Development of applications for CEC diagnostics line

- Temporal profile of the electron bunch. ~Ready.
- Finding of zero-crossing RF phase.
- Energy (dp/p) spread. ~Ready.
- Emittance using multi-slit. To be tested.
- Time resolved emittance.

Transverse Deflecting Cavity

It will convert the beam's longitudinal distribution to transverse distribution which is measurable

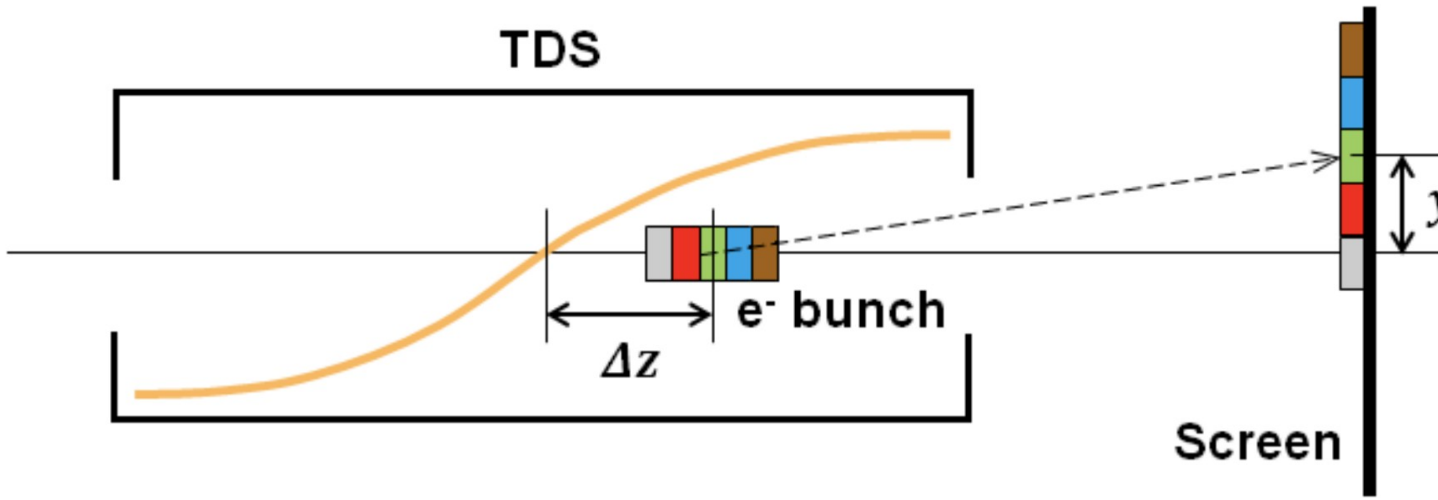


Table 1 key beam parameters of CEC 1.5nC operation

parameter	*Symbol*	Value	*Unit*
Beam size at yag without Deflecting cavity		~0.4	*mm*
Beta function at screen		0.1	*m*
Normalized rms emittance		~1.5	*mm-mrad*
Beam energy at deflector		14.5	*MeV*
Beam energy at screen		14.5	*MeV*
bunch length (edge to edge)		~30	*ps*

Table 2 Main parameters of 1.3GGHz TDS

parameter	*Symbol*	Value	*Unit*
RF deflector frequency	ω_{rf}	1.3	*GHz*
RF deflector shunt impedance	R_T	~3.5	MΩ
RF deflector unloaded quality factor	Q	9450- 10050	
RF deflector power	P_0	~10	*KW*
RF deflector maximum accelerating voltage	V_0	~ <0.26	*MV*

* resolution of <1ps (accurate to 1THz)
* measure the beam's longitudinal phase space info

Conversion of image coordinate to time

If bunch length is much smaller than the RF wavelength:

$$d\theta = \frac{dy}{L} = \cos(\phi)\frac{V}{p}(\sin(\omega\, dt))$$

Where:

dy is displacement on the YAG screen,

L is deflecting base,

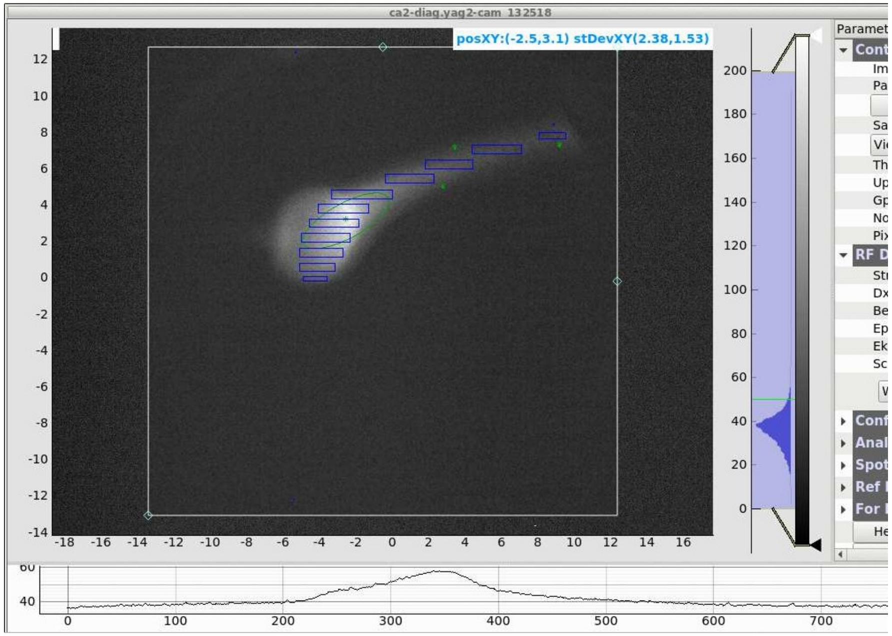
V is the total transfer voltage of the cavity,

$\boldsymbol{\omega}$ is angularfrequency,

p is momentum (eV/c),

$\boldsymbol{\phi}$ is the RF phase of the cavity, for analysis it is assumed that $\phi = 0$.

Temporal Profile of the Electron Bunch



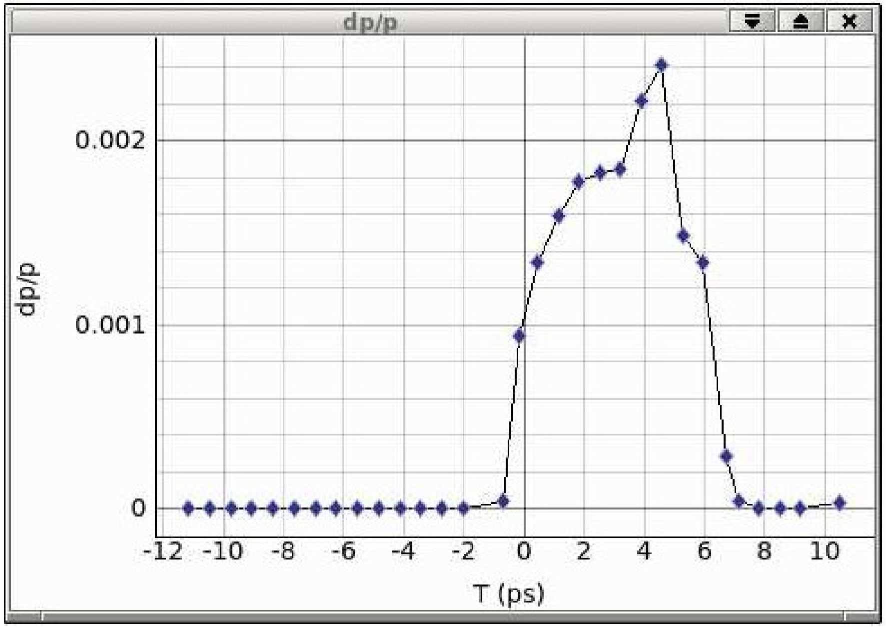
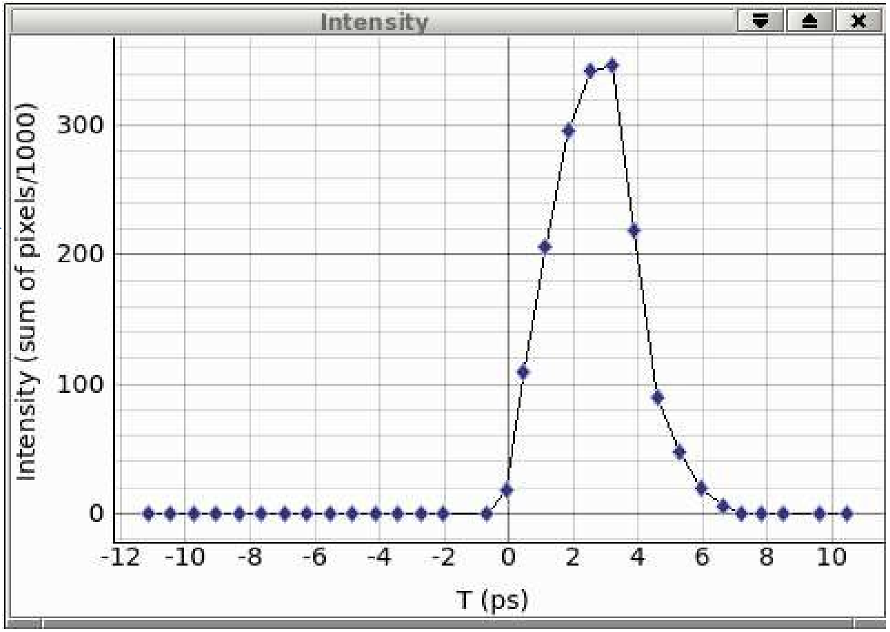
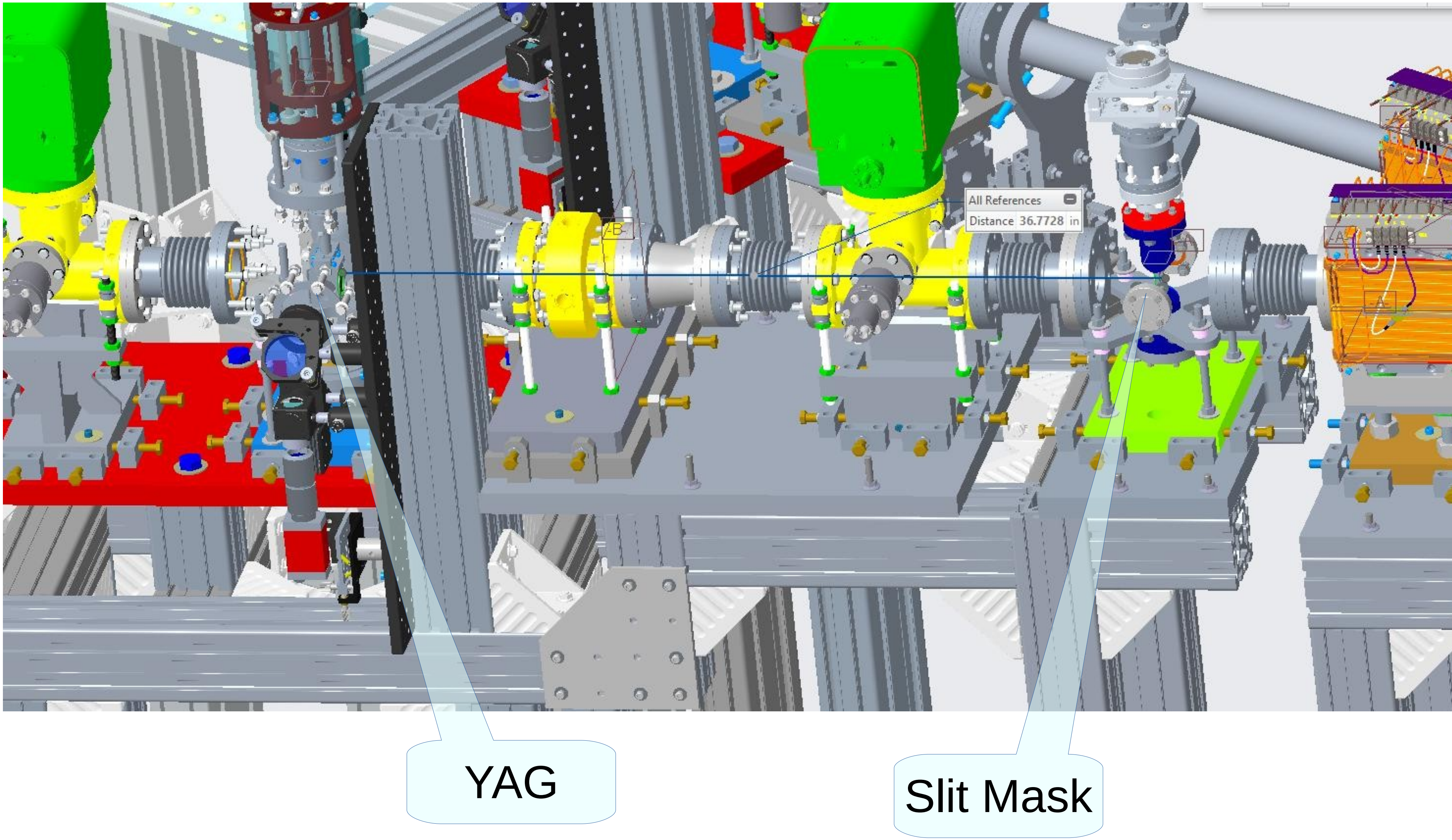


Image at CEC YAG screen downstream of deflecting cavity.

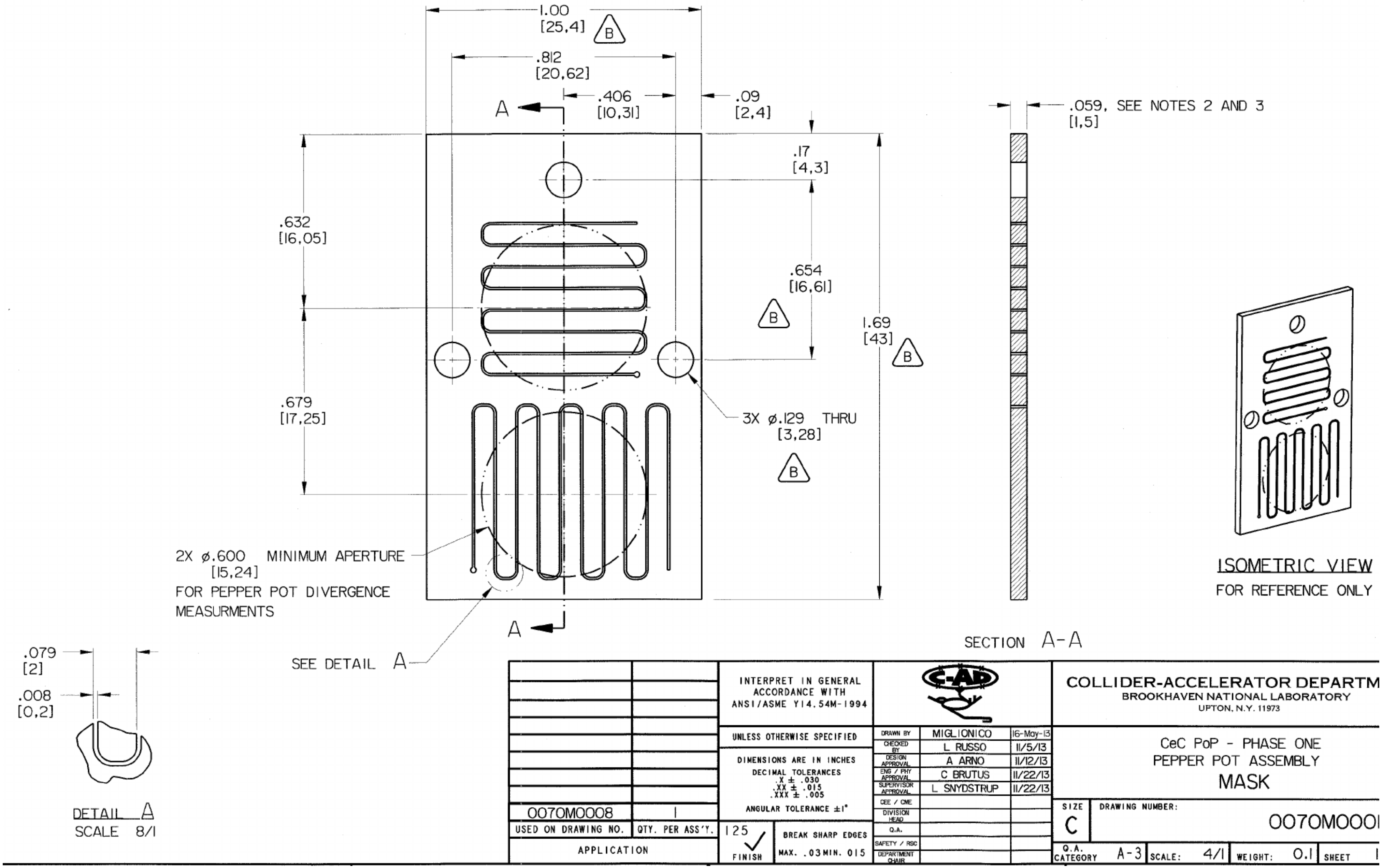
TODO:
Normalize by bunch charge to show bunch current vs time



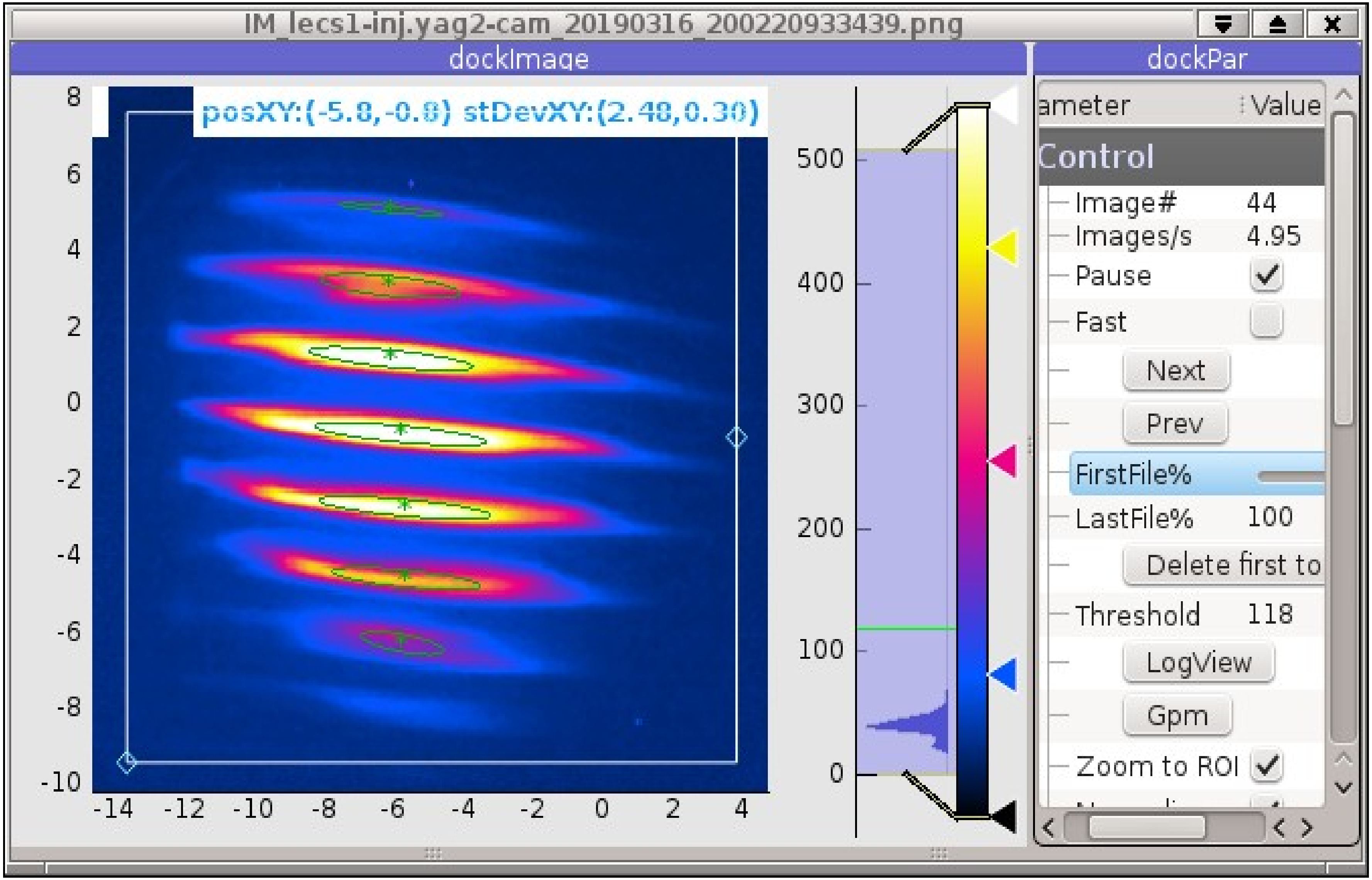
Multi-slit Emittance Measurement



Multi-slit Mask



Multi-slit Emittance Application



YAG screen image downstream of the multi-slit mask at LEReC.

Emittance Calculation for Multi-slit

Input parameters:

i – beamlet index

$\boldsymbol{m_i}$ – slit position on the mask

t – slit width

L – drift length

$\mathbf{w}_i$ – beamlet intensity

$\mathbf{x_i}$ – x-coordinate of the beamlet centroid

$\boldsymbol{\sigma_i}$ – standard deviation of the beamlet, projected along its long axis

$s_i=\sqrt{\sigma_i^2-t^2/12}$ Reduced σ_i due to finite slit width

$$N=\sum w_i$$

$$\overline{m}=\frac{1}{N}\sum w_i m_i$$

$$x'_i=\frac{1}{L}(x_i-m_i)$$

$$\overline{x'}=\frac{1}{N}\sum w_i x'_i$$

$$s^2(m)=\frac{1}{N}\sum w_i(m_i-\overline{m})^2$$

$$s^2(x')=\frac{1}{N}\sum w_i\left(\frac{s_i^2}{L^2}+(x'_i-\overline{x'_i})^2\right) \quad (1)$$

$$\overline{x\,x'}=\frac{1}{N}\sum w_i m_i x'_i-\overline{m}\,\overline{x'} \quad (2)$$

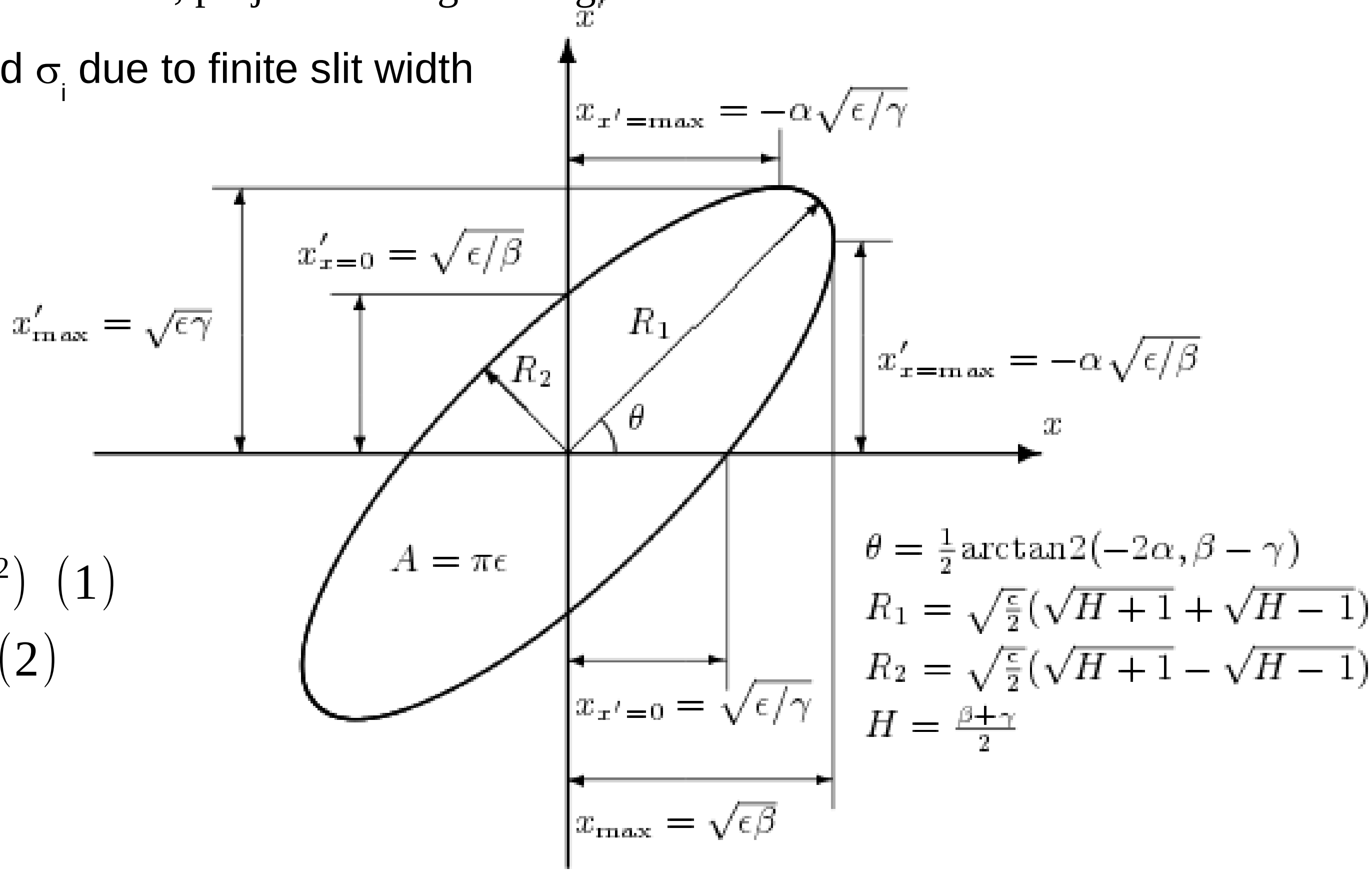
Calculated Twiss parameters

$$\epsilon=\sqrt{\left(s^2(m)\,s^2(x')-(\overline{x\,x'})^2\right)} \quad (3)$$

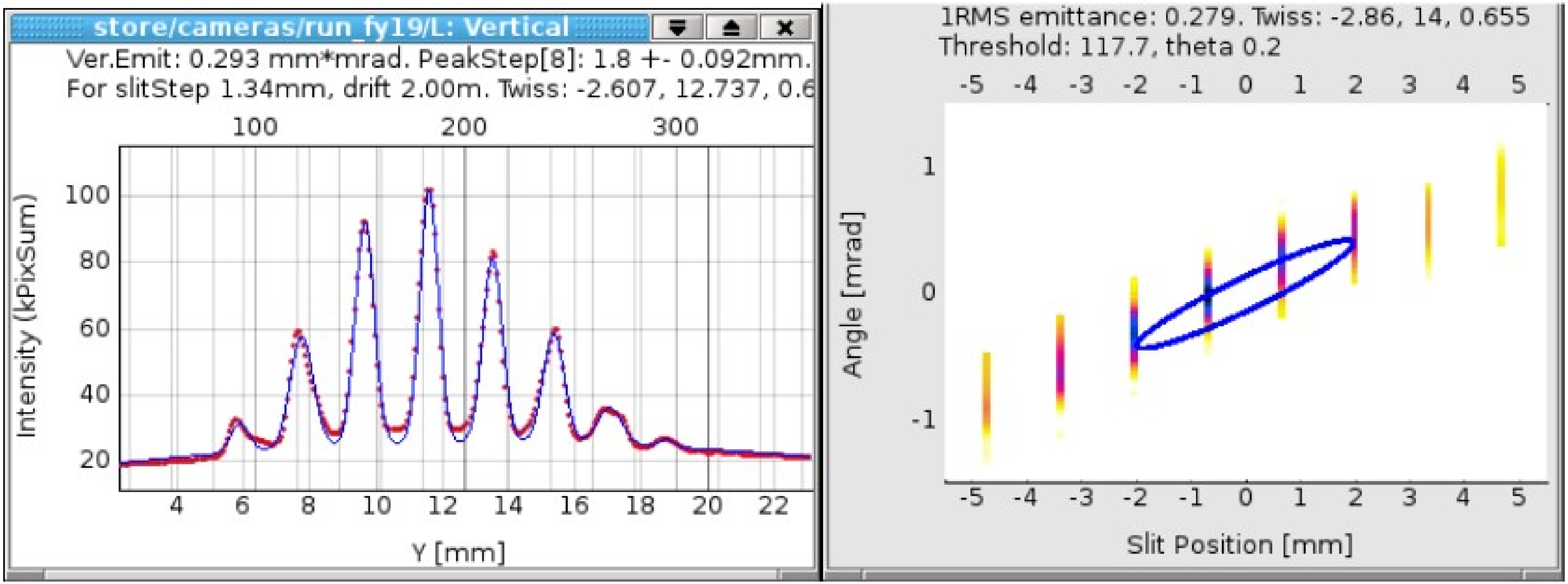
$$\alpha=\frac{-\overline{x\,x'}}{\epsilon} \quad (4)$$

$$\beta=\frac{s^2(m)}{\epsilon} \quad (5)$$

$$\gamma=\frac{s^2(x')}{\epsilon} \quad (6)$$



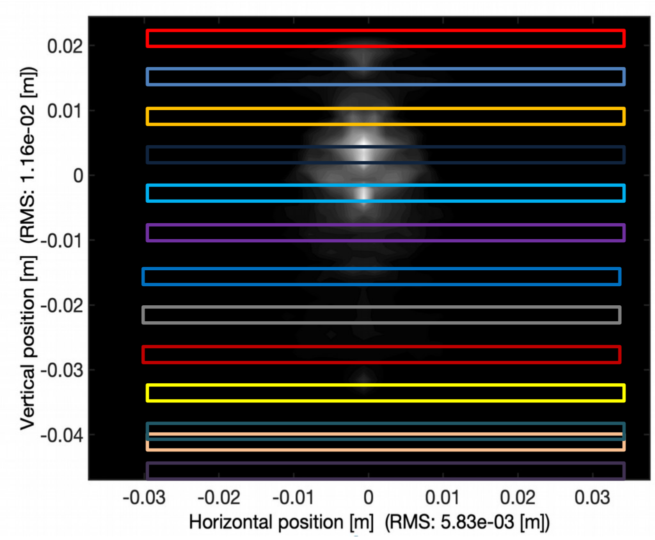
Phase space



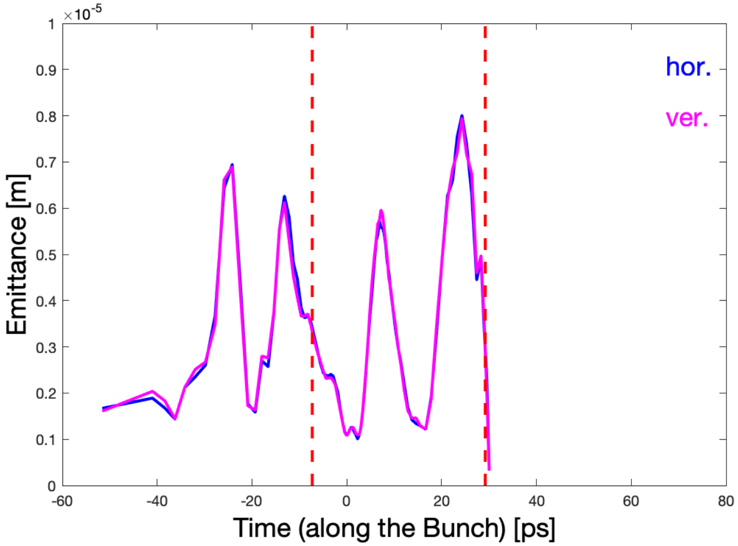
Multi-slit emittance measurement at LEReC, drift length = 2.0m
At CEC the mask is the same, drift length = 0.93m.

Time-resolved emittance measurement

- With TDC, Slice's emittance can be measured using standard quad scan method.



Through standard Quad scan method



Emittance measurements using thick lenses and multiple quadrupoles
(by Yuan Wu)

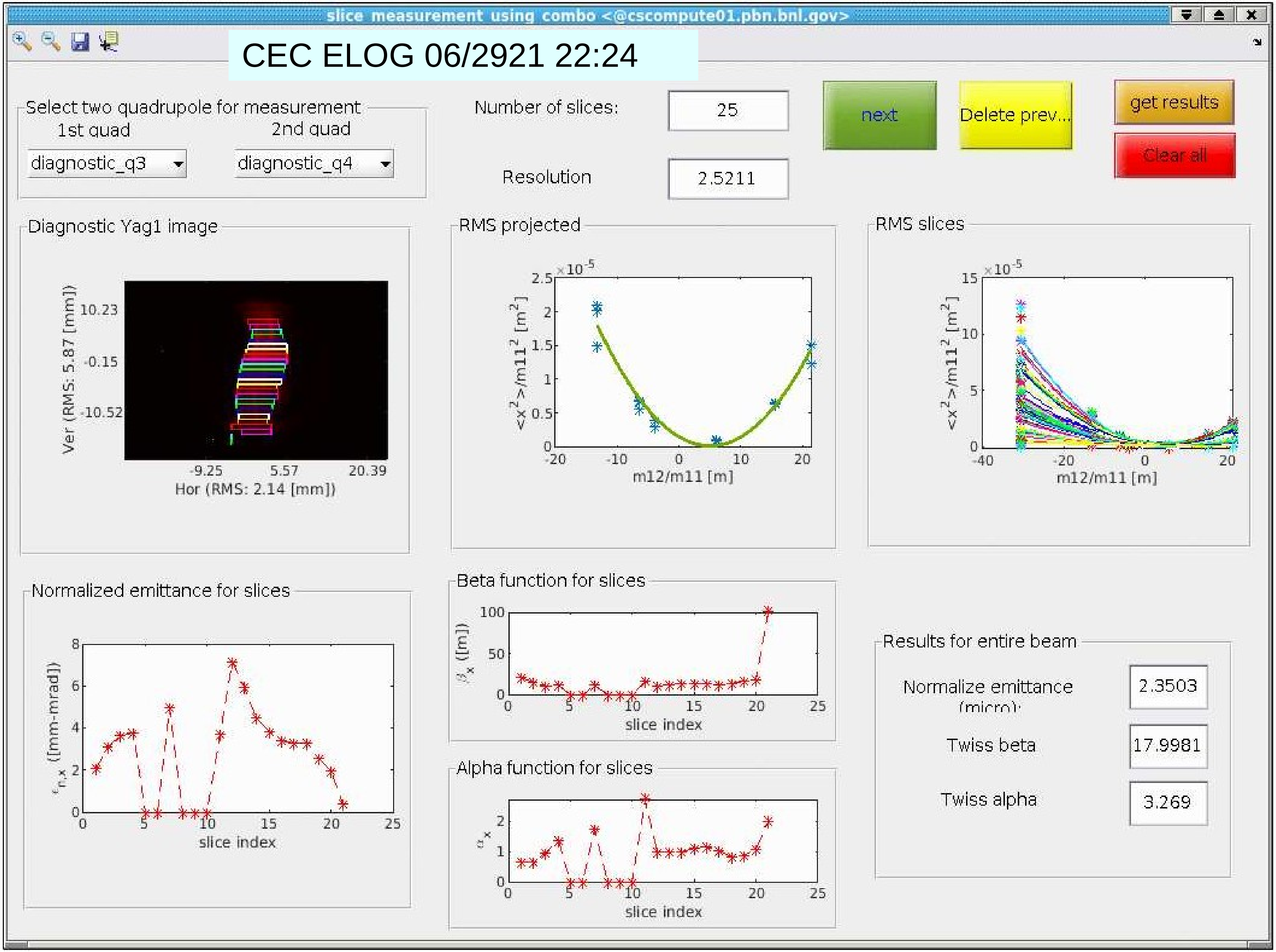
Matrix coefficients m_{11} and m_{12} have to be calculated using matrices for thick lenses and real beamline geometry. Depending of what matrix elements are not becoming zero, use of the formulae to fit parabola and calculate the beam parameters at s_o:

$$u = \frac{m_{12}}{m_{11}}; \frac{\langle x_i^2 \rangle}{m_{11}^2} = \varepsilon\left(\beta - 2u\alpha + u^2 \frac{1+\alpha^2}{\beta}\right) = A + 2Bu + Cu^2;$$

$$A = \varepsilon\beta; B = -\alpha\varepsilon; C = \varepsilon\frac{1+\alpha^2}{\beta}; \frac{\alpha}{\beta} = -\frac{B}{A}; \frac{A}{C} = \beta^{-2} + \left(\frac{\alpha}{\beta}\right)^2 = \beta^{-2} + \left(\frac{B}{A}\right)^2;$$

$$\beta^{-2} = \frac{A}{C} - \left(\frac{B}{A}\right)^2 \rightarrow \beta = \frac{1}{\sqrt{\frac{A}{C} - \left(\frac{B}{A}\right)^2}}; \ \varepsilon = \frac{A}{\beta}; \alpha = -\beta\frac{B}{A};$$

TODO: Develop Python app from Matlab:



Summary, Plan

- Update the application for energy spread.
- Adopt the multi-slit application for CeC.
- Develop app for zero-crossing RF phase.
- Develop app for time-resolved emittance measurement, based on Matlab code from Yuan. In first release use thin-lense approach.