TRANSVERSE EMITTANCE MEASUREMENT VIA PEPPER-POT

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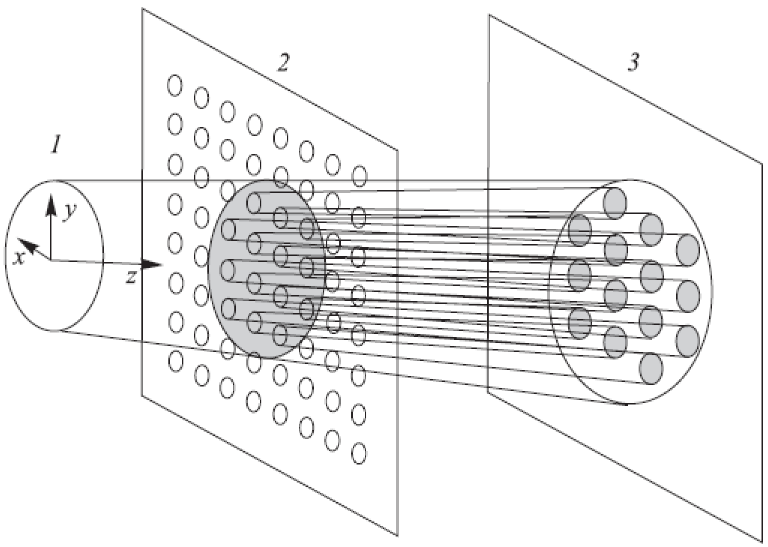
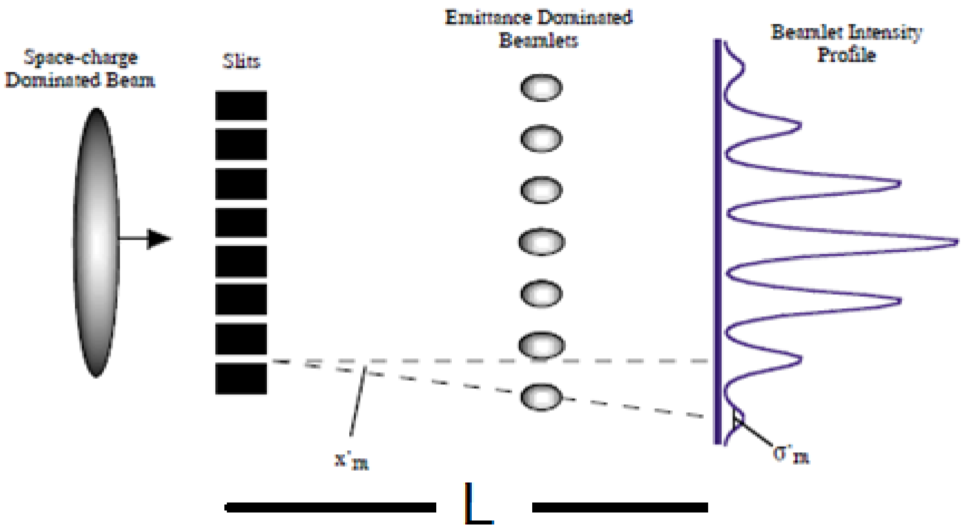
CONTENTS

THE PEPPER-POT



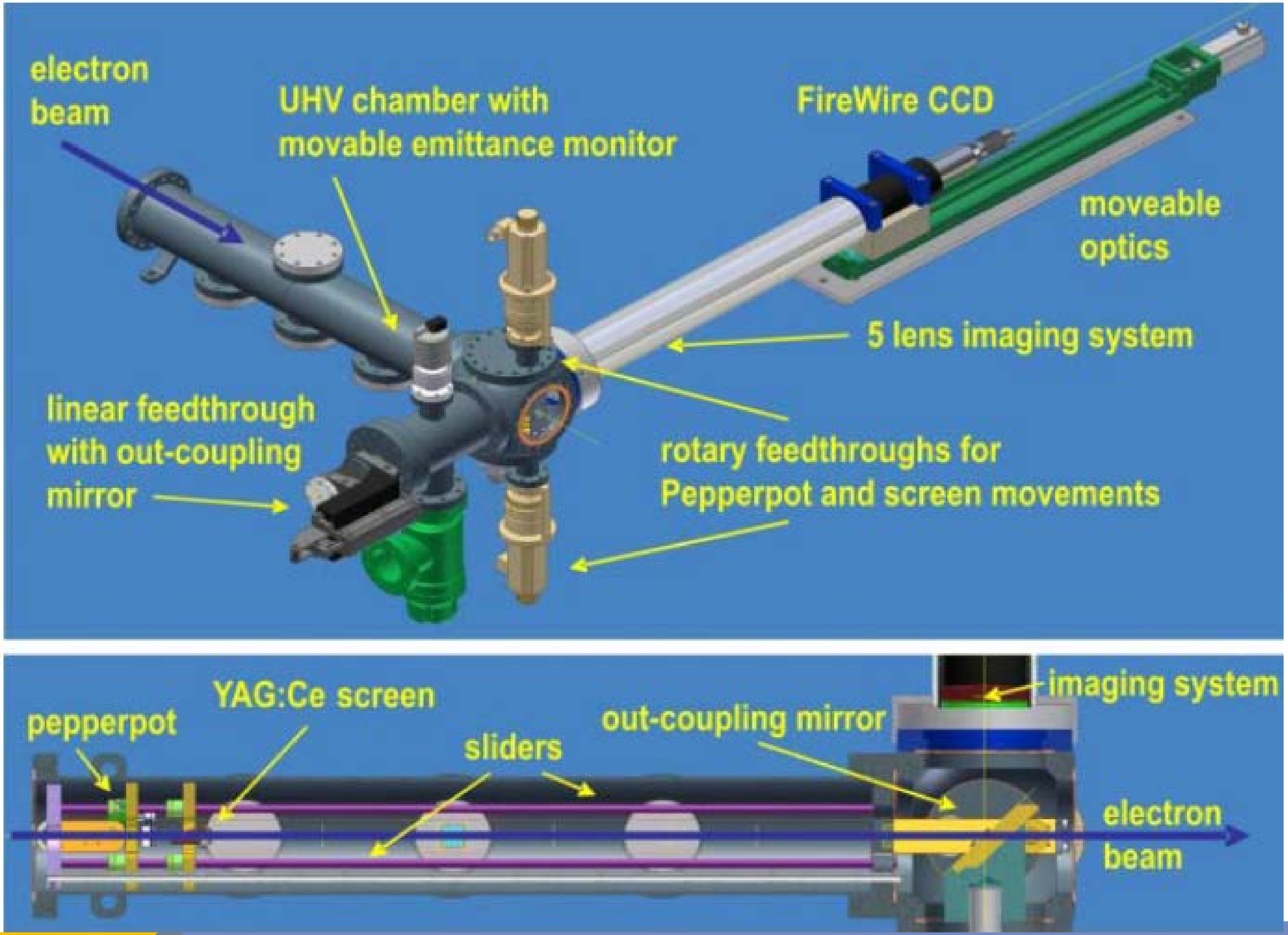
PEPPER-POT METHOD



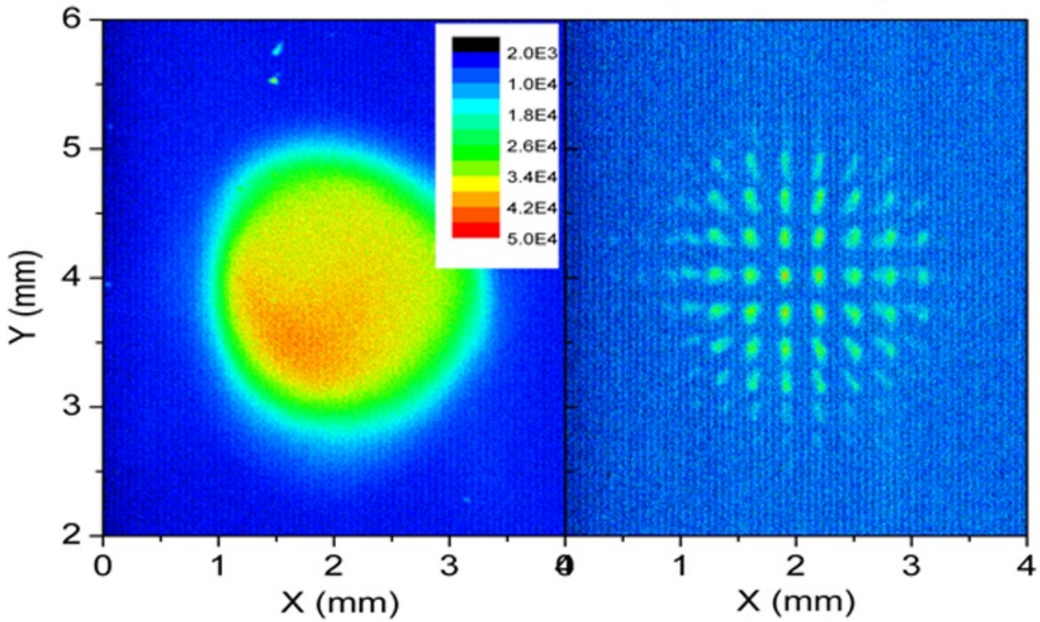
- Beam segmented by plate with regular array of holes
- Beamlets move in a short drift before hitting the scintillation screen and producing image
- The distance L value is chosen to prevent beamlet overlapping
- CCD camera records images of lightspots

L- Distance between pepper-pot plate and screen

$L \geq \Delta p / 2x'$, Δ =100 μm – screen spot resolution limit
p – number of holes

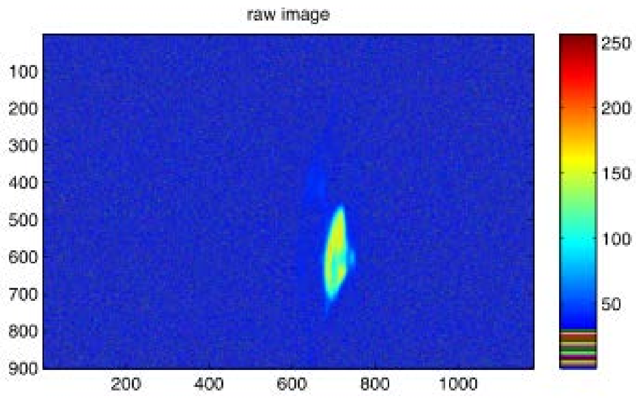

electron beam
UHV chamber with movable emittance monitor
FireWire CCD
moveable optics
5 lens imaging system
linear feedthrough with out-coupling mirror
rotary feedthroughs for Pepperpot and screen movements
pepperpot
YAG:Ce screen
sliders
out-coupling mirror
imaging system
electron beam

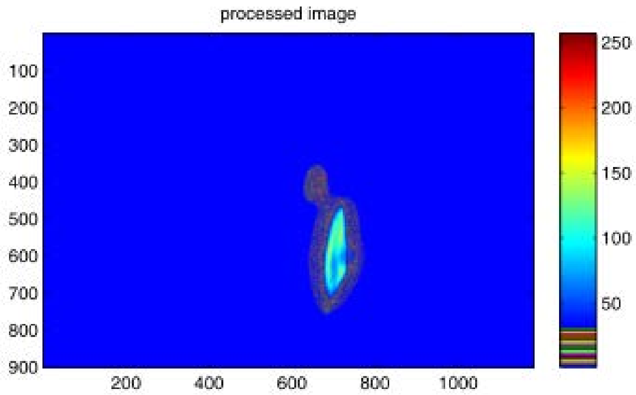
PEPPER-POT METHOD



THRESHOLD PARAMETER

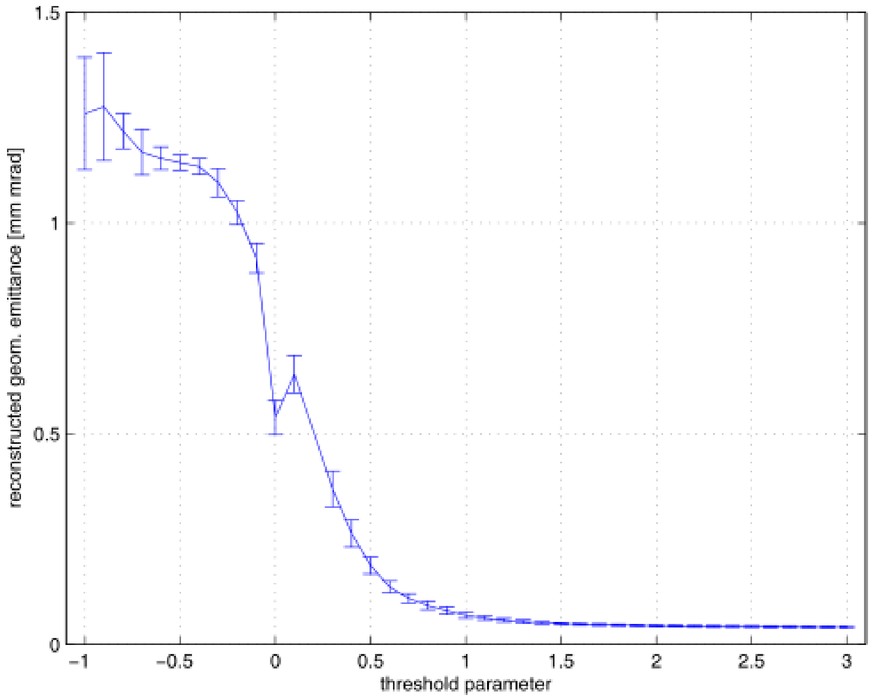
- First standard step – the subtraction of the background (for every position of the mask)
- The problem of readout noise from CCD or pixel illuminated by stray radiation
- The idea is to mask parts of the image which are not related to the beam (removing noise contributions from these regions)
- Masking procedure is controlled by threshold parameter, which determines the size of the mask
- The average pixel intensity of the masked region is subtracted from the whole image to remove remaining offsets and then all masked parts are set to zero





The color map is adjusted to increase the visibility of the noise

THRESHOLD PARAMETER



The determination of threshold parameter is crucial since the emittance value depends on it.

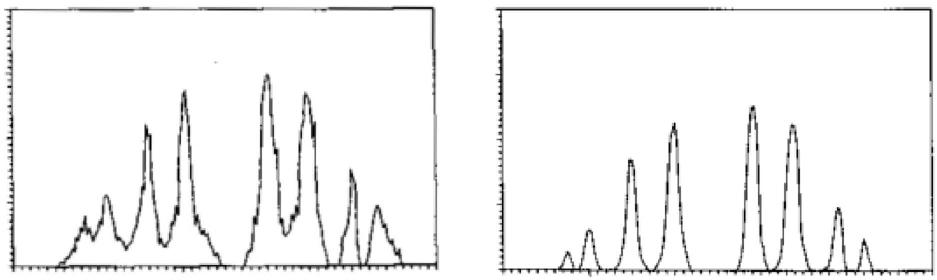
The fluctuations will be large with a strong dependence on the threshold parameter if the CCD noise dominates or is relatively small and constant in case the beam jitter dominates.

The criterion for the choice of threshold parameter is in selecting the lowest threshold value for which the statistical error is still stable.

Higher values would cut parts of the beamlet spot, thus leading to an underestimation of the measured emittance.

IMAGE PROCESSING ALGORITHMS

- **A smoothing process along all pixels in each line of the image should be performed**



Measured data along one pixel line(left) and after smoothing(right)

$$I(x) = \sum_{k=0}^{m} c_k \cdot L_k(x),$$

$$[x_0, x_n]$$

- **Detecting and distinguishing each spot, assuming no overlap (algorithm starts at the position of the center hole)**
- **The vertical and horizontal size of each spot must be determined**
- **For further processing two projections (vertical and horizontal) of one spot are needed.**

IMAGE PROCESSING ALGORITHMS

- **For further processing two projections (vertical and horizontal) of one spot are needed.**
- **Approximation of the projected spot curves by Gaussian functions**

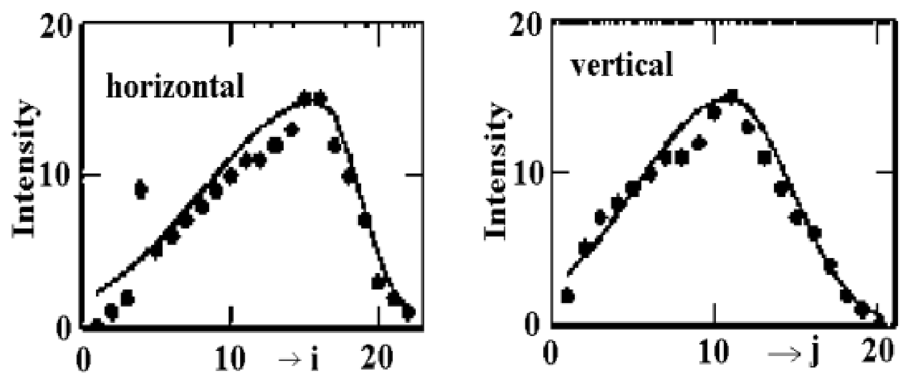


IMAGE PROCESSING ALGORITHMS

Each spot will be described by 4 Gaussian functions, maximum intensity I_0 and Δx , Δy describe the relation to the corresponding hole position. Then, it will be possible to determine the divergences for different fractions of the maximum intensity. From the formula

$$I(x) = I_0 \cdot \exp\left(-\frac{(x-x_0)^2}{2\sigma^2}\right)$$

The linear deviation is determined by

$$\Delta x = \sigma \cdot \sqrt{2 \cdot \ln \frac{I_0}{I(x)}}.$$

IMAGE PROCESSING ALGORITHMS

As an example, divergences given by`

$$XR' = \frac{(dx + \Delta xr) \cdot h}{L} \qquad XL' = \frac{(-dx + \Delta xl) \cdot h}{L}$$

With $dx = x_o - x_{hole}$

X_o - position of the maximum intensity in the spot

x_{hole} - the coordinate of the corresponding hole

And $h = \Delta h / N_p$

Δh – spacing between two holes

N_p – the number of pixels between two holes

IMAGE PROCESSING ALGORITHMS

Then

$$\Delta xr = \sigma r \cdot \sqrt{2 \cdot \ln\left(\frac{IN_m}{PR}\right)}.$$

PR – fraction, [0 ≤ PR ≤ 1] , IN_m – normalized intensity

- 5 matrixes should be formed for describing divergence in the directions left, right, up, down and one matrix for total spot intensities.
- To determine 2-dimensional emittance in the horizontal plane the averages for each vertical column must be calculated.
- Determination of Twiss parameters

EMITTANCE

$$\begin{aligned}\epsilon_x^2 &= \langle x^2 \rangle \langle x'^2 \rangle - \langle xx' \rangle^2 \\ &\approx \frac{1}{N^2}\left\{\left[\sum_{j=1}^{p} n_j (x_{sj} - \bar{x})^2\right]\left[\sum_{j=1}^{p}[n_j \sigma_{x'_j}{}^2 + n_j(\bar{x}'_j - \bar{x}')^2]\right] - \left[\sum_{j=1}^{p} n_j x_{sj} \bar{x}'_j - N\bar{x}\bar{x}'\right]^2\right\}. \quad (30)\end{aligned}$$

This is the final slit emittance formula. All the terms in the formula are expressed by slit positions and beamlet spots parameters on the screen. Specifically, they are

- x_{sj} – j-th slit's position;
- p – total number of slits;
- n_j – number of particles passing through j-th slit and hitting the screen. Practically it is a weighting of spot intensity;
- $\bar{x}$ – mean position of all beamlets
- $\bar{x}'_j$ – mean divergence of j-th beamlet
- $\bar{x}'$ – mean divergence of all beamlets
- $\sigma_{x'_j}$ – rms divergence of j-th beamlet

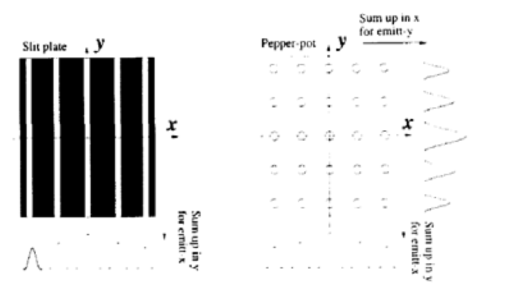
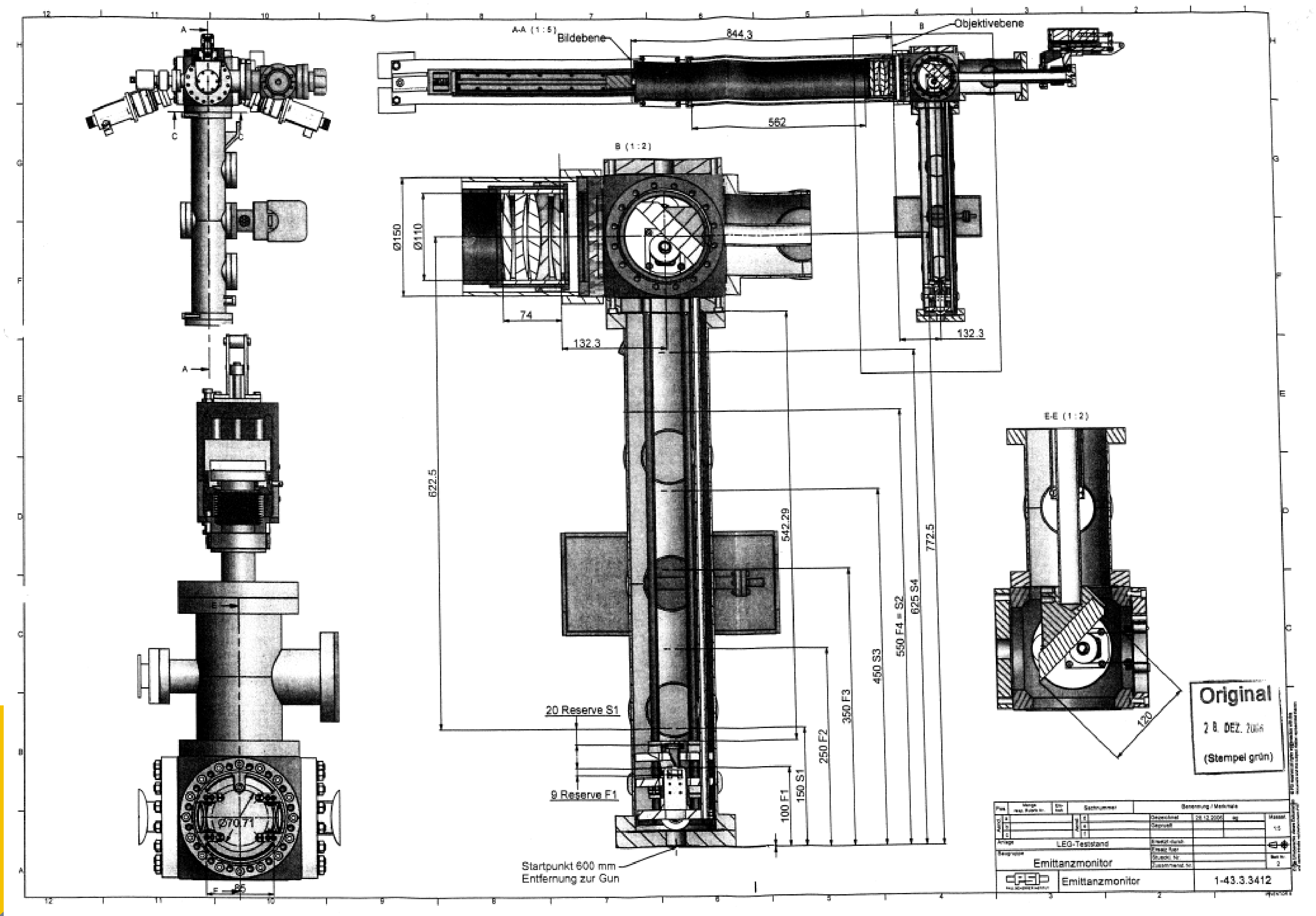


Illustration for slit and pepper-pot image analysis

The generalization of the above slit emittance formula to the pepper-pot case is straightforward. Instead of projecting slit image lines to the x axis, we sum up all pepper-pot spot images in y direction for ϵ_x and in x direction for ϵ_y

OUR PEPPER-POT



OUR PEPPER-POT

Initial data for calculation:

- Particle energy – 5 MeV
- Mask diameter – 5 mm
- Mask thickness – 0.5 mm
- Hole diameter – 20 μ m
- Hole spacing - 150 μ m
- Distance between pepper-pot plate and screen - L

Thank You

REFERENCES

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