Electronics and Software: Functionality description

O. M. Røhne[1]

[1]University of Oslo

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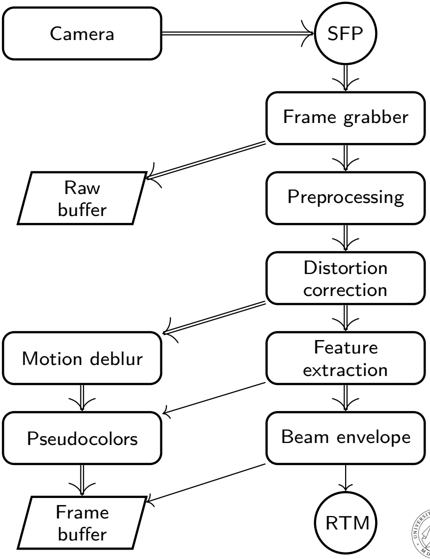
Outline

Functionality	SW	FW
Processing/correction		
- Median noise filter	?	?
- Background subtraction	v	
- Dead pixel mask	v	
- Vignetting correction	v	?
- Geometric distortion	v	?
- Motion deconvolution		
Parameter extraction		
- Centroid position	v	v
- Peak intensity	v	v
- Percentage outside footprint	v	v
- Normalization to beam current		
- Position of fiducials		o
- Correction for temp./yield	?	?
- Histogram and intensity contours	?	
- Beam diagnostic pulse		
Display the image @ 14 fps	v	o
- Pseudocolors		
- Store also raw data		



Light yield from luminous coating

Al_2O_3 — proton stopping power

$$S_{p^+}(2\ \mathrm{GeV}) = 1.66\ \mathrm{MeV} \cdot \mathrm{g/cm^2}$$

PSTAR @ 2 GeV, NIST, 2017,
URL: https://physics.nist.gov/PhysRefData/Star/Text/PSTAR.html

Coating effective thickness

$$d_{Al_2O_3} = 100\ \mu\mathrm{m} \cdot 3.95\ \mathrm{g/cm^3}$$

$Al_2O_3 : Cr^{3+}$ — light yield

$$y_{ph} = 10^4\ \mathrm{ph/MeV}$$

LHC Dump (Chromox), T Lefèvre et al., 2007,
URL: https://cds.cern.ch/record/1045239

Photons per pulse

$$y_{ph} = 7.34 \cdot 10^{17}\ \mathrm{ph/pulse}$$

nominal pulse: $1.12 \cdot 10^{15}\ p^+$

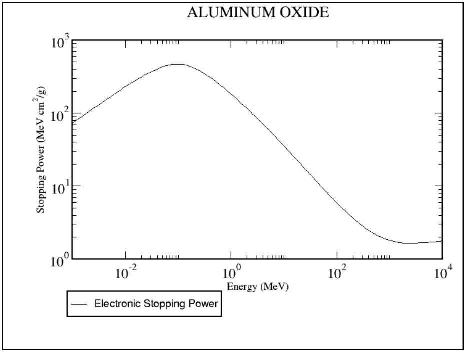


Photo-electrons on camera

$$y_{pe} \simeq 18\ \mathrm{ke/pix}$$

N.A. = 0.001, $\langle T \cdot \mathrm{Q.E.} \rangle = 20\ \%$, 2 Mpix image

Preprocessing: background- and noise suppression

Background subtraction

Subtract residual stray light, gracefully handling broken pixels:

- dead pixel -> black
- stuck-on pixel -> black
- hot pixel -> half the frames black

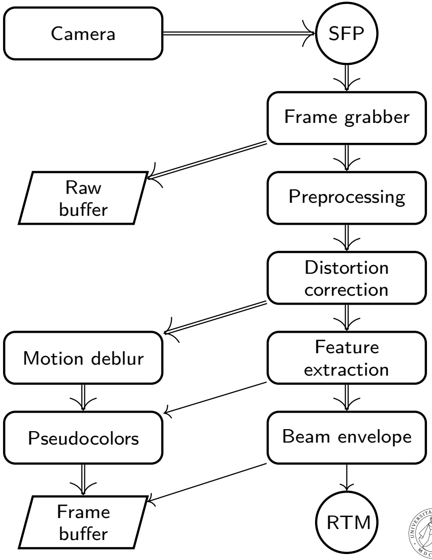
Cost: stream access to full pixel map, stream mode arithmetic
Extra credit: interpolate across broken pixels

Sliding window median filter

Standard adaptible noise filter

- effective against incoherent noise
- robust against singular subfunctional pixels

Cost: resolution degration
Extra credit: fold with background subtraction, explicitly mask broken pixels



Preprocessing: correction and normalization

Temperature correction

Temperature is known to affect Luminescence:

- spectrum broadens, lines vanish
- total light yield reduced

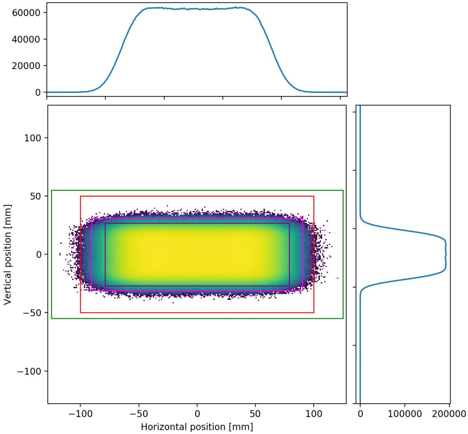
Mitigation strategy:

- measure temperature in situ
- apply calibration curves

Worst-case scenario:

- significant variation across luminous field
- predict response map from simulation

Cost: anther full pixel map

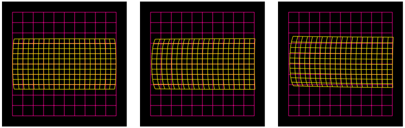


Distortion correction

Projection distortion

Analytic composition of two projections:

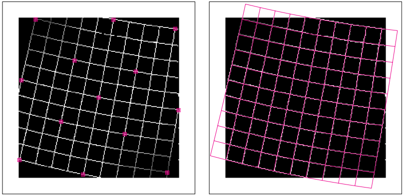
- Beam-normal system projects onto target wheel
- Wheel rim projects thru off-axis pinhole camera matrix



Curved mirror distortion

In-situ calibration:

- Use actual or simulated image of rectilinear system
- Fit with 2nd degree xy-binomial

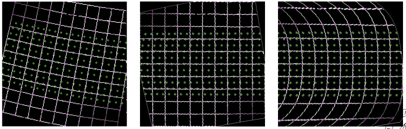


Combined correction

Combination of two distortions

- Projection distortion
- Curved mirror distortion
- Fit with 4th degree xy-binomial

Explicit 2D correction map



Motion deblur

Moving screen beam imaging

Motion blur effect:

- Rotational motion: $3\ \mathrm{m/s}$
- Luminous lifetime: $1\ \mathrm{ms}$

Exponential decay PSF: $3\ \mathrm{mm}$

Richardson-Lucy deconvolution

Iteratively reconstruct the latent image from the observation

$$u^{(t+1)} = u^{(t)} \cdot \left(\frac{d}{u^{(t)} \otimes p} \otimes \hat{p} \right) .$$

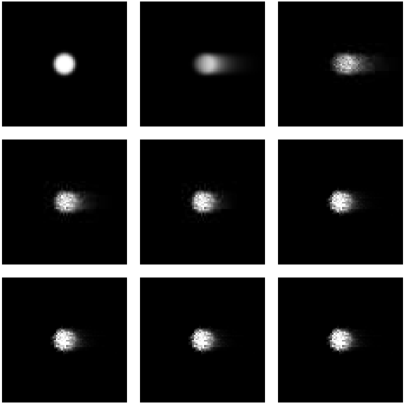
W H Richardson, 1972, DOI: 10.1364/JOSA.62.000055
L B Lucy, 1974, DOI: 10.1086/111605

Example demonstration

NumPy/OpenCV modeling:

- Lumnious disk: $6\ \mathrm{mm}$ diameter
- Motion blur: $3\ \mathrm{mm}$ lenght
- Poisson noise: $n = 100\ \mathrm{ph/pix}$

Deconvolution, six iterations shown



Feature extraction

Peak intensity and position

Sliding window maximum search

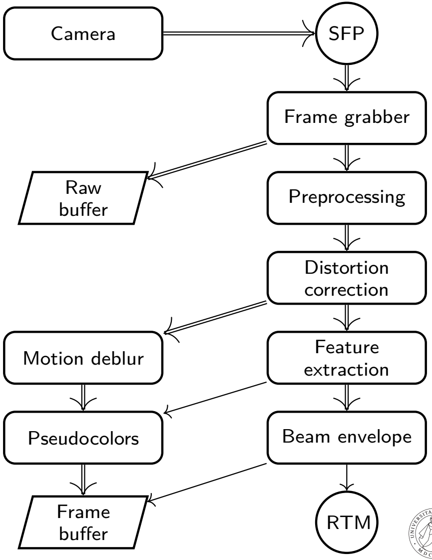
- Use noise filtered and normalized image
- Streaming mode, conveniently done in HW
- Peak position can be corrected *a posteriori*

Centroid and RMS

Moments of the intensity distribution

- Calculate on corrected image
- Streaming mode, conveniently done in HW
- Possibly correct for motion blur

Extracted parameters are exported as EPICS PV



Beam-outside-box

Nominal beam profile

8 M simulated protons (H D Thomsen, Aarhus)

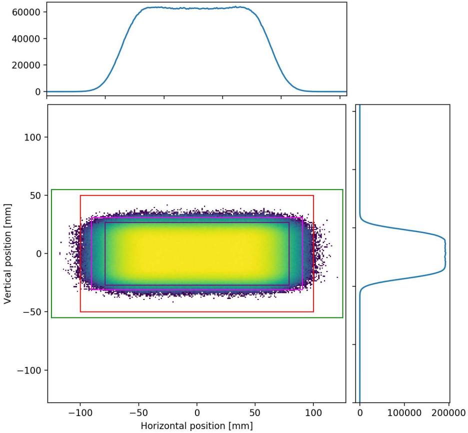
- Green: nominal field-of-view
- Red: beam entrance window
- Pink: 99.9% nominal beam
- Purple 99.0% nominal beam

Marginal intensity

Counting photo-electrons in margins

- Marginal pixels: 10 % / 0.4 Mpix
- Pixel noise: 1.4 e−
- Achievable threshold: 4.5 ke− (5σ)
- Comparable full pulse: 36 Ge− (est.)

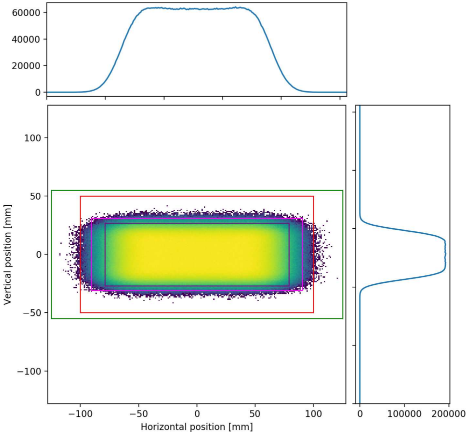
Relative threshold e.g. 99.9 % well within reach



Operator screen presentation

EPICS processing and presentation

- Apply logarithmic pseudocolors
- Add parameters annotations
- Overlay nominal envelope etc
- Collect horizontal and vertical profiles
- Accumulate intensity histogram



Summary and outlook: processing functionality

Hardware baseline:

- background subtraction
- median filter
- temperature correction
- scaling and normalization
- distortion correction
- extract centroid and RMS
- extract beam-outside-box

Software baseline

- all the above
- motion deblur
- annotation and presentation for operator
- store raw, intermediate, final streams