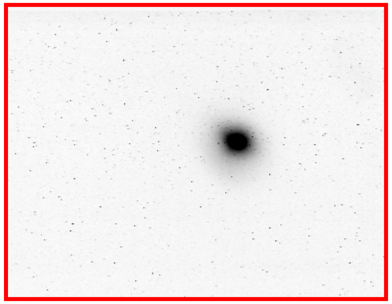
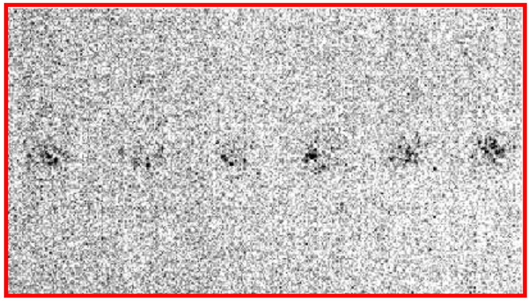
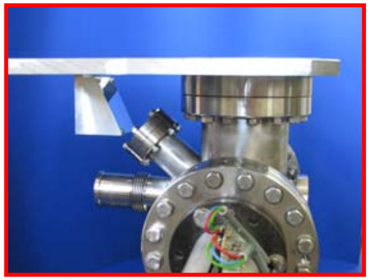
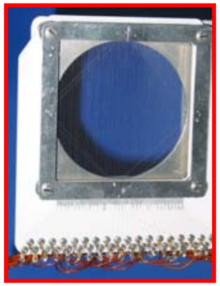
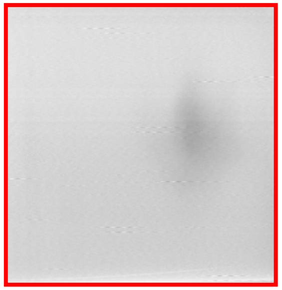
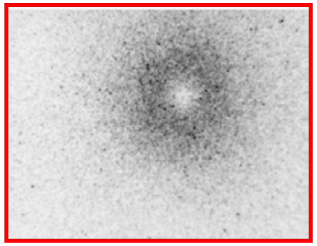
Beam profile monitors

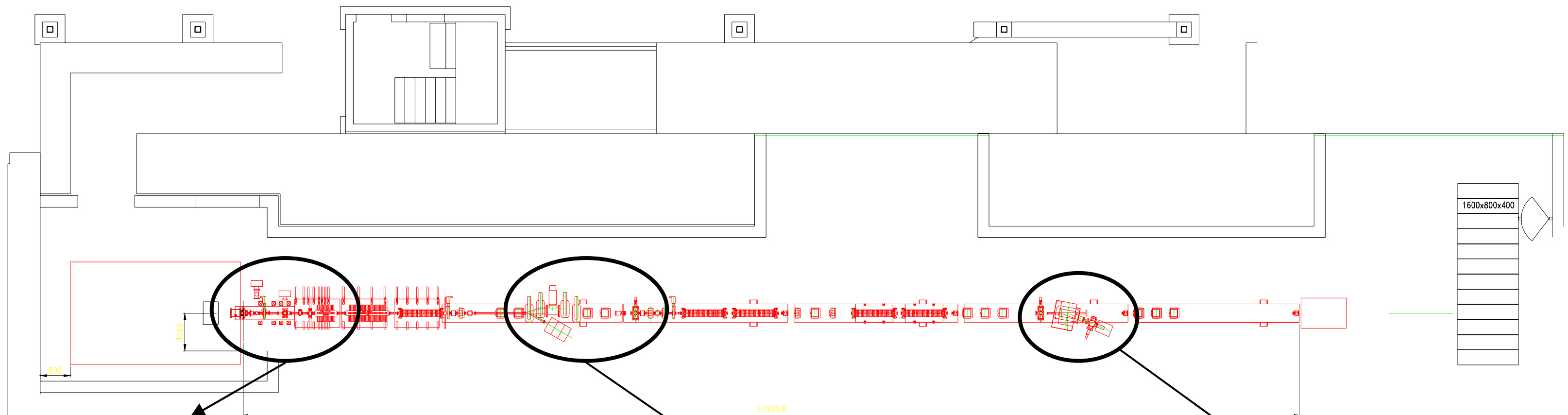


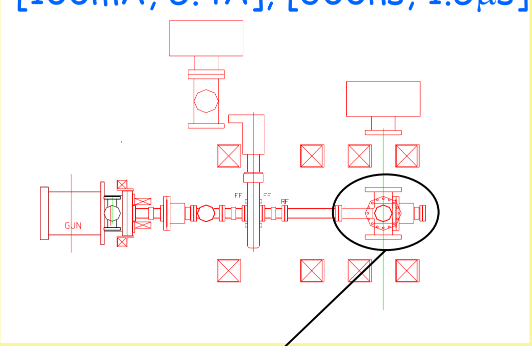
- Design of thermal resistant profile monitor
- Performances of already tested equipments
- Perspectives for the next run

CTF3 beam & diagnostic requirements



Injector

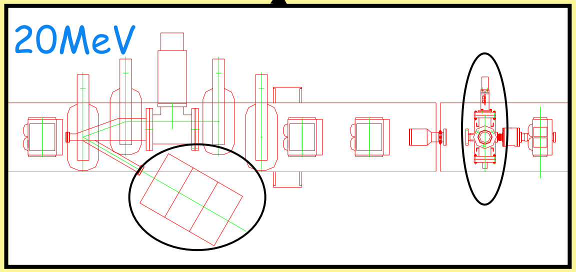
•[100mA, 5.4A], [300ns, 1.5μs]

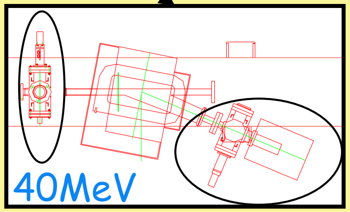


Screen + camera

- •140keV
- •[30nC , 8μC]
- •Beam Size : 1-10mm

Linac & Spectrometer lines





•[65mA, 3.5A], [300ns, 1.5μs] ⟶ [20nC, 6μC]

Spectrometer

- •Screen + camera
- •SEM grid
- •Beam Size : 3-20mm

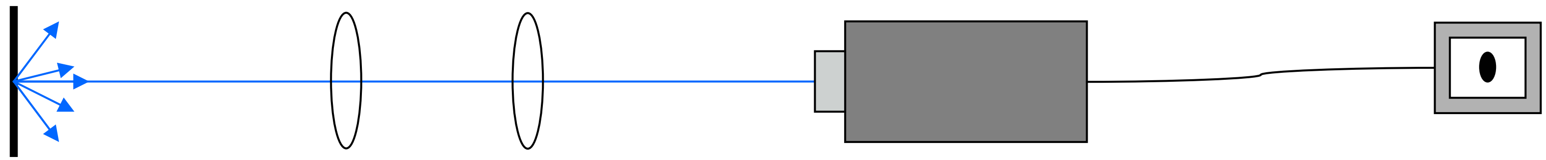
Linac

Screen + camera

•Beam Size : 0.25-4mm

Beam profile monitors

Screen and Camera



Screen

- Spatial resolution
- Temporal resolution
- Emission spectrum
- N^0 ph/el

Optical system

- Transmission
- Magnification
- Field depth
- Aberration

Camera

- Sensitivity
- Photo thode size:
  12 mm
- Spec tivity:
  [400
- Vide
  360

Frame grabber

- 1024 x 1024 (h x v)

- New radiation hard camera : First prototype built for CTF3
- Camera sensitivity in july : >10^9 photons (10^2 less efficient than a CCD)
- Camera sensitivity now : x 10 (increasing the voltage on the vidicon tube)

Thermal analysis : Material study

$$\frac{\Delta T(r,t)}{\Delta t} = \frac{1}{c_p \rho}\left[\frac{dE}{dx}\rho e^{-\frac{r^2}{2\sigma^2}} N(t) - k\nabla^2 T(r,t) - \frac{2\varepsilon\sigma_s}{\delta}\left(T(r,t)^4 - T_0^4\right)\right]$$

Target :
- ε : Emissivity
- δ : Thickness
- c_p : Specific heat
- ρ : Density
- k : Thermal conductivity

Electron beam :
- σ : beam size
- $N(t)$: beam current

Heating term

- Use of thin foils to avoid the reabsorption of the X-rays in order to minimize the energy deposition dE/dx
- The 'collision' stopping power changes by less than a *factor 2 among Be, C, Al, Si, Ti, Mo, W*

Cooling terms

- Heat exchange is negligible within the pulse duration
- Heat exchange due to black body radiation is small (mW)

Material	c_p *J/gK*	k *W/mK*	T_{max} *°C*
Be	**1.825**	**190**	**1287**
C	**0.7**	**140**	**3527**
Al	0.9	235	660
Si	**0.7**	**150**	**1414**
Ti	0.523	22	1668
Mo	0.25	139	2623
W	0.13	170	3422

Need thin foil of a material with a
- High fusion temperature
- High specific heat c_p
- *High thermal conductivity*

(for graphite ΔT=12% after 1ms)

Good candidates : *Be (poison)*, **Graphite**

Thermal analysis : Material study

Calculations for the injector profile monitor

I = 5.4A , E = 140keV , σ = 1mm				
t_p (μs)	T (°C) @ 10Hz C	Al	T (°C) @ 50Hz C	Al
0.2	103	83	164	132
0.8	272	194	558	421
1.56	440	434	1003	*x*

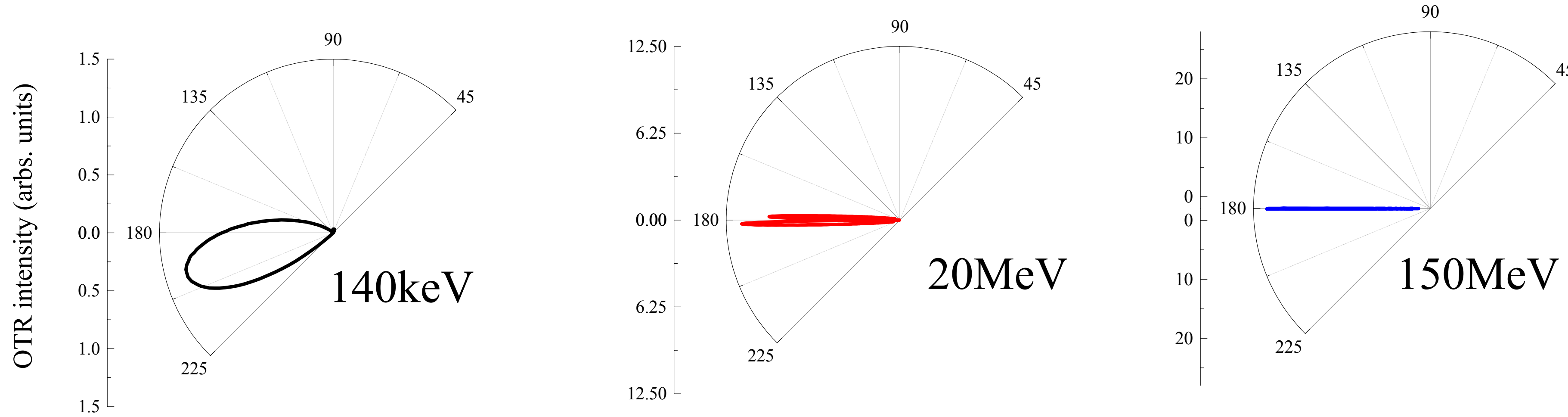
Calculations for the linac profile monitors

I = 3.5A , E = 150MeV , t_p =1.56μs				
σ (mm)	T (°C) @ 10Hz C	Al	T (°C) @ 50Hz C	Al
0.25	1730	*x*	2250	*x*
0.5	-	*x*	-	*x*
0.6	-	510	-	*650*

- **Carbon screens will stand the full beam intensity for the maximum repetition rate at every energy**
- Other material like aluminum can only be used for a reduced bunch charge and a lower repetition rate

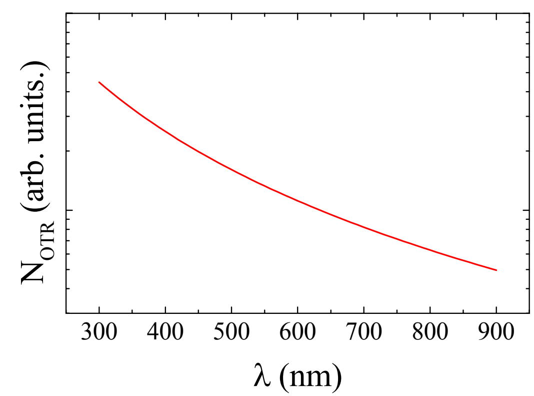
Electron-photon conversion process

Optical Transition radiation



- The number of OTR photons emitted by an electron in the wavelength range $[\lambda_a, \lambda_b]$

$$N_{OTR} = \frac{2\alpha}{\pi}\left[\left(\beta + \frac{1}{\beta}\right)\cdot \ln\left(\frac{1+\beta}{1-\beta}\right) - 2\right]\ln\left(\frac{\lambda_b}{\lambda_a}\right)$$

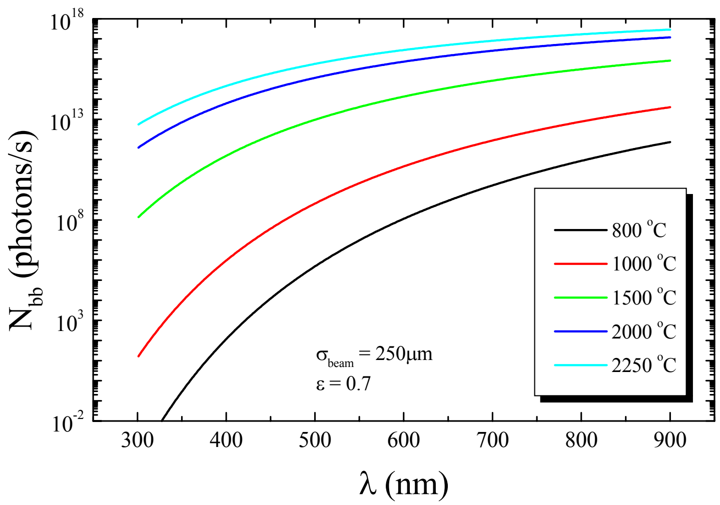


Electrons energy (MeV)	0.14	20	40	150
[400,600]nm OTR photons per electron	$7.2\ 10^{-4}$	$7.3\ 10^{-3}$	$8.6\ 10^{-3}$	$1.1\ 10^{-2}$
[400,600]nm OTR photons on the camera	$4\ 10^{8}$	$6\ 10^{10}$	$7\ 10^{10}$	$9\ 10^{10}$

OTR versus Black Body radiation

• The number of Black body photons emitted per second in the wavelength range [λ_a,λ_b] and in 2π sr is given by:

$$N_{BB} = \int_{\lambda_a}^{\lambda_b} \frac{2\pi c}{\lambda^4} \frac{2\pi\sigma^2\varepsilon}{e^{\frac{hc}{kT\lambda}} - 1} d\lambda$$



• Black Body spectrum depends on the temperature. In our temperature range it is more intense in the red

• N_{BB} increases with the temperature

Electrons energy (MeV) / Beam size (mm)	0.14 / 1	20 / 0.25
Temperature (°C) : 50 Hz / 10 Hz	1003 / 440	2250 / 1730
Number of BB photons on the camera	2 10^5 / 4 10^{-9}	4.5 10^9/ 5.4 10^8

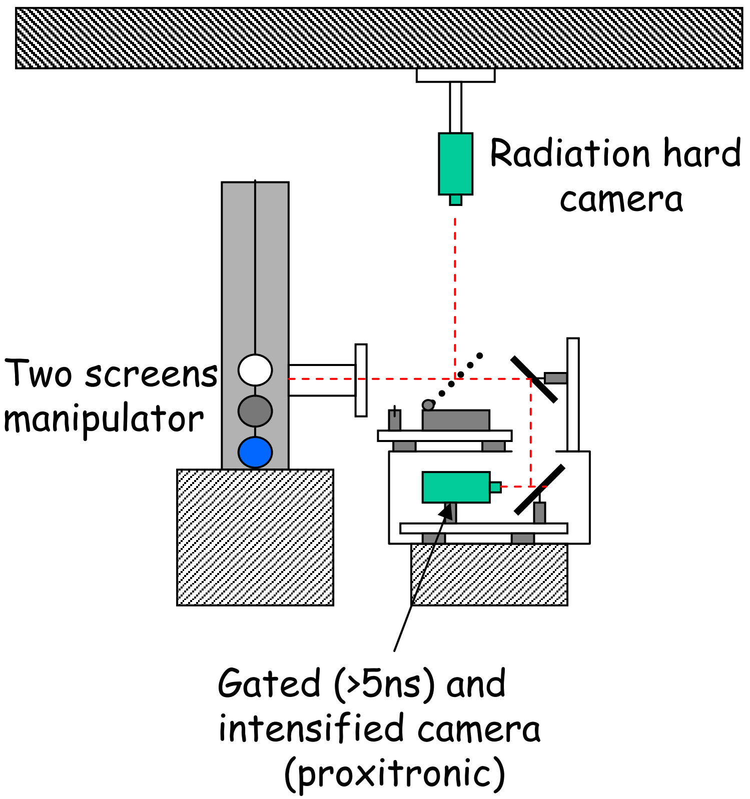
• The target temperature has decreased by 15% in 10ms so that N_{BB} in the visible range has dropped by at least a factor 10

• Calculated in the range [400, 600]nm assuming a detection angle of 1.26msr and considering that BB emission lasts 10ms

• BB emission is only problematic at full beam charge and maximum repetition rate
• Can be suppressed using optical filter
• Need to be considered in the case of beam halo measurement

Injector profile monitor

Layout of the system



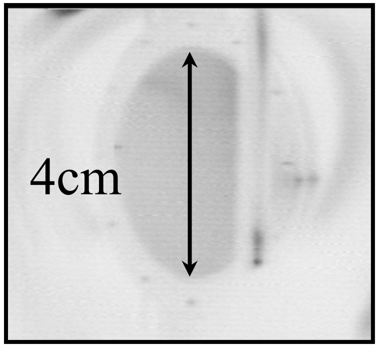
- P47 Phosphor (Y2SiO5:Ce) deposit on a 10µm thick aluminum foil
  - 5µm thick with 1µm grain size
  - Spectral response : [370, 480nm], Max at 450nm
  - Decay time : 100ns (90-10%) , 2.9µs (10-1%)
  - 400 ph/el in 2π and 0.1 ph/el on the camera

- Lot of light : 6.10^{10} ph for 30nC
- High risk of damage

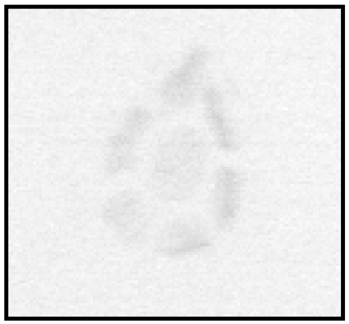
- Thin carbon foil (OTR)
  - 5µm thick
  - Spectral response : visible region [400-600nm]
  - Temporal response : few fs
  - $7\ 10^{-4}$ ph/el (total), $3\ 10^{-6}$ ph/el (camera), $7\ 10^{-7}$(proxitronic)

- Few photons : $1.5\ 10^{8}$ ph for 8µC
- Need light intensification but fast time response

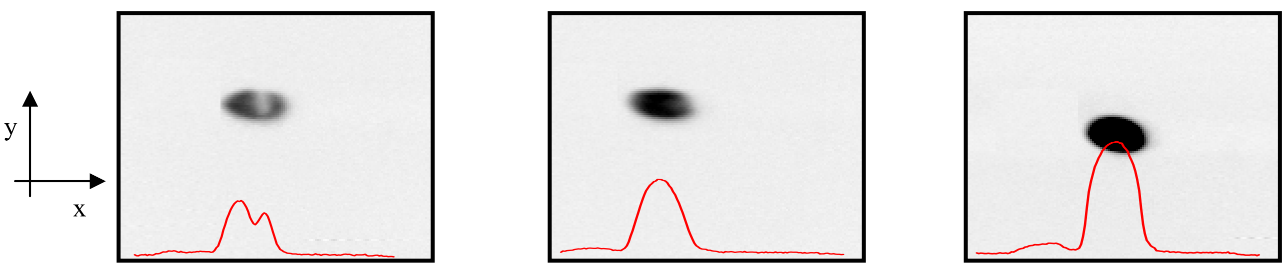
Injector profile monitor



- Calibration : 200μm/pixel – 5.5cm total



P47 is sensitive enough to observe dark current from the grid (10-100μA)



σ_x = 1.6mm

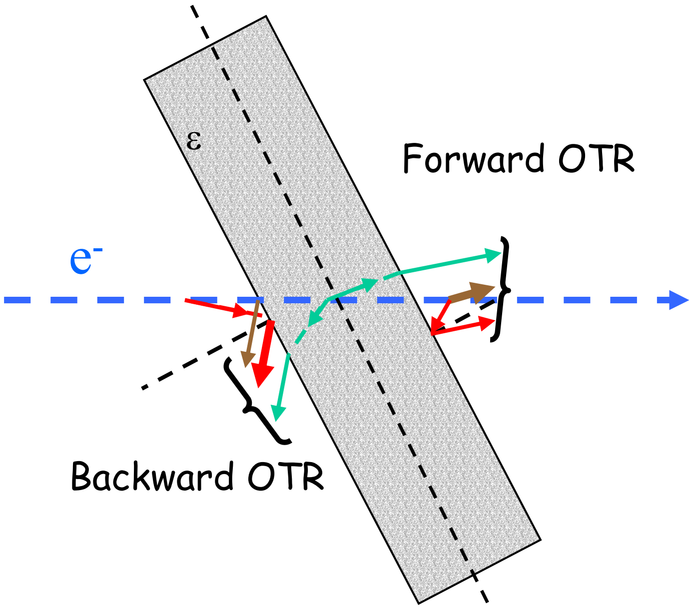
σ_y = 1mm

Emitted light intensity is reduced by 77% after a total charge lower than 1C/cm^2 (*20days, 15minutes per day, 5Hz and 100nC*)

(Expected value 5C/cm^2 for a 50% light intensity reduction)

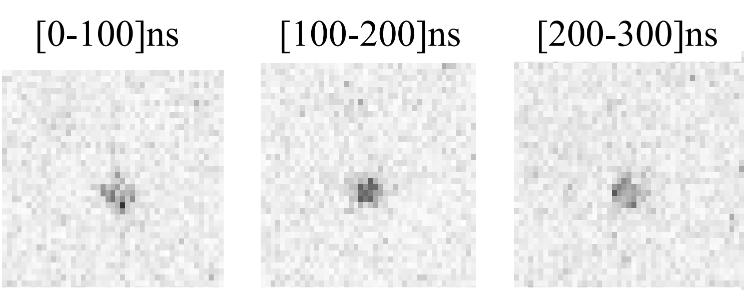
Injector profile monitor

Observation of forward OTR from a graphite foil



- Backward OTR depends on the material reflectivity
- Provided the screen is very thin, the beam quality and beam size are not perturbed and the OTR light emitted in the forward direction is 5 times higher than the backward emission

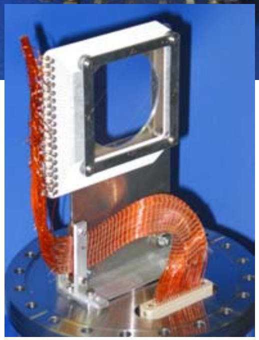
Temporal evolution of the beam profile within the pulse duration



- 1 A beam current : 100nC - 4 10^5 photons over 100ns
- Images taken using a factor 500 light amplification (compared to a CCD camera)

Possible improvements using a better light collection system

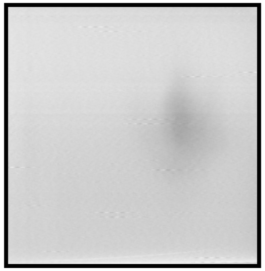
Spectrometer line profile monitor



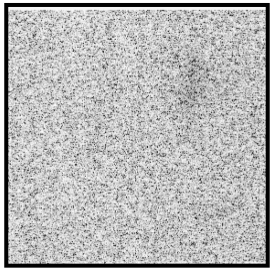
- Calibration : 200μm/pixel
  5.5mm total
- OTR screen :
  - 100μm thick aluminum foil
  - Size : 10cm x 4cm
  - 2.8 10^{-3} ph/el (on camera)

→ '4.1 10^{8}- 7.2 10^{10} ph'

Observation for a beam with a minimum charge of 90nC (~ 1.2 10^{9} photons)



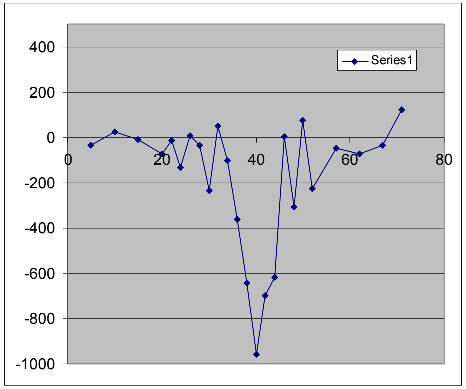
Radiation hard camera



CCD camera

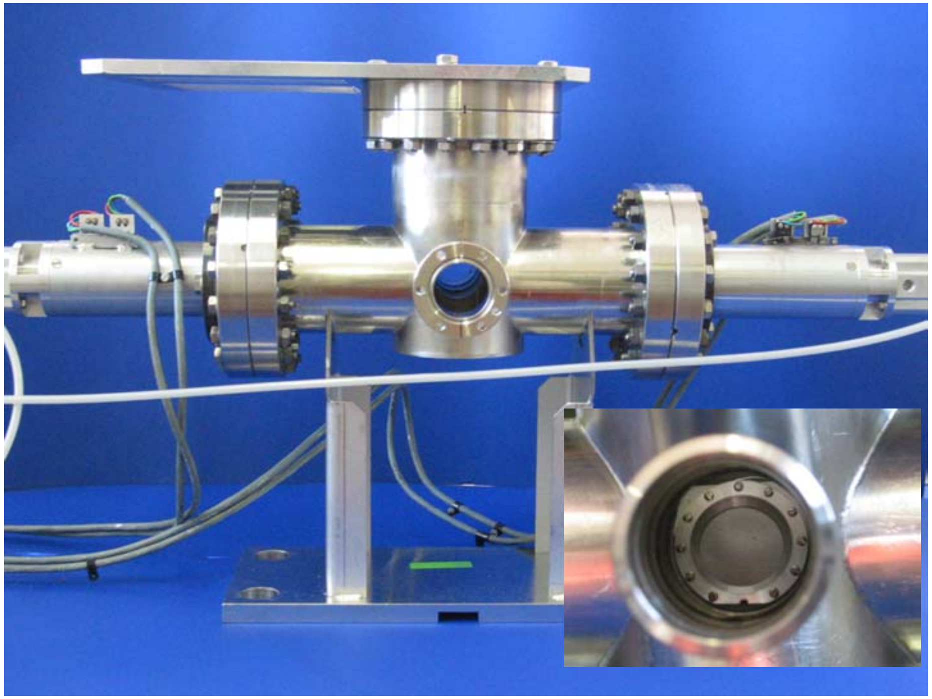
Minimum energy dispersion ~ 0.9% (σ = 3.6mm)

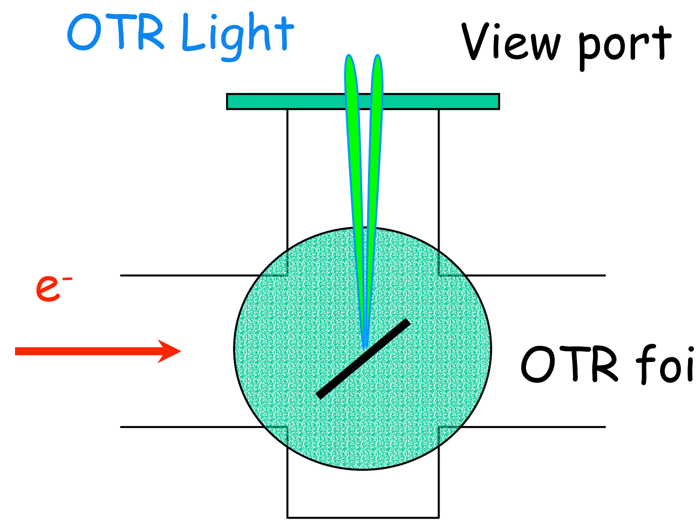
SEMgrid profiles
~ 1 A – 320 ns – 25.5 MeV



Problems for higher beam charge that need to be understood

Linac profile monitor





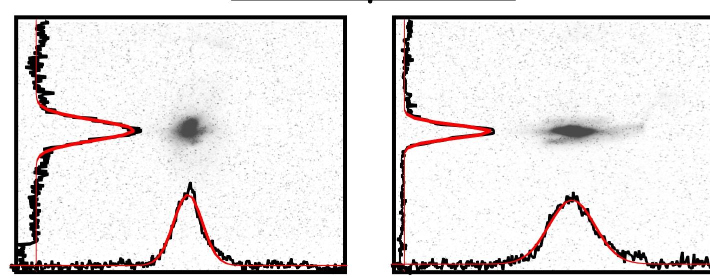
- Calibration : 150μm/pixel – 40mm total

- OTR screen :
  - 100μm thick carbon foil (26% reflectivity)
  - Size : Ø3cm
  - 0.9 10^{-3} ph/el (on camera) for 20MeV electrons

' 1.1 10^{8}-3 10^{10} photons '

Possible improvements using an aluminum screen for the observation of lower beam charge

Beam profile

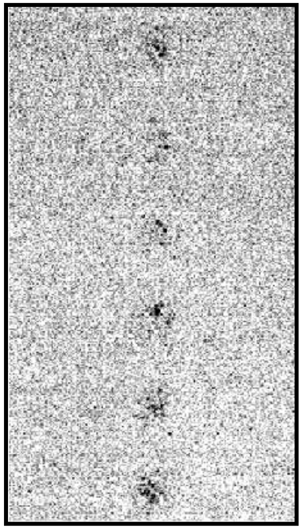


σ_x = 4.7 mm
σ_y = 3.3 mm

σ_x = 7.6mm
σ_y = 2.1 mm

Bunch length measurement using the streak camera

OTR carbon screen – 3.5 A 20 MeV
Streak camera image – slow sweep speed



3.5 10^5 photons per bunch

- Not enough light per bunch to allow a good bunch length measurement (*Need 5 10^6 photons per bunch*)

- Graphite screen : 26% less reflectivity than 'perfect' (mirror like) OTR screen

- Low light transmission (30%) between the screen and the camera :
  - 35m long optical line
  - at 20MeV OTR emission angle is still large (50mrad)

- Better light collection for higher beam energy (gain a factor 2 between 20 and 40MeV)
- Aluminum screen for the observation of reduced pulse length (at least gain x4 in light intensity)

- *Alternative solution : Move closer the streak camera lab*

Conclusions & Perspectives

- All the beam profile monitors have been tested during the commissioning
    - Based on the obtained results, an optimization remains to be done. (modification of the radiation hard camera sensitivity)
    - OTR for non relativistic electrons is potentially very interesting and need to be studied carefully.
- For more critical points (like the SEMgrids) a rigorous experimental study is needed to understand and solve the observed problems.

- Things will be easier for higher energy electrons (up to 150MeV)
- Test of beam halo and OTR lobe monitoring on its way