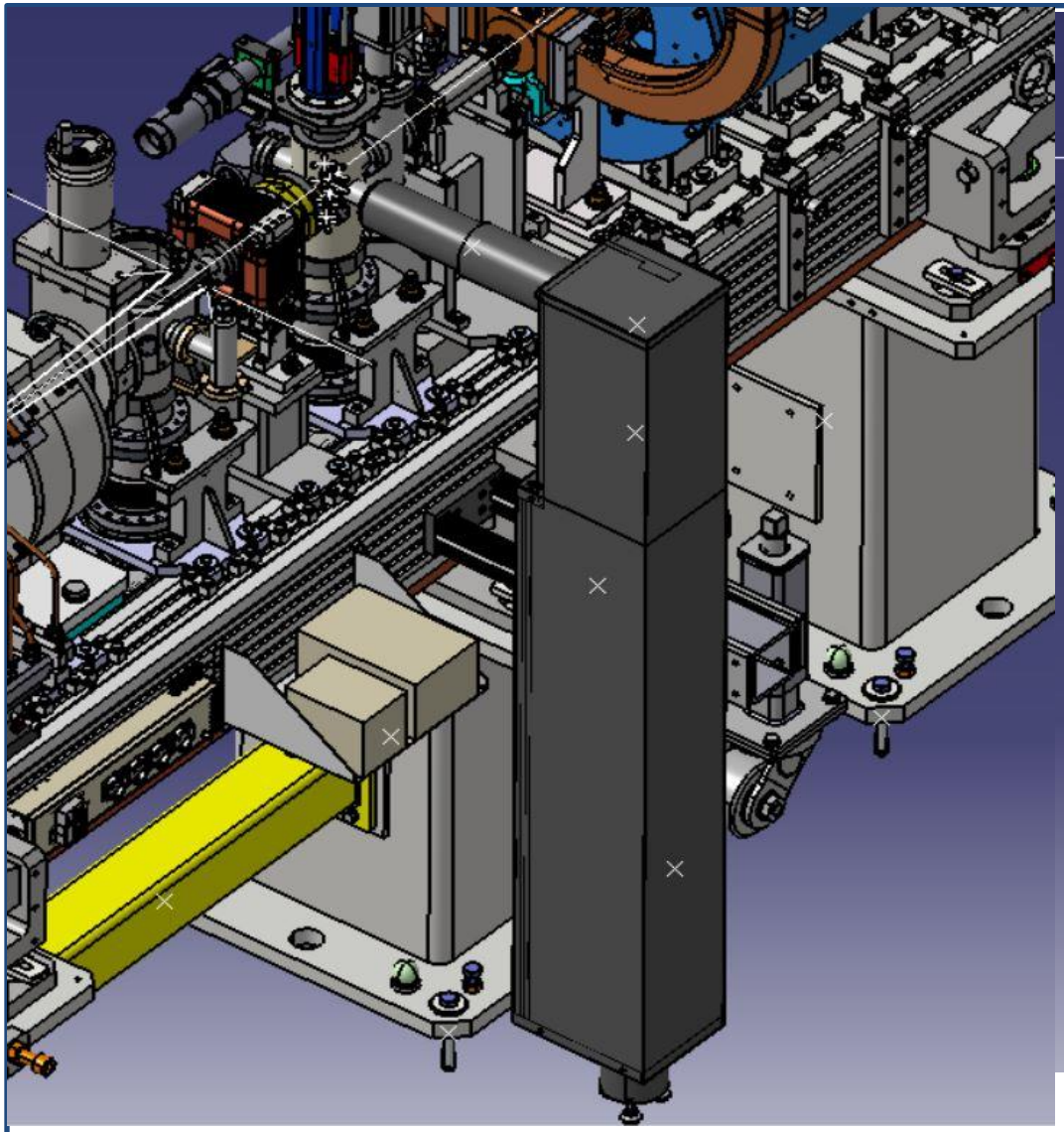
Spot size vs Camera Gain

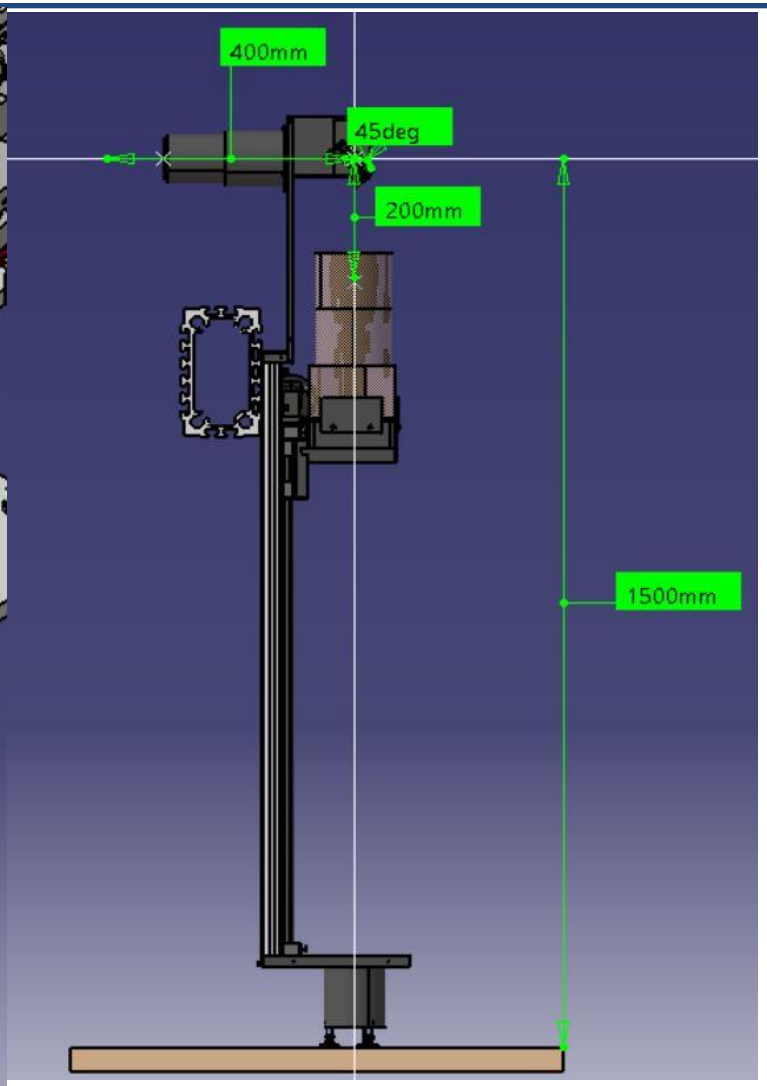


- Good SNR
- Avoid Saturation
- Find Optimal Gain Value for given values of photons per pixel (different working point)

Courtesy of A. Variola

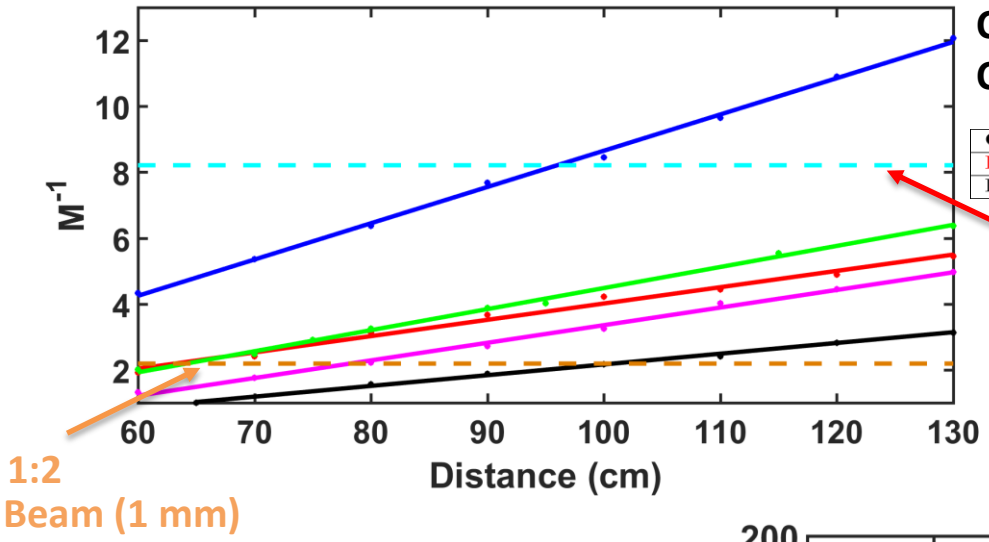
Camera lens test-bench





F. Cioeta, D. Cortis

Magnification and Resolution @ SPARCLAB

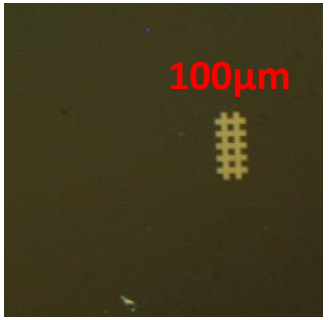


1:2
Beam (1 mm)

1:8
Screen (3 cm)

Camera Lens 180mm w/o teleconverter (2x)
Camera Lens 105mm w/o teleconverter (2x)

Camera Model	R (μm)	Sensor size (px)	Field of View (mm)
Basler Scout A640-70gm	7.4	659x494	5x4
Hamamatsu Orca-flash4	6.5	2048x2048	13x13



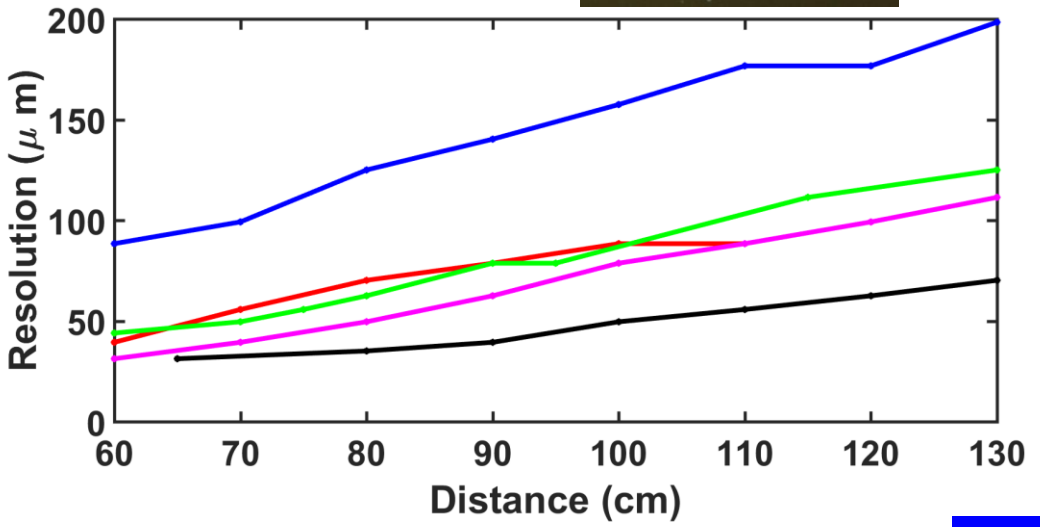
105mm

105mm with teleconverter (2x)

180mm

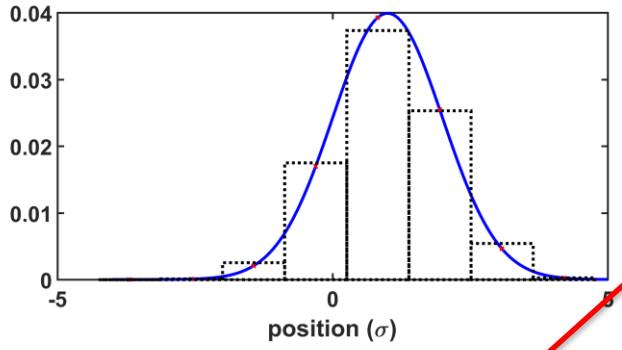
180mm with teleconverter (1.4x)

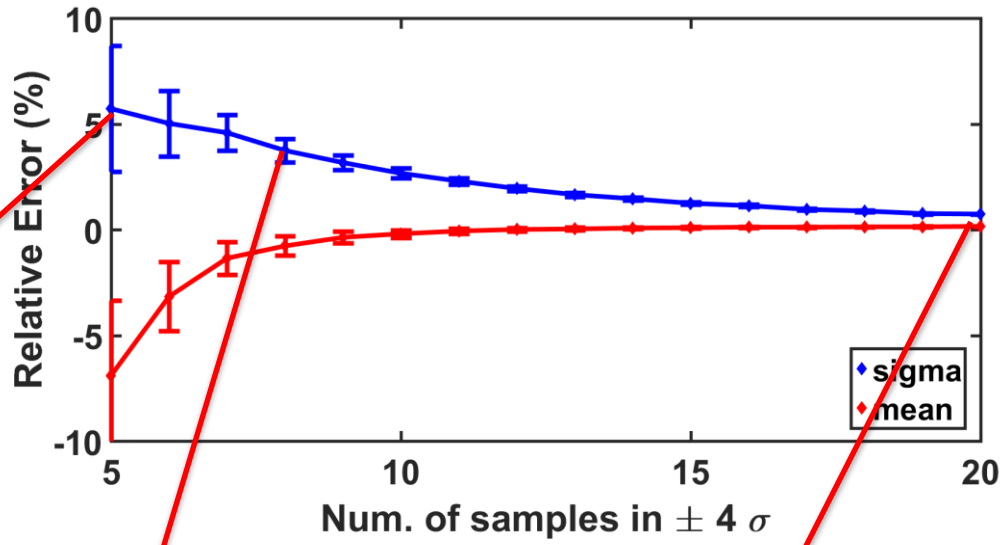
180mm with teleconverter (2x)



F. Cioeta

Gaussian Reconstruction





- 5 Samples
- Error ~7%

If Resolution=30µm and σ>19µm
If σ=10µm and Resolution<16µm

- 8 Samples
- Error ~4%

If Resolution=30µm and σ>30µm
If σ=10µm and Resolution<10µm

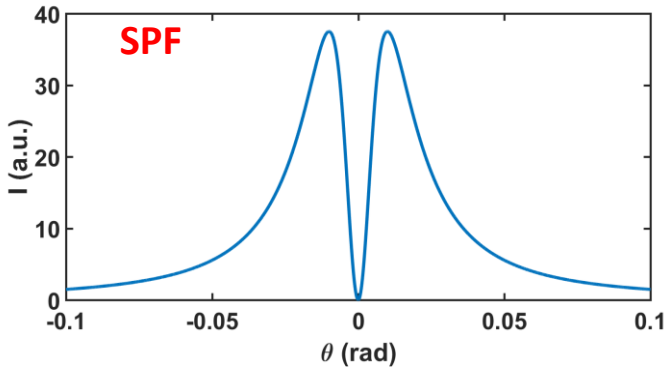
- 20 Samples
- Error <<0,01%

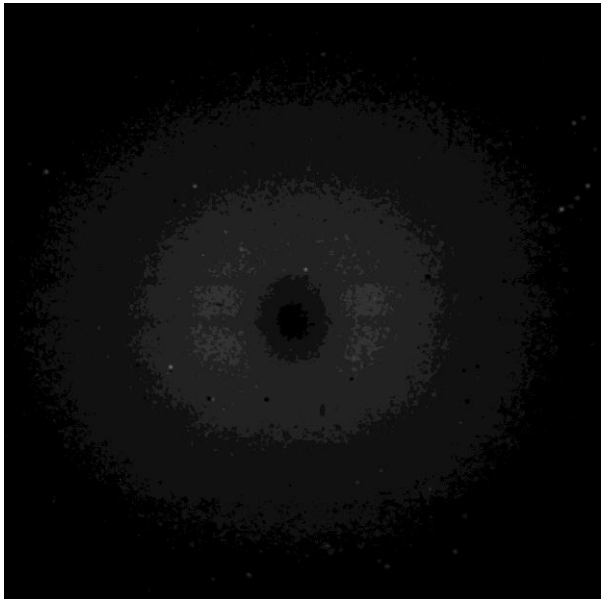
If Resolution=30µm and σ>75µm
If σ=10µm and Resolution<4µm

A. Mostacci

Energy Measurements

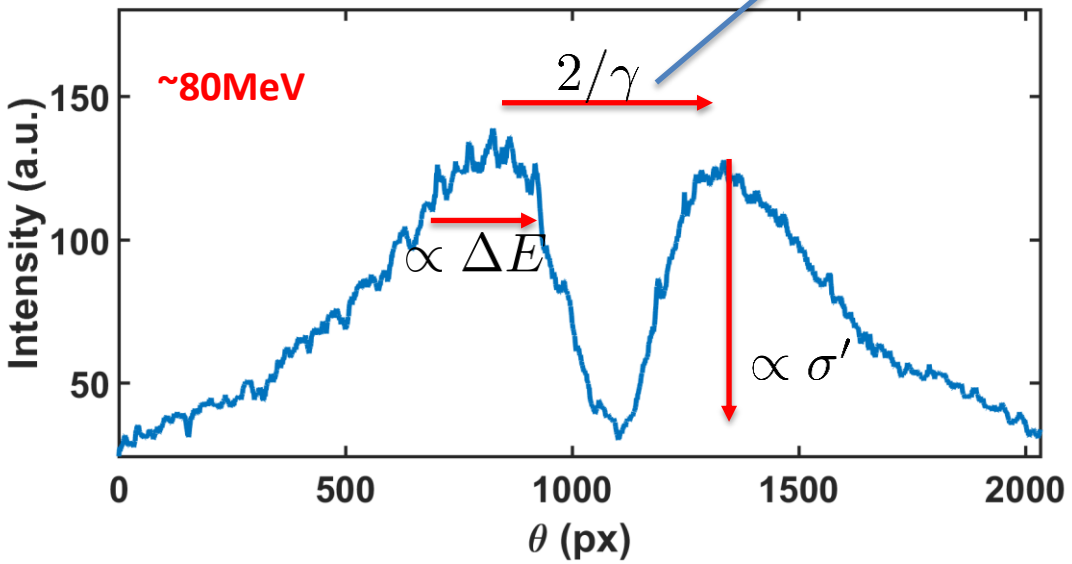
$$\frac{d^2I}{d\omega d\Omega} = \frac{\alpha}{\pi^2}\frac{\theta^2}{\left(\theta^2+\frac{1}{\gamma^2}\right)^2}$$





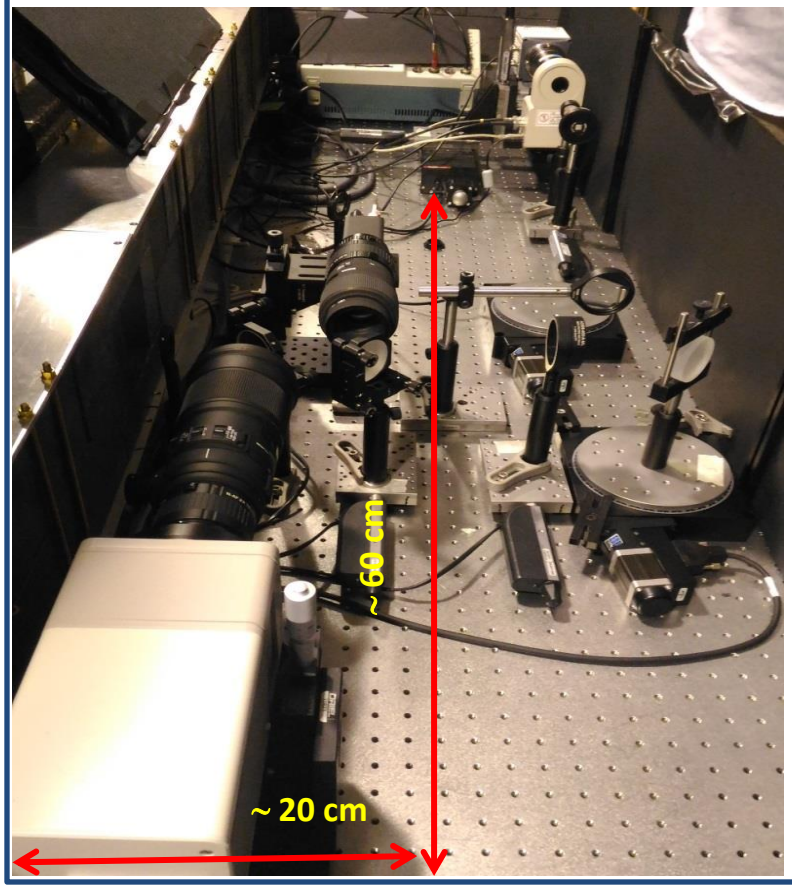
$$V = \frac{<I_{max}> - I_{min}}{<I_{max}> + I_{min}} \geq 0.1$$

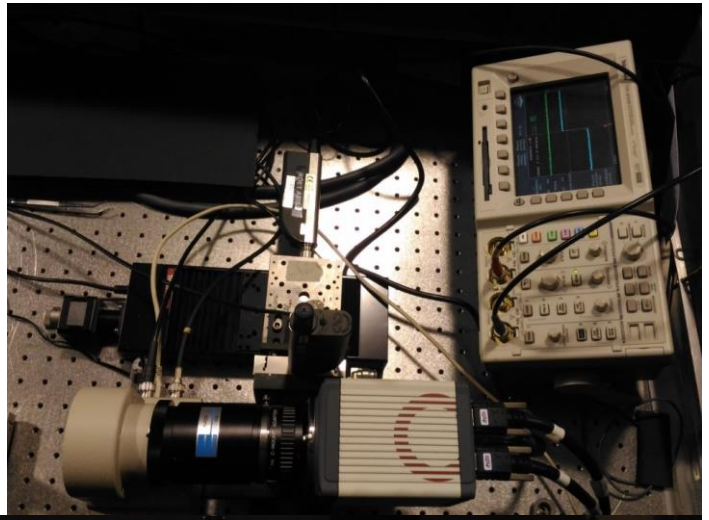
$$\frac{\sigma_\gamma}{\gamma} > \frac{1}{\sqrt{6}N_{pixel}}$$



Measurements @ SPARC_LAB

SPARC Layout





SPARC_LAB

Open Issues and foreseen studies

Improvements of spatial resolution: interaction point diagnostics (i.e. PSF dominated beam diagnostics)

Limit of γ resolution: is it possible to measure the energy jitter shot-to-shot (<0.2%)?

$$\frac{\sigma_\gamma}{\gamma} > \frac{1}{\sqrt{6}N_{pixel}}$$

Limit of γ resolution: is it possible to measure the energy spread (<0.1%)

Evaluation of the limits of the beam divergence measure as a function of the beam energy

Conclusions

A Gamma ray Compton source for nuclear physics research in the context of ELI initiative is being built.

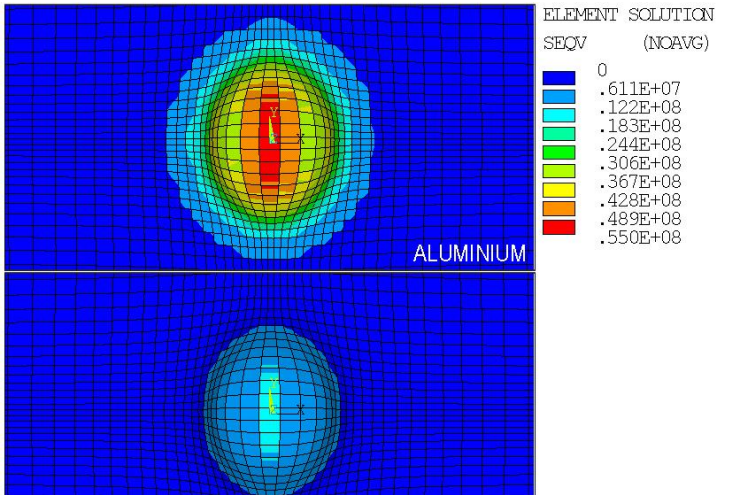
High repetition rate (100Hz), multi bunch operation (32 bunches) for the LINAC poses some challenge to the diagnostics:

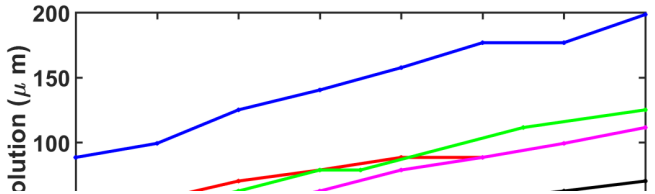
- mechanical stress -> silicon OTR (lower reflectivity)
- low intensity OTR radiation -> Intensifier
- Bunch to bunch measurements -> Gated camera

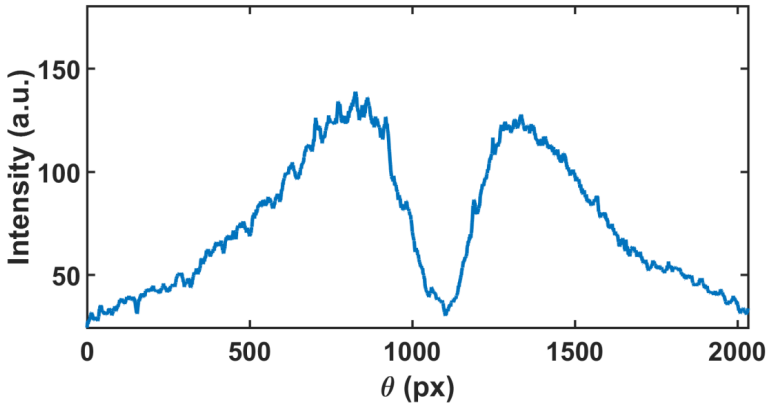
A high resolution diagnostics is required in order to verify the beam parameters (especially at the interaction point) with the relative uncertainties.

Energy measurement in each diagnostic station:

- Measurements limit -> energy, energy spread, energy jitter, beam divergence
- Possible layout



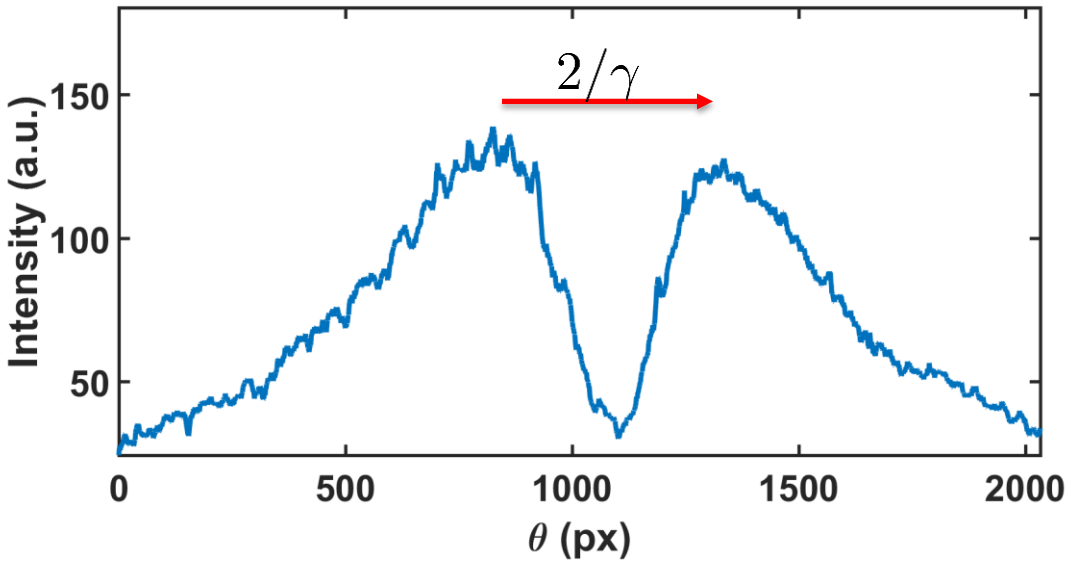




Thank you for your attention!

Energy Measurements

$$\frac{d^2 I}{d\omega d\Omega} = \frac{\alpha}{\pi^2} \frac{\theta^2}{\left(\theta^2 + \frac{1}{\gamma^2}\right)^2}$$



$$\gamma = \frac{2}{\theta_1 - \theta_2}$$

$$\sigma_\gamma = \sqrt{\left(\frac{\partial\gamma}{\partial\theta_1}\right)^2 \sigma_\theta^2 + \left(\frac{\partial\gamma}{\partial\theta_2}\right)^2 \sigma_\theta^2} = \sqrt{\frac{8}{(\theta_1-\theta_2)^2}\sigma_\theta^2} = \sqrt{2}\frac{2}{(\theta_1-\theta_2)^2}\sigma_\theta$$

$$\frac{\sigma_\gamma}{\gamma} = \frac{\sqrt{2}}{\theta_1 - \theta_2}\sigma_\theta \approx \frac{\sqrt{2}}{N_{pixel}}$$

$$\sigma_\theta^2 = \frac{\Delta_{x,y}^2}{12} + \sigma_{fit}^2 = \frac{\Delta_{x,y}^2}{12}\left(1 + \frac{12\sigma_{fit}^2}{\Delta_{x,y}^2}\right)$$

$$\theta_1 - \theta_2 = N_{pixel}\Delta_{x,y}$$

Measurements @ SPARC_LAB

Camera lens test-bench @ SPARC_LAB

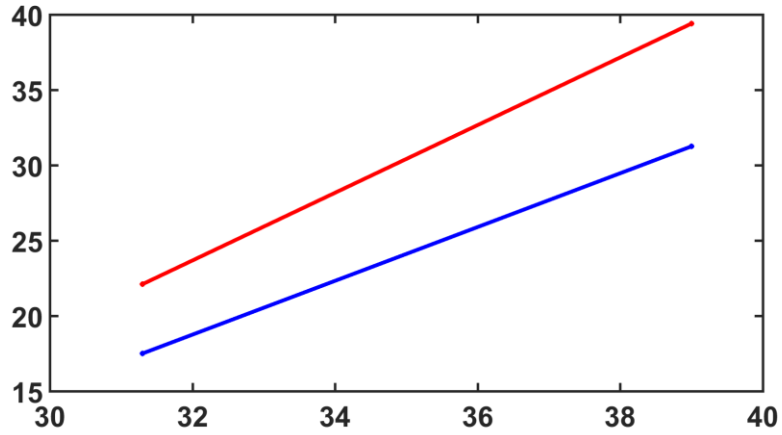
Basler scA1300-32gm

Resolution (HxV)	1296 px x 966 px
Pixel Size (HxV)	3.75 µm x 3.75 µm
Frame Rate	32 fps
Pixel Bit Depth	12 bits
Sensor Size	4.86 mm x 3.62 mm

Distance [cm]	Resolution [µm]	M	Field of View [cm]
31.3	18	1	0.49 x 0.37
39	31	2	0.98 x 0.74

Basler scA640-70gm

Resolution (HxV)	659 px x 494 px
Pixel Size (HxV)	7.4 µm x 7.4 µm
Frame Rate	70 fps
Pixel Bit Depth	12 bits
Sensor Size	4.88 mm x 3.66 mm



Distance [cm]	Resolution [µm]	M	Field of View [cm]
31.3	22	1	0.49 x 0.37
39	39	2	0.98 x 0.74

F. Cioeta, A. Stella