TRANSITION RADIATION BASED DIAGNOSTICS FOR NON-RELATIVISTIC ION BEAMS

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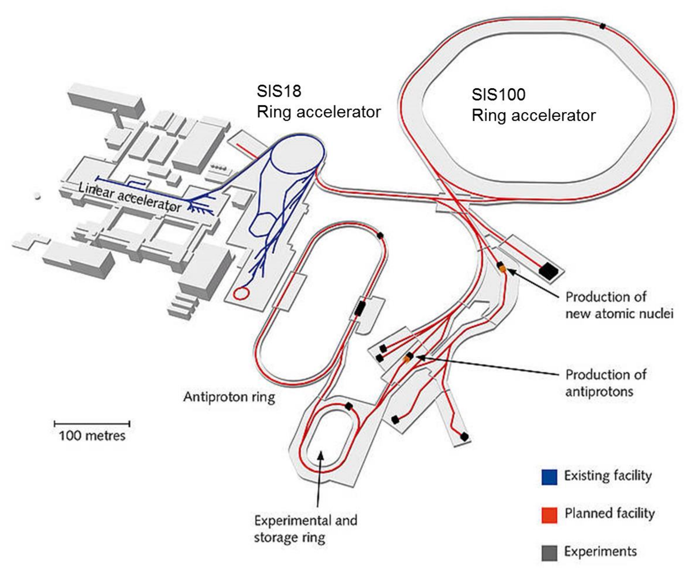
Abstract

The usage of optical transition radiation for profile monitoring of non-relativistic electron beams is well known. In this contribution, we study the application of transition radiation in optical (OTR) and GHz regime (GTR) for non-relativistic ion beams. The light emitted from a metal target after ion beam irradiation consists of polarized transition radiation as well as significant amount of unpolarized photons depending on the angle of incidence. The dependence of light yield on beam current and comparison of measured transverse profiles with alternative device is shown. Simulations and pilot measurements demonstrating the potential usage of coherent transition radiation in GHz regime for bunch-by-bunch longitudinal profile measurements is also discussed.

Introduction

- GSI will host three LINACs (UNILAC, pLINAC and cw-LINAC) with a maximum beam velocity (beta < 0.3) with a relatively high intensity and a variety of charge states
- Typical transverse diagnostics at these energies are based on secondary electron emission monitor (SEM) grids or inorganic scintillators
- The typical longitudinal bunch shape diagnostics like faraday cups, pick-ups or fast current transformers provide beam field distribution rather than beam charge distribution especially for small bunches < 1ns at LINAC velocities



We investigate the usage of transition radiation (TR) in optical regime for transverse beam profile measurements as well as TR and diffraction radiation (DR) in GHz regime for longitudinal charge profile measurements (bunch shape measurements) for the LINAC parameters at GSI

Transition radiation concepts

OTR (low β): The far field energy per unit frequency and solid angle for a charge q in vacuum incident on target plane with permittivity ε_r due to TR reads

$$\frac{d^2W^{\parallel}}{d\omega d\Omega}=\frac{q^2\beta^2}{4\pi^3\varepsilon_0 c}\left|\frac{(\varepsilon_r-1)\cos\theta\sin\theta\cos\psi}{\varepsilon_r\cos\theta+\sqrt{\varepsilon_r-\sin^2\theta}}\right|^2 \qquad \frac{d^2W^{\perp}}{d\omega d\Omega}=\frac{q^2\beta^6}{4\pi^3\varepsilon_0 c}\left|\frac{(\varepsilon_r-1)\cos\theta\sin\varphi\sin\psi\cos^2\psi}{\cos\theta+\sqrt{\varepsilon_r-\sin^2\theta}}\right|^2$$

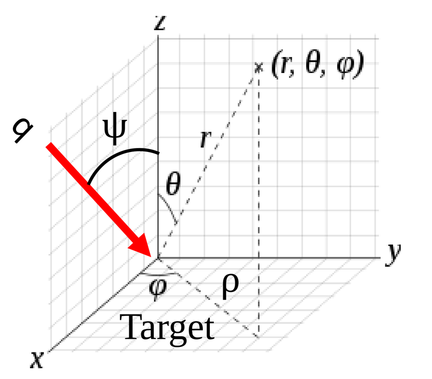
GTR: The far field electric field for a charge q in vacuum *normally* incident on a perfectly conducting target plane due to transition radiation is given by

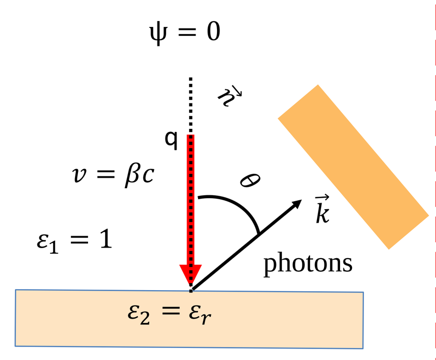
$$E_\rho=\frac{q\beta}{2\pi\varepsilon_0 cr}\frac{\cos\theta\sin\theta\ \delta\left(\frac{r}{c}-t\right)}{1-\beta^2\cos^2\theta} \qquad E_z=\frac{q\beta}{2\pi\varepsilon_0 cr}\frac{\sin^2\theta\,\delta\left(\frac{r}{c}-t\right)}{1-\beta^2\cos^2\theta}$$

Coherent TR: For a bunch of N charges with length l_b the radiated energies W due to single charges will sum up coherently $W_{sum}\sim N^2 W$ if the detected wavelength $\lambda \gg l_b$. For $\lambda \ll l_b$ the scaling is linear $W_{sum}\sim N\,W$ (incoherent TR).

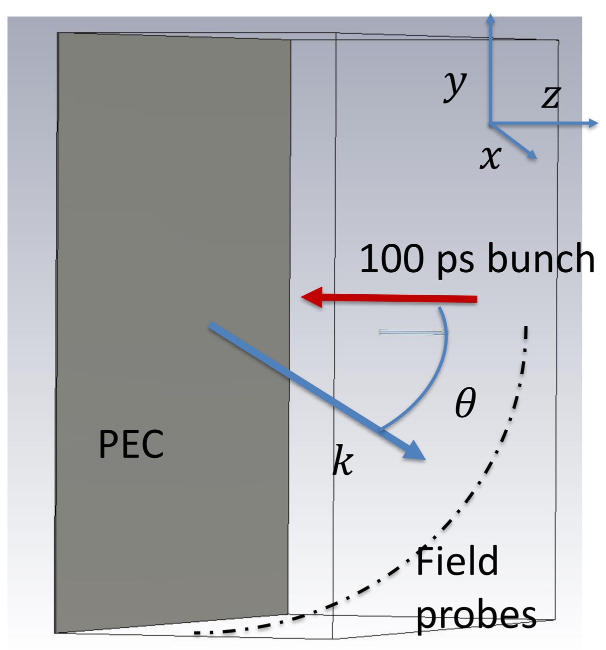
Formation zone, formula and discussion: Formation zone is the hindrance free length around the target which is required for the radiation to be formed. For the case of vacuum:

$$L_f=\frac{\beta\lambda}{1-\beta\cos\theta}$$

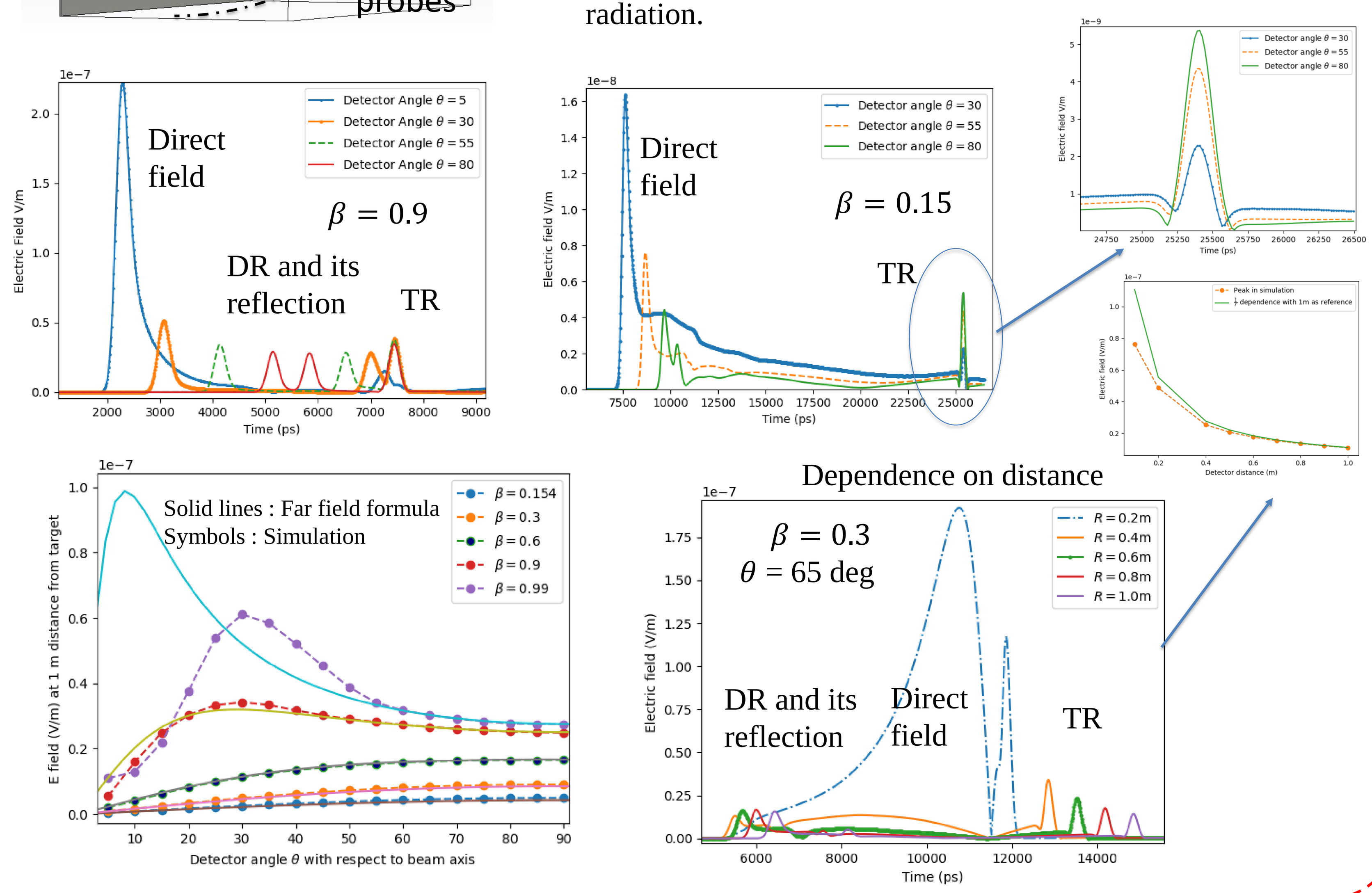




CST Simulations



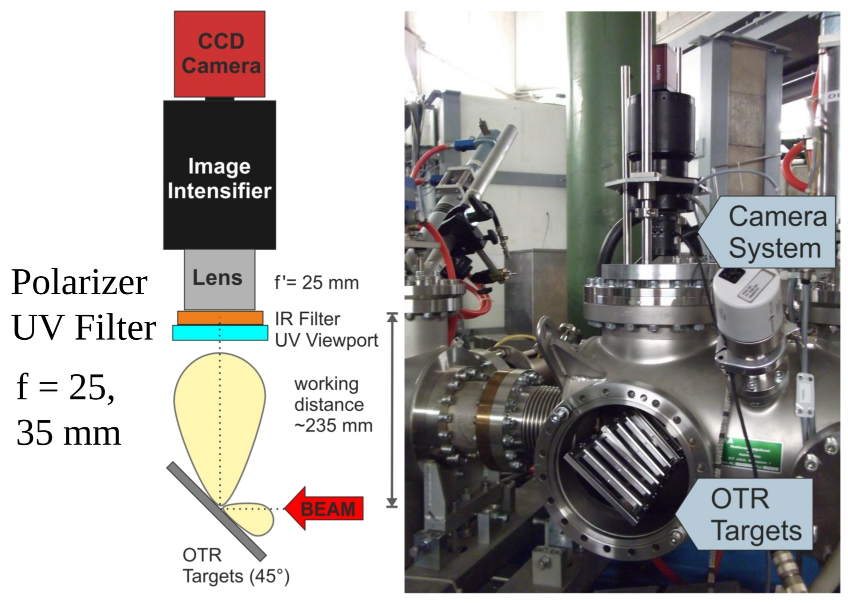
- Backward transition radiation simulations were performed using particle-in-cell solver using PML boundary conditions.
- A gaussian charge distribution corresponding to σ = 100 ps (tails cut at 4σ) has been simulated in a domain of size 2m × 1m × 1m for different velocities.
- Electric field was probed at various angles and distances and compared with the expected far field distribution
- At higher betas ($\beta > 0.6$) , there is a significant discrepancy in angular distribution at smaller angles, which we currently assign to finite target size and reflections of entry diffraction radiation.



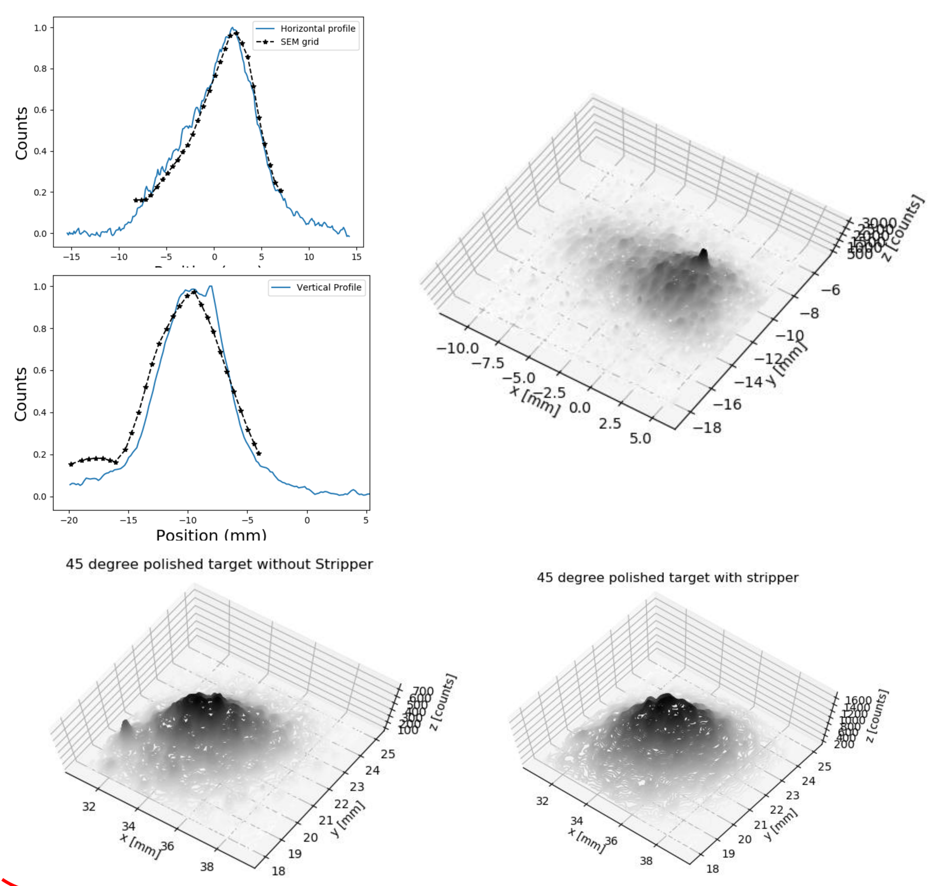
OTR set-up and measurements

Ion and charge state	Fe, 25+ and Ar 10+
Current	20- 100uA
Energy	6 to 11.4 MeV/u
MCP gate	50- 1000 us
Filter/Polarizer	Polarizer
Target type	4 thin polised, 2 thick unpolished
Target normal (Ψ)	varied

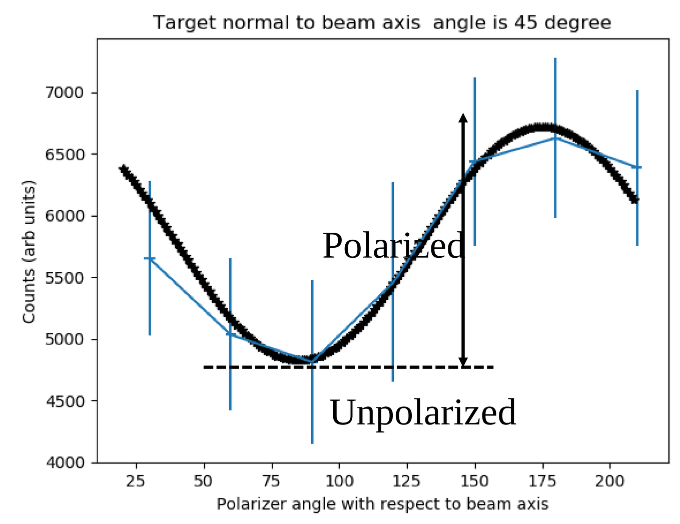
- Reproduces beam profile projections measured with SEM grid under similar beam conditions
- The photon counts increase with the beam charge state and proportional to the beam current
- Thermal heating observed at currents above 200uA with macropulses longer than 200 us



Target normal angle varied with respect to beam (Ψ=0-90˚)

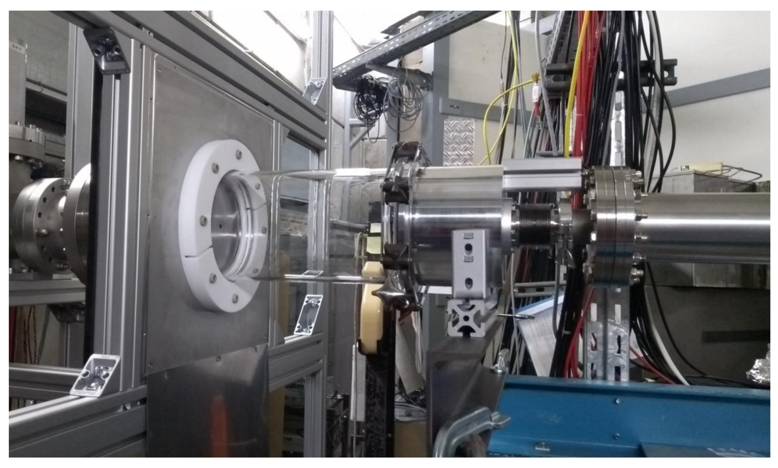


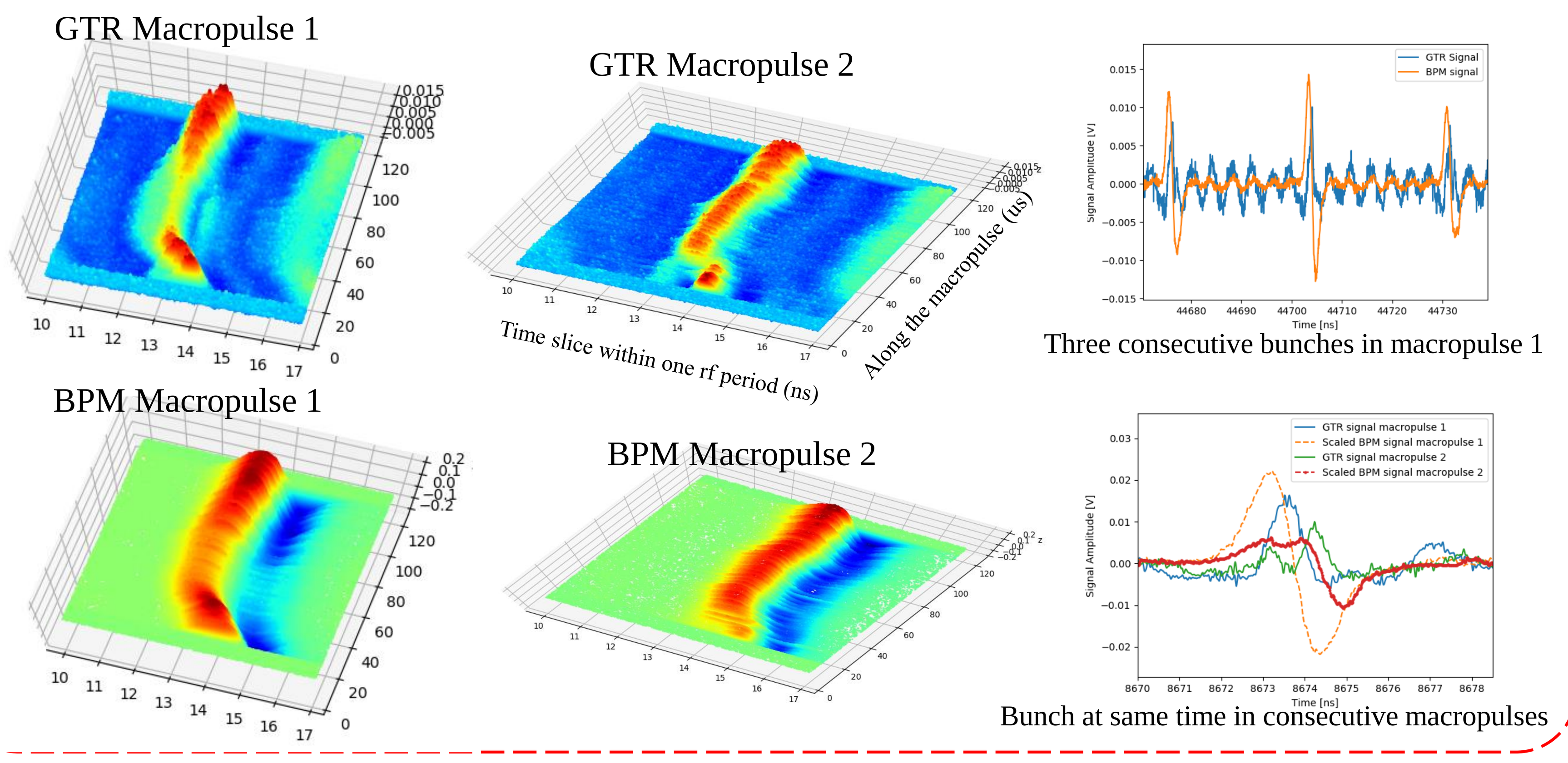
- OTR is polarized in the incidence plane as expected
- Lot of un-polarized photons also obtained when beam is incident on small (grazing) angles → spectroscopic studies needed



GTR set-up and measurements

- First pilot measurement with GHz transition radiation were performed with 11.4 Mev/u ($\beta = 0.154$) Bi^{23+} with a beam current of 200-600 uA.
- TR and BPM signal from two consecutive 100 us long macropulses were measured Biconical Antennas was placed at θ = 40° at distance 1m





Conclusions

- Optical transition radiation was used for beam profile measurements in the energy range 6 to 11.4 Mev/u for beam currents ranging from 4 uA to 1 mA. The polarization of the radiation was measured. Lots of unpolarized photons observed at grazing angles
- CST simulations were performed to understand the frequency and angular dependence for TR and DR with a focus on developing a non-destructive bunch shape diagnostics.
- Transition radiation in GHz regime was used for measured bunch-by-bunch shape measurements within a macropulse with beam current > 100 uA. This requires usage of broadband linear phase or phase calibrated Antennas. At energies above beta >0.15, diffraction radiation is also shown to work appropriately paving way for a non-destructive measurements.

References are provided in the associated paper