ESRF | The European Synchrotron

ESRF Diagnostics Group within the Accelerator and Source Division

Diagnostics group members:

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} *Engineers/Physicists*

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} *Technicians*

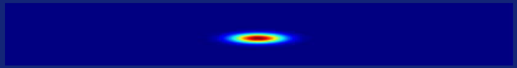
Elena Buratin (post-doc)

Close collaboration with:

Beam Dynamics Group
(Simon White, Simone Liuzzo, Nicola Carmigniani, Lee Carver Lina Hoummi, Thomas Perron)

Front End Group
Accelerator Control
Vacuum
Operation
…

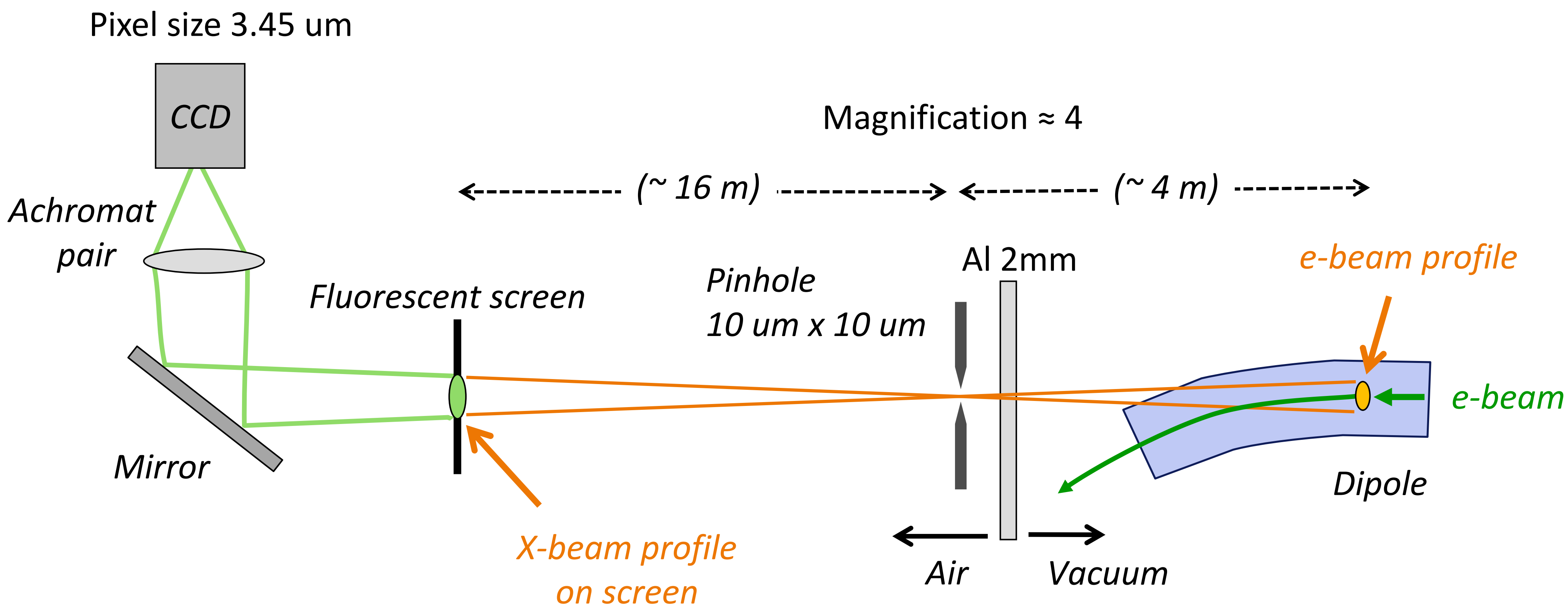
TRANSVERSE BEAM SIZE DIAGNOSTICS AND SOME APPLICATIONS TO STORAGE RING OPERATION AND BEAM STUDIES AT THE ESRF



FRIEDERIKE EWALD

I.FAST Workshop 2022:
Beam Diagnostics and Dynamics in Ultra-Low Emittance Rings
25-29 March 2022

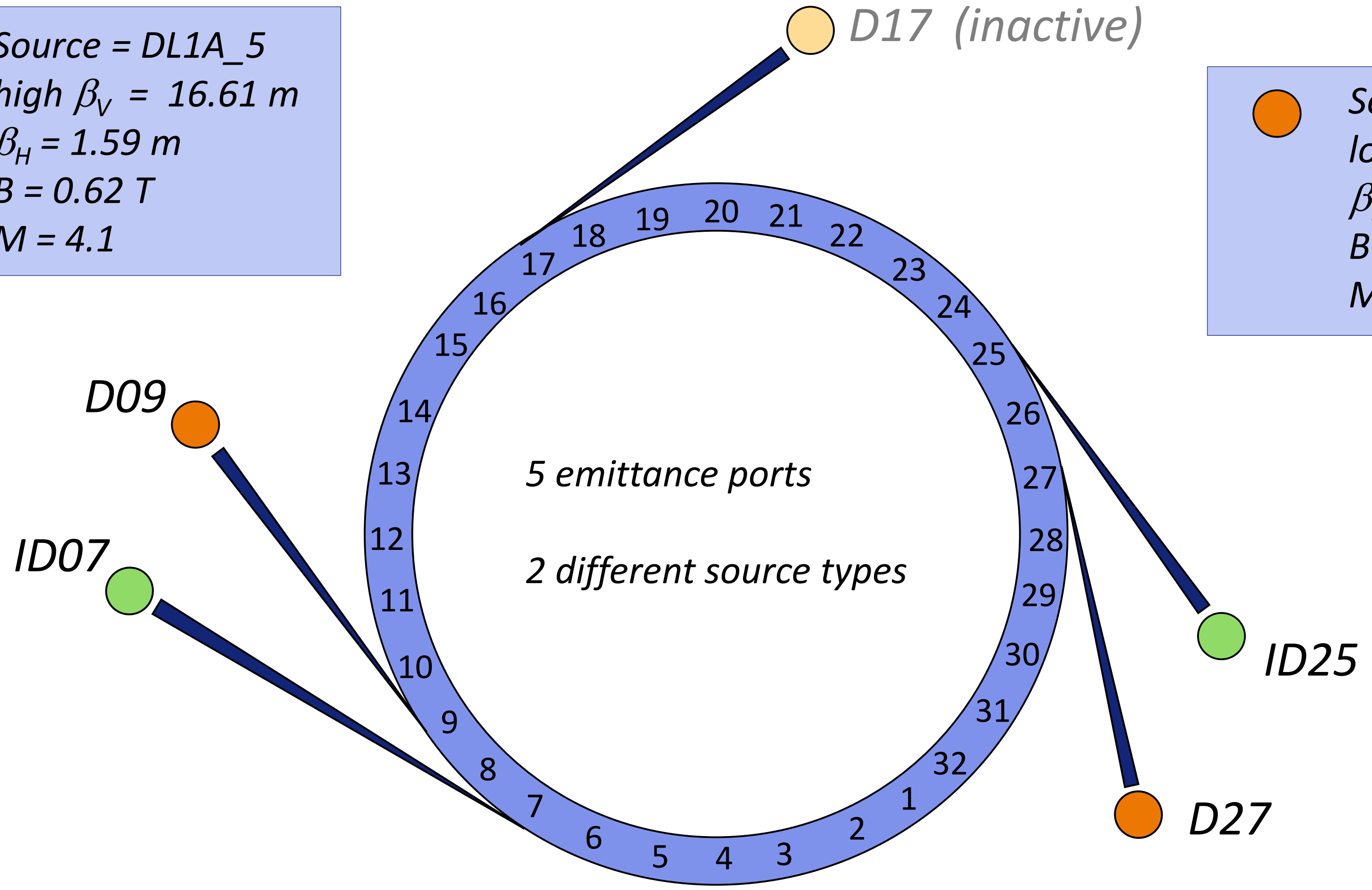
Recall of Pinhole Principle



Pinholes in the ESRF Storage Ring

Source = DL1A_5
high β_V = 16.61 m
β_H = 1.59 m
B = 0.62 T
M = 4.1

Source = DQ1D
low β_V = 3.8 m
β_H = 1.43 m
B = 0.55 T
M = 2.9



Pinholes in the ESRF Storage Ring

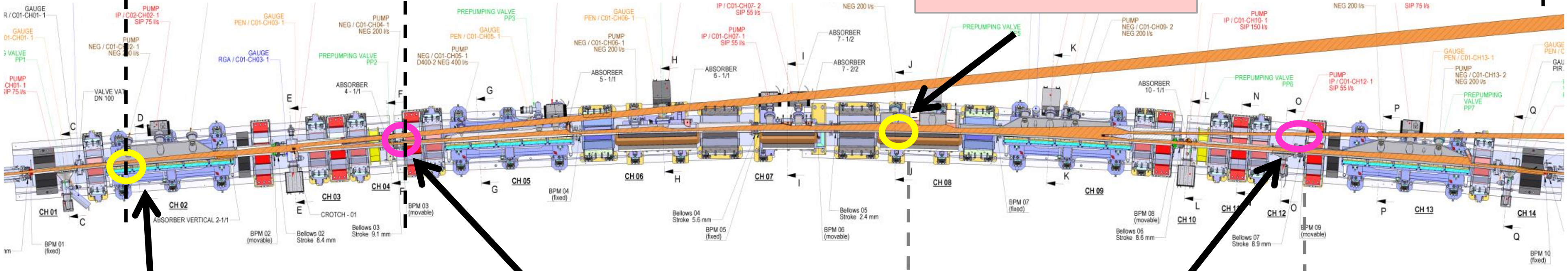
M = 4.1

Screen

D = 16.33 m

d = 3.98 m

Source 2: DQ1D



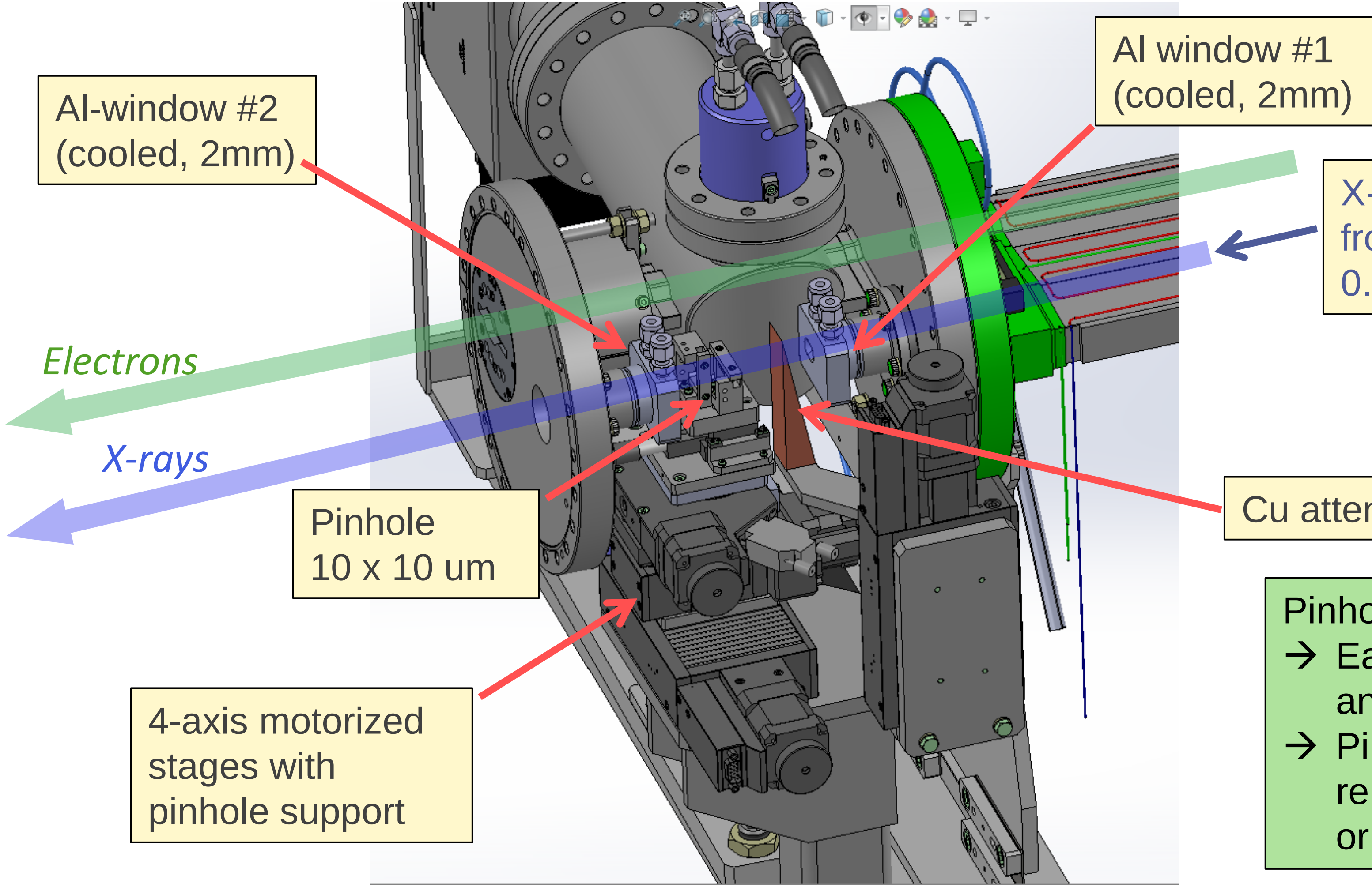
Source 1: DL1A_5
B = 0.62 T
βz = 16.6 m

Pinhole/lens position 1

Pinhole position 2:

5.8 m

Pinhole Implementation in Front End

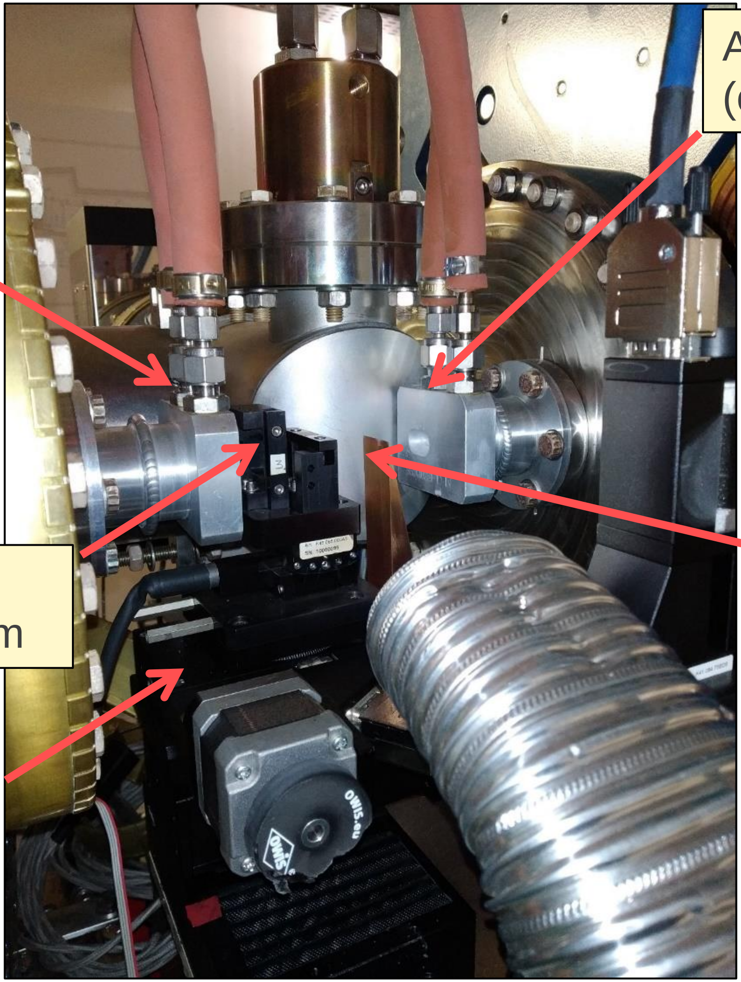


Pinhole assembly **in air**

→ Easy intervention and maintenance

→ Pinhole may be replaced by lens or diffraction mask.

Al-window #2
(cooled, 2mm)



Al window #1
(cooled, 2mm)

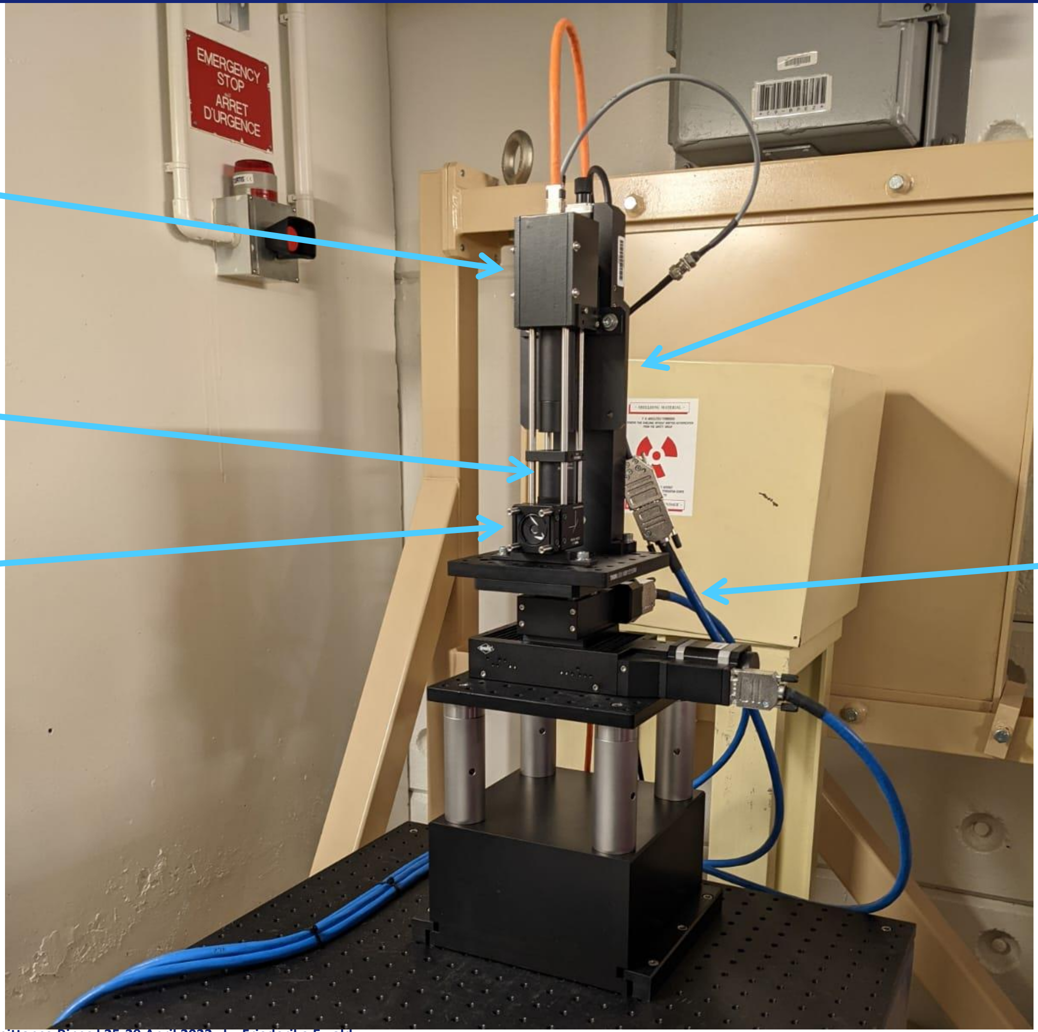
Pinhole
10 x 10 um

Cu attenuator

4-axis motorized
stages with
pinhole support

Pinhole assembly **in air**
→ Easy intervention and maintenance
→ Pinhole may be replaced by lens or diffraction mask.

Detector

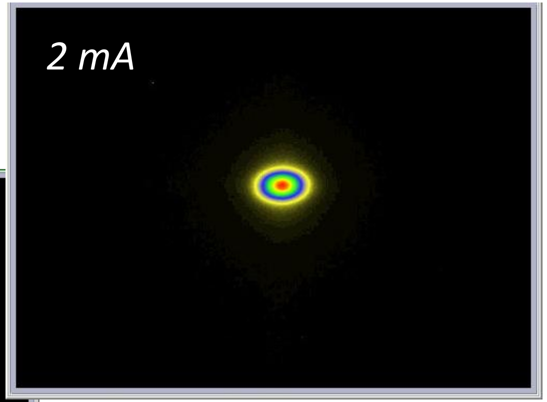

CCD behind 5mm Pb
Double achromat
Scintillator
Translation stage for focusing
X-Y stages
EMERGENCY STOP
ARRET D'URGENCE

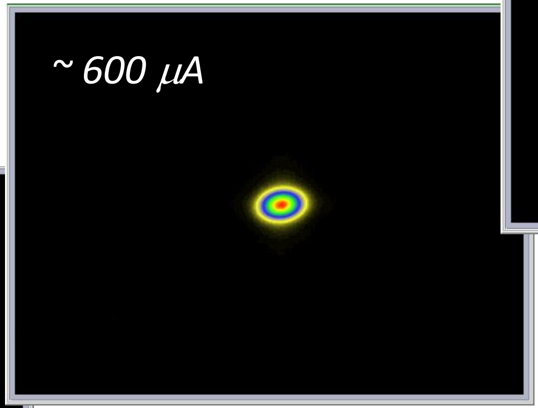
Pinholes used for

- *Permanent quantitative emittance monitoring (at 1Hz, data available at 15Hz maximum)*
- *Permanent energy spread measurement*
- *Stabilisation of vertical emittance using a feedback system*
- *Qualitative observation of coupling, beam blow-up, instabilities*
- *For Beam Dynamics studies,*
- *Evaluation of influence of insertion devices on the stored beam*
- *… And (most of) this from day 1 of the ESRF-EBS commissioning…*

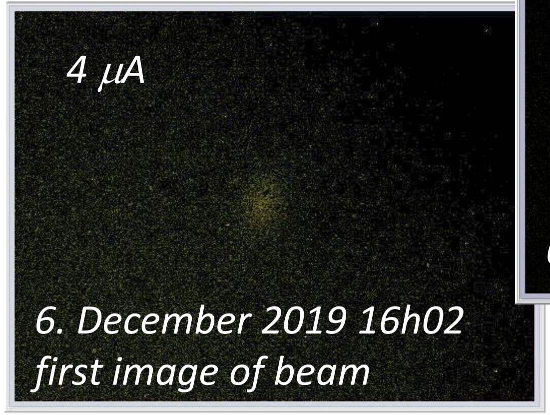
First 2D Images from Stored Beam (6. December 2019)

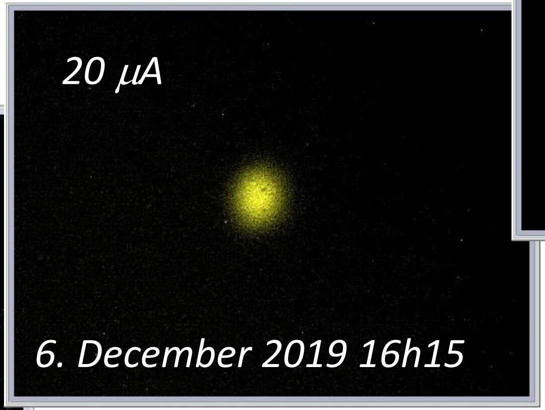
No pinhole inserted
(projection of dipole radiation only)





With pinhole:





Pinhole was operational nearly immediately after first beam was stored

Pinhole Resolution

Must be known precisely for low systematic error on measurement

Beam size measured on screen

PSF of pinhole (E)

PSF of visible light imager

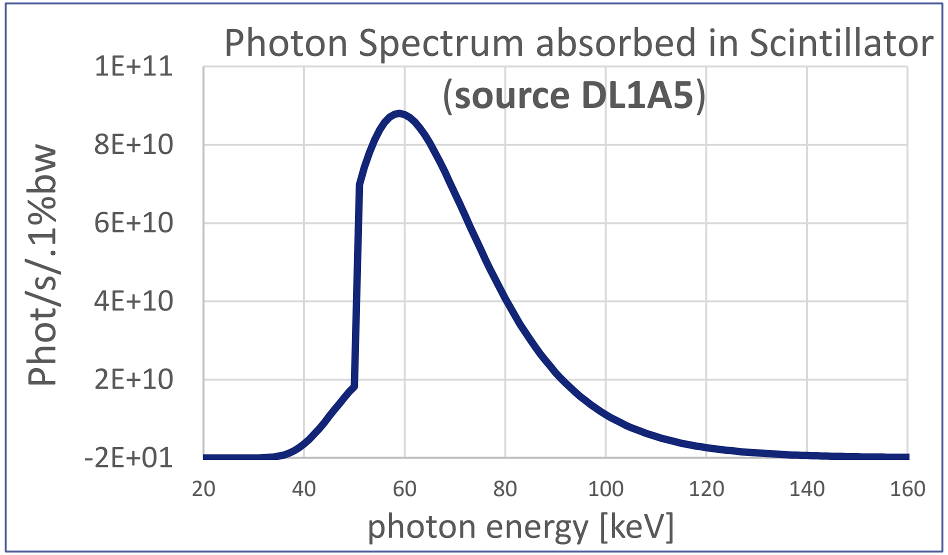
$$\varepsilon = \frac{1}{\beta}\left[\frac{\sigma_m{}^2 - \sigma_{psf,X}^2 - \sigma_{psf,CCD}^2}{M^2} - \eta^2\delta^2\right]$$

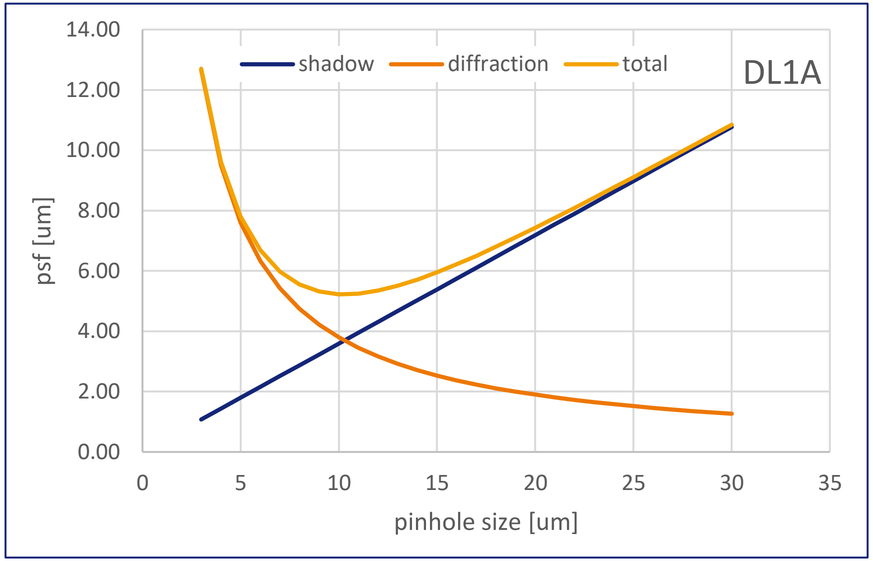
Beta-function at source

Magnification = Source->Pinhole / Pinhole->Screen

Must be high for good resolution

Pinhole PSF





Optimum pinhole opening at 65 keV: $A_{opt} = f\,(E_X) = 10$ *um*

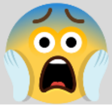
=> *pinhole PSF :* ~ 5.2 *um*

=> *corresponds to* $\varepsilon_H = 17$ *pm.rad*

$\varepsilon_V = 1.6$ *pm.rad*

Performance

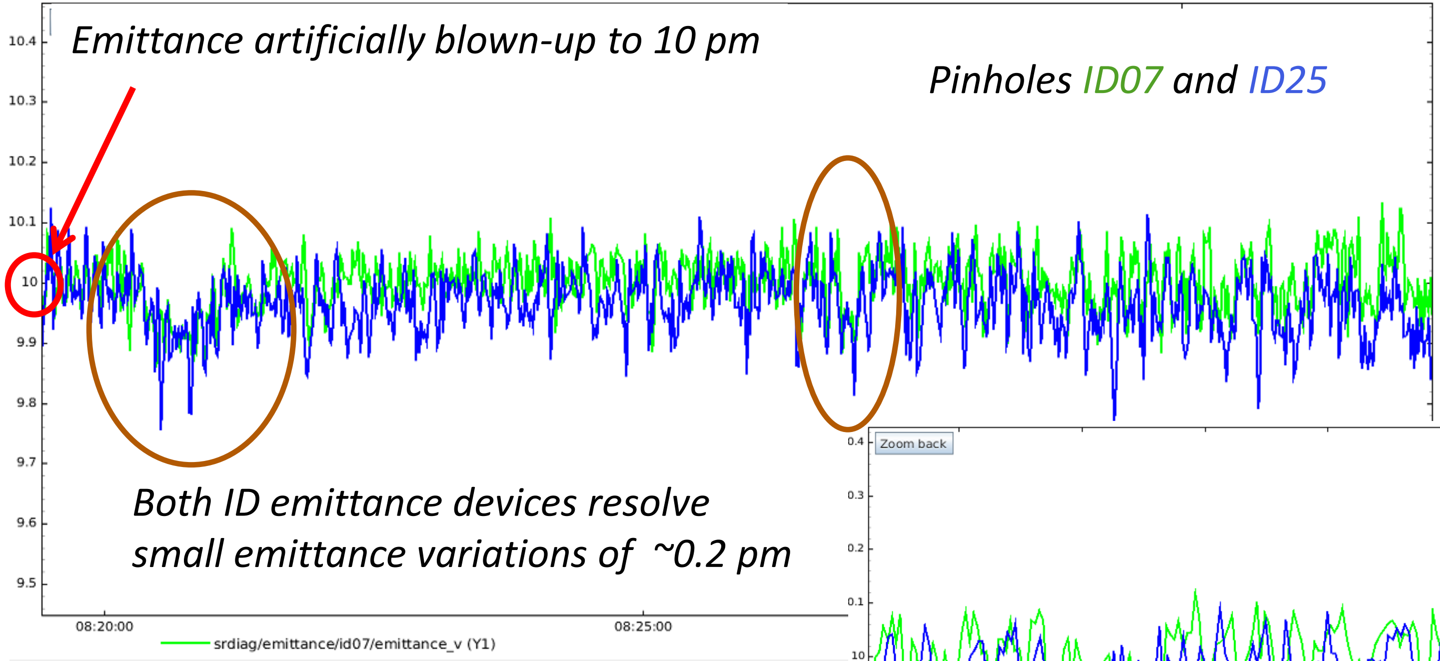
→ *Deconvolution of measured beam size with contributions from diffraction at the pinhole and resolution of visible light imaging*
→ *An error of the emittance value is calculated from uncertainties of all input parameters (PSFs, lattice functions, magnification, data treatment,)*

	Horizontal Gaps open	Horizontal Gaps closed (USM)	Vertical with blow-up (USM)	Vertical without blow-up (coupling 0.1 %)
Design value	139 pm	~ 125 pm(*) $\sigma \triangleq$ 14 μm at source	10 pm $\sigma \triangleq$ 13 μm at source	0.125 pm $\sigma \triangleq$ 1.4 μm at source
Measured	✓	122 – 129 pm (insertion devices, machine correction,…)	✓ Fixed by emittance feedback	Down to < 1 pm difficult to determine the real absolute value
calculated systematic error	~10%	~10%	~13%	> 100% …. 

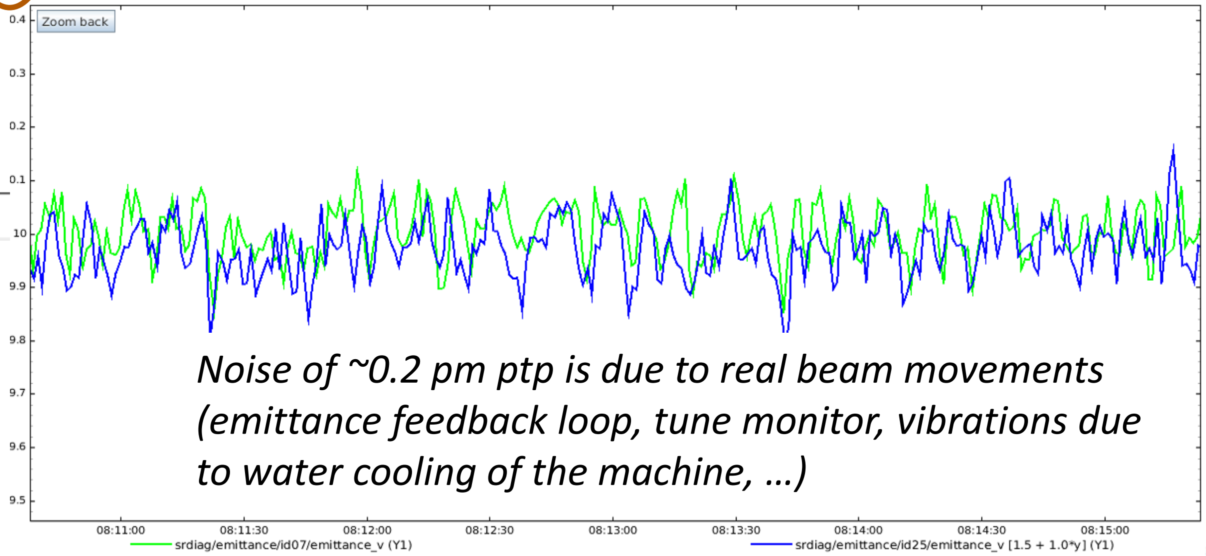
(*) depends on exact radiated power

But relative changes < 0.1 pm can be monitored!

Vertical Emittance During Beam Delivery to Users (200 mA)



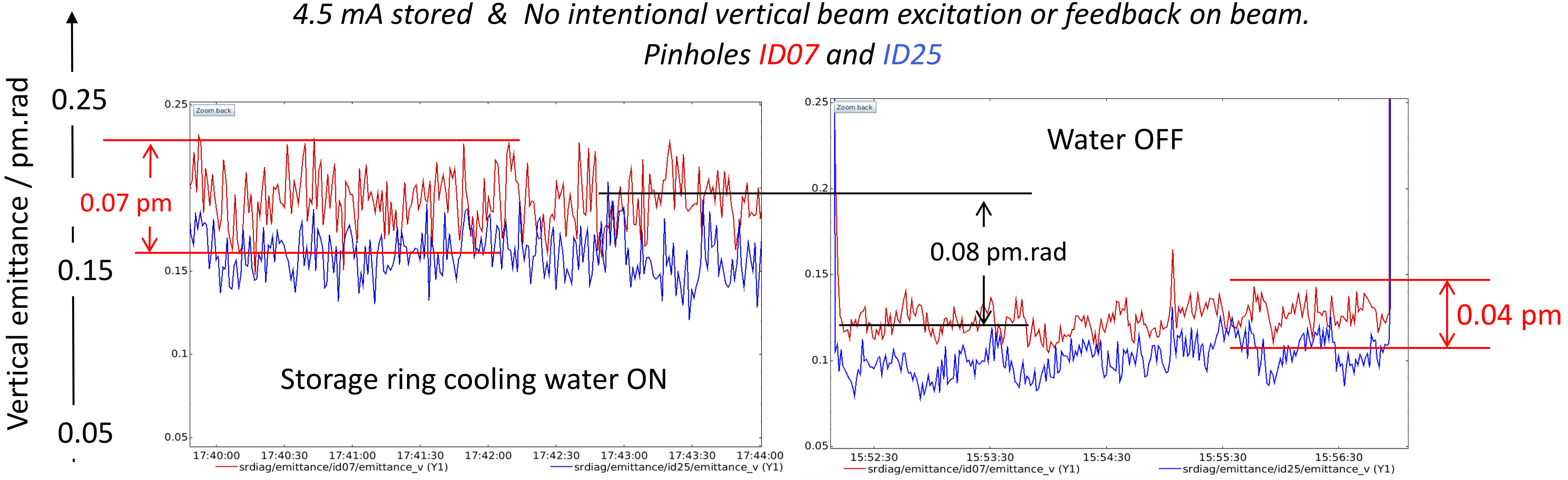
We use a vertical emittance feedback to keep ε_V constant during beam delivery.



Beam Without Storage Ring Water Cooling

4.5 mA stored & No intentional vertical beam excitation or feedback on beam.

Pinholes ID07 and ID25



- *Clear effect on the emittance, which is reduced by 0.08 pm (high frequency vibrations)*
- *and peak-to-peak values reduced by a about a factor of 2 (low frequency vibrations)*
- *Well corrected machine -> measured emittance close to design values -> is this real ?*

Energy Spread Measurement

Two pinhole source points available with

$$\eta_1 = 12{,}9\,mm > \eta_2 = 0{,}6\,mm$$

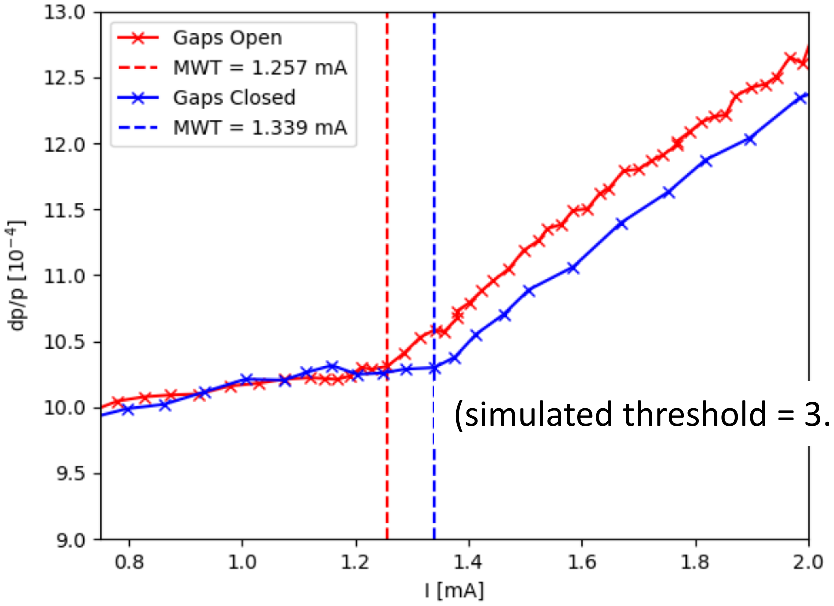
from

$$\sigma_{1,2}^2 = \beta_{1,2}\varepsilon_{1,2} + \eta_{1,2}^2\delta^2$$

we calculate the energy spread:

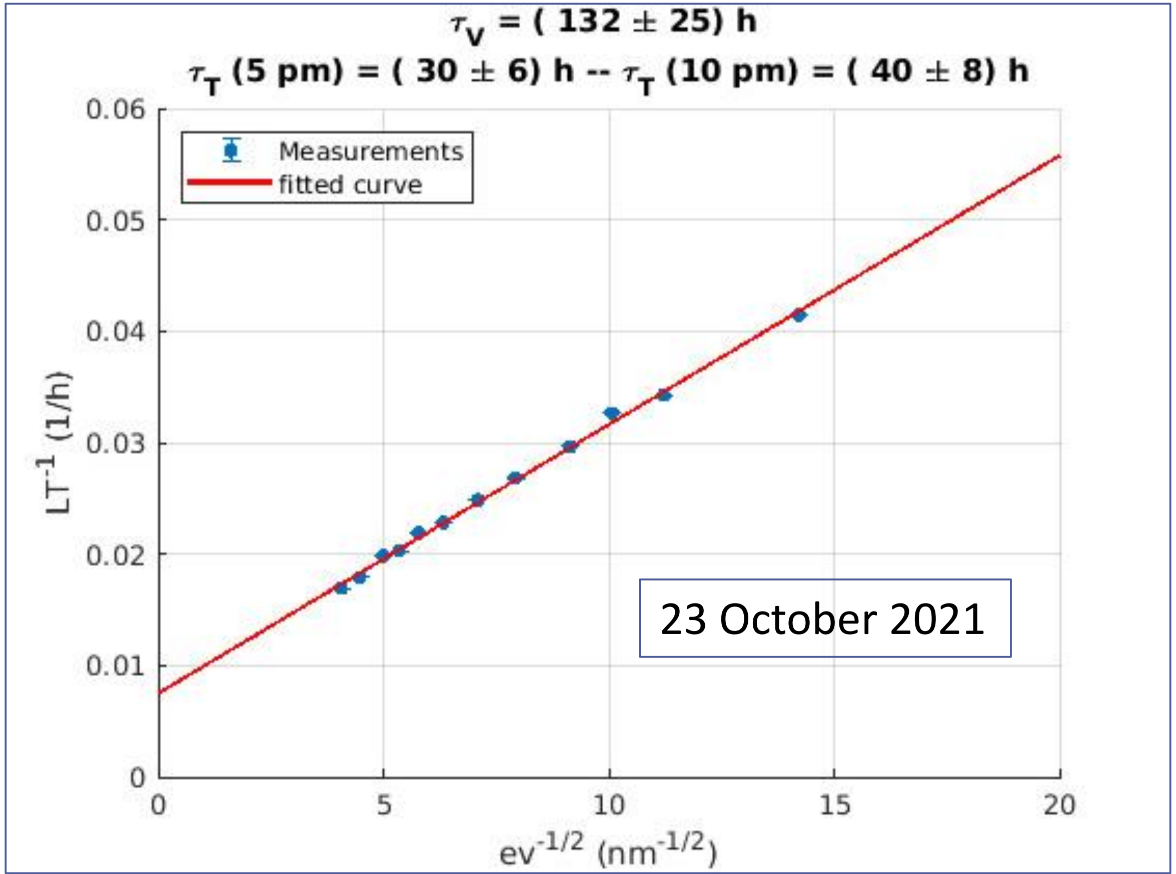
$$\delta = \sqrt{\frac{\beta_1\sigma_2^2 - \beta_2\sigma_1^2}{\beta_1\eta_2^2 - \beta_2\eta_1^2}}$$

Measurement of Microwave Threshold:



L. Carver et al.,
Single Bunch collective effects in the EBS storage ring,
Proceedings of IPAC21

Measurement of Touschek Lifetime



At large vertical emittance values the Touschek lifetime can be supposed to be infinite or $1/\sqrt{\varepsilon_V} = 0$.
During the scan $LT_{vac} = const.$

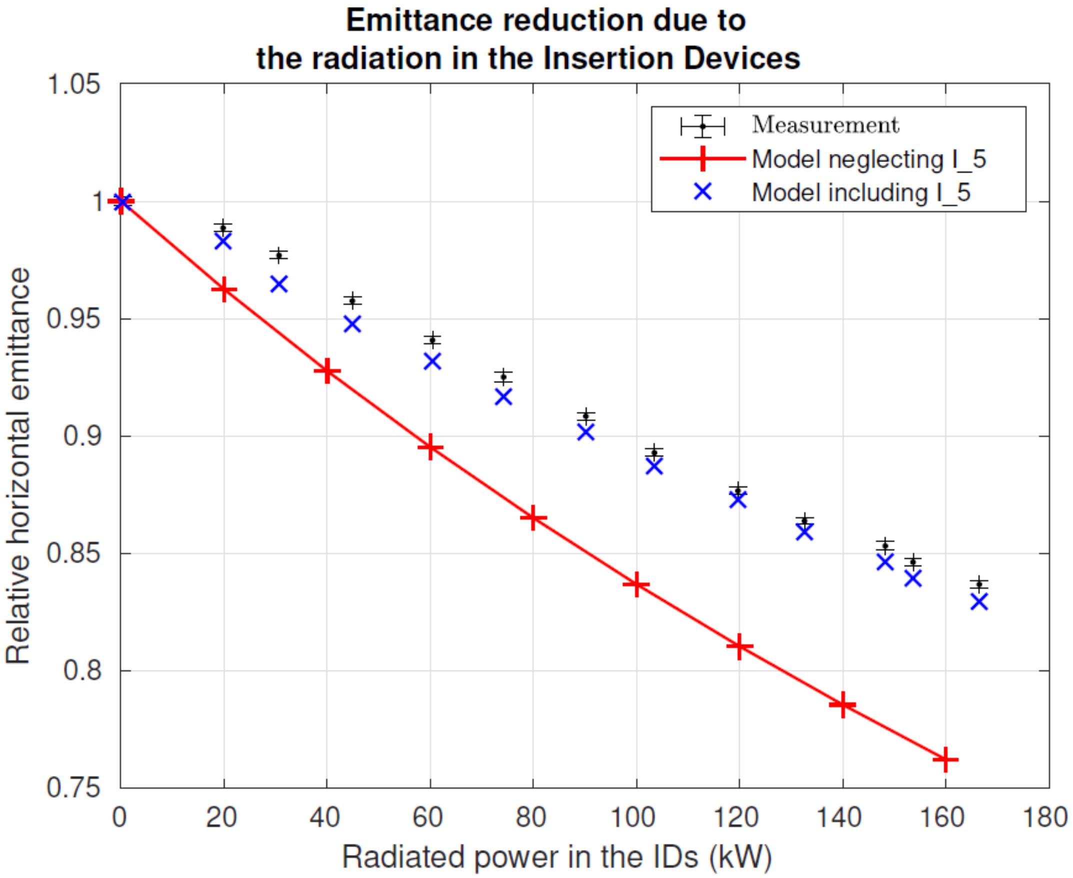
$$\frac{1}{LT} = \frac{1}{LT\_vac} + \frac{1}{LT\_Touschek}$$

and

$$\frac{1}{LT\_Touschek} \propto = \frac{1}{\sqrt{\varepsilon_V}}$$

Courtesy of N. Carmignani & S. Liuzzo
ESRF – Beam Dynamics Group

Horizontal Emittance vs Radiated Power



5th Synchrotron integral:

$$I_5 = \oint \frac{\mathcal{H}}{|\rho^3|} ds$$

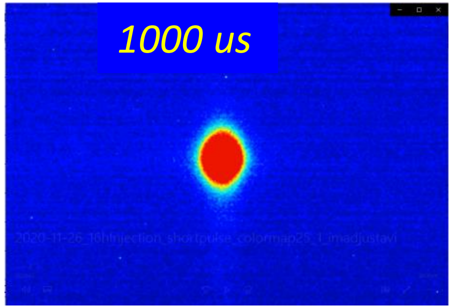
with

$$\mathcal{H} = \gamma_x D_x^2 + 2\alpha_x D_x D_x' + \beta_x D_x'^2$$

→ *Dispersion in straight sections must not be neglected,*
otherwise the effect of undulator radiation on equilibrium emittance is over estimated.

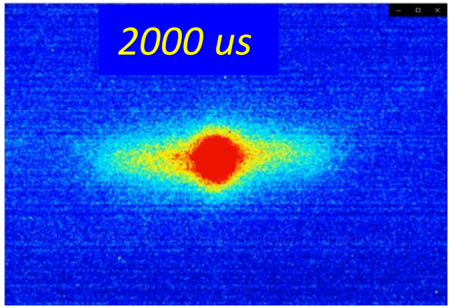
Courtesy of Reine Versteegen
ESRF - Insertion Device Group

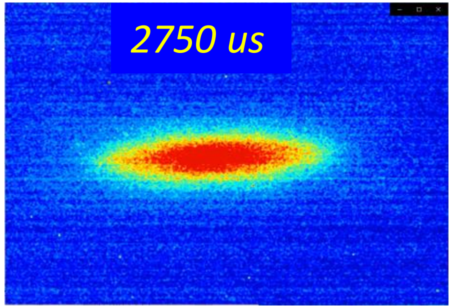
Qualitative Observation of Beam Perturbations During Injection

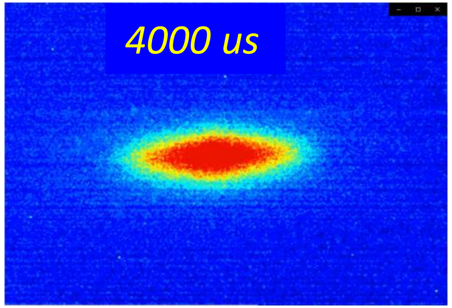


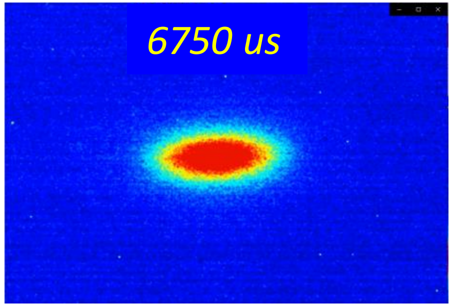
Pinhole ID07 configured to measure the beam profile during injection

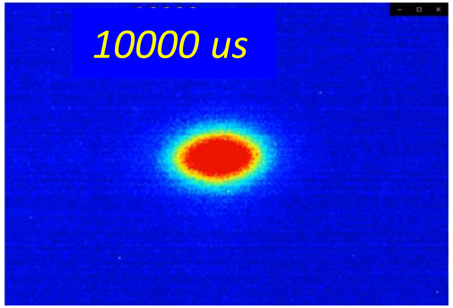
- *one image = one injection shot, with different trigger delay*
- *Exposure time 250 us ≈ 90 turns for the below images.*
- *Blow-up completely damped after > 25 ms*

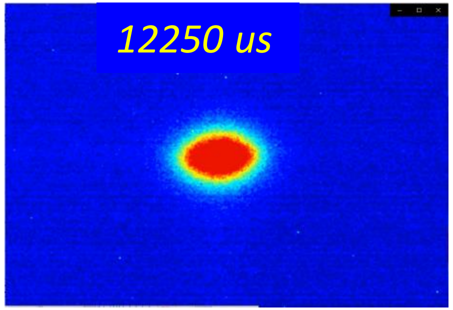


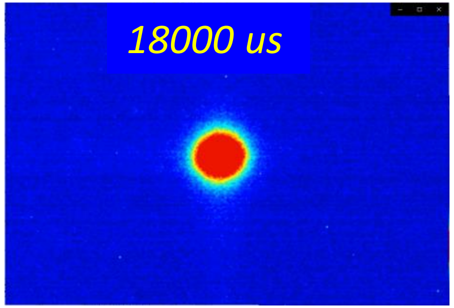


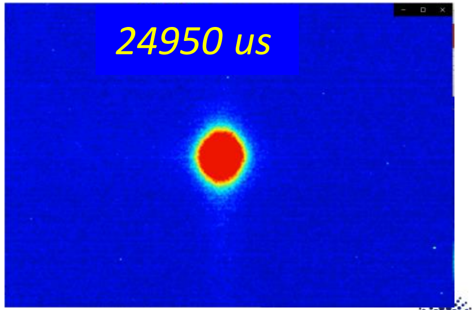




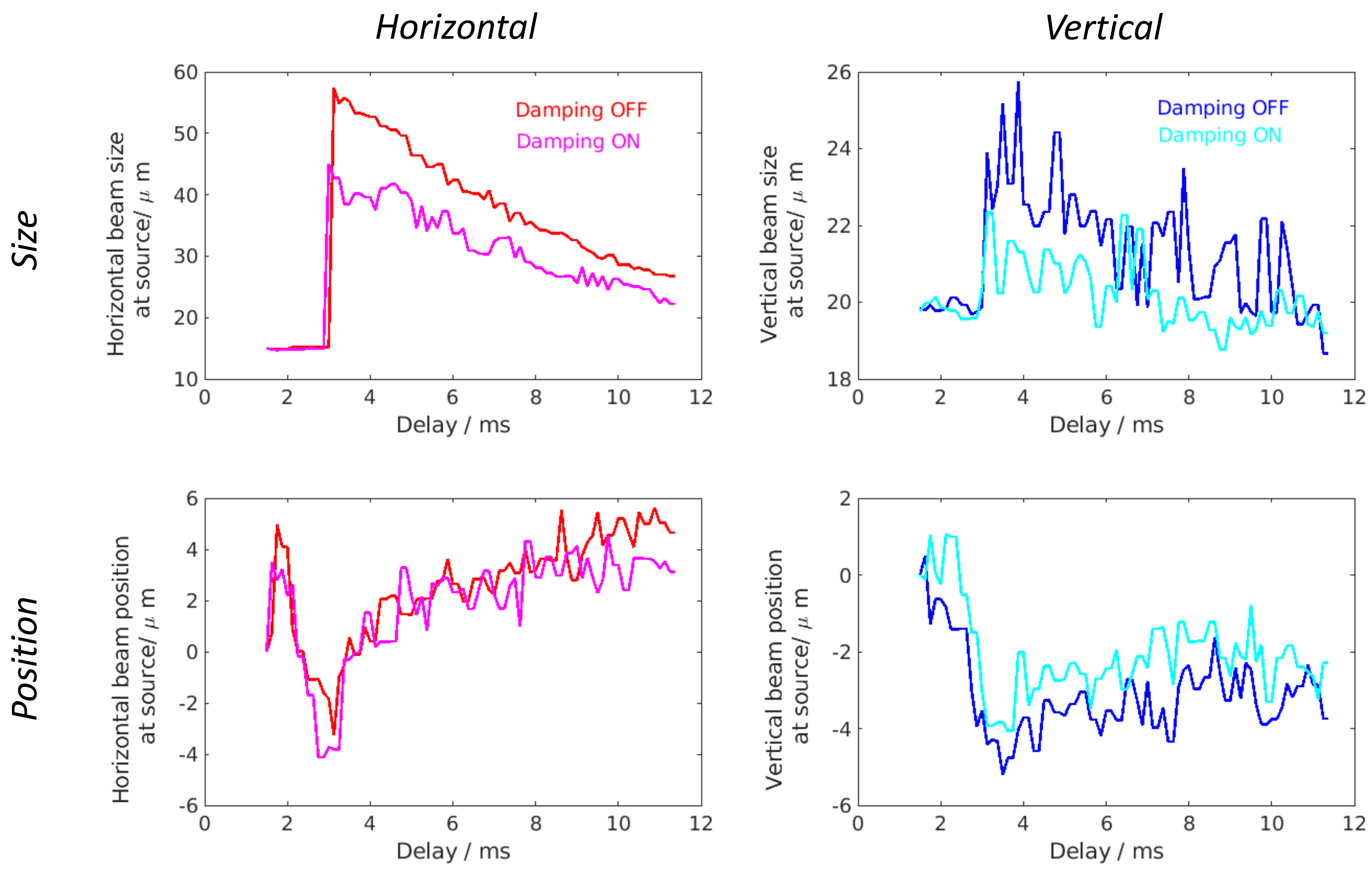








Observation of Actively Damped Beam Perturbations During Injection



2. December 2020

Exposure Time: 100us

We continuously monitor the beam blow-up (at a fixed delay) during normal operation in order to follow-up the beam perturbations during injection.

Conclusions

*The pinhole camera is the **workhorse of emittance measurements** at the ESRF.*

-> Reliable, robust, only few maintenance operations

-> resolves small vertical emittances down to a few pm.rad (few μm σ)
(depends on implementation: β, X-ray magnification !)
and relative emittance variations of < 0.1 pm.rad (σ < 1μm

-> serves for several other measurements as well, e.g.:

Touschek life time
Energy spread
vertical emittance feedback
qualitative evaluation of injection perturbations
…

However, for beam studies, exploring the ultimate machine performances, alternative methods with better resolution should be developed.

*-> tests using **X-ray lens imaging** are **in the process of being installed** (first results 2022 expected)*

-> later, X-ray diffraction techinques will be evaluated and tested (Fresnel diffraction from slit).

Thank you for your attention!