Optical diagnostics for self-modulated proton bunches

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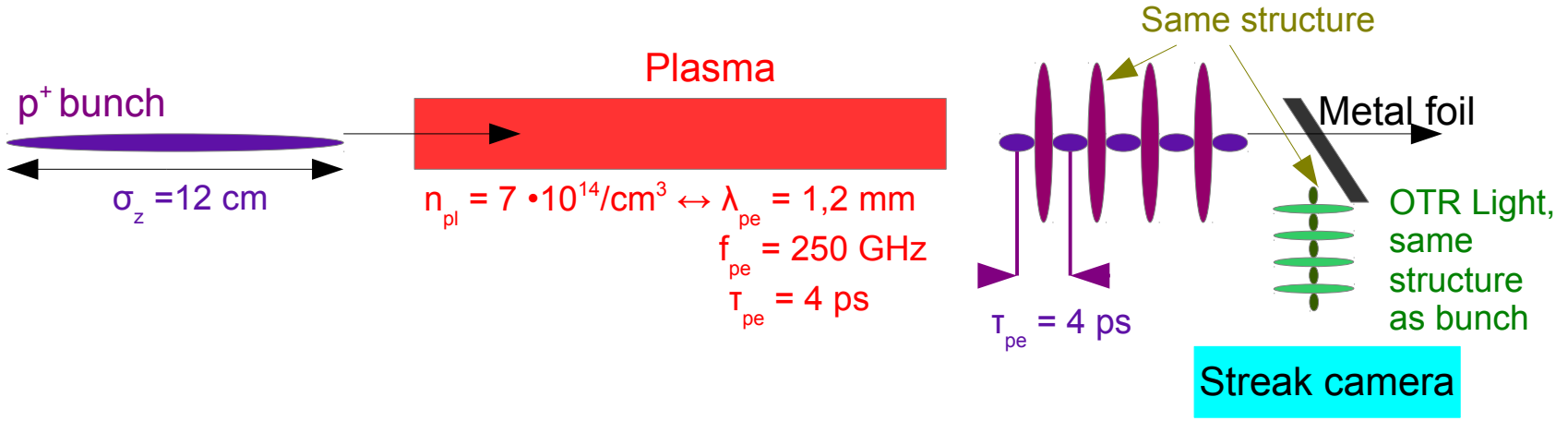
Outline

1. AWAKE Experiment as Motivation
2. Streak cameras and issues
3. Experimental Setup
4. Results
5. Conclusion

1. AWAKE Experiment

Relativistic proton bunch self-modulates in a plasma and this shall be detected

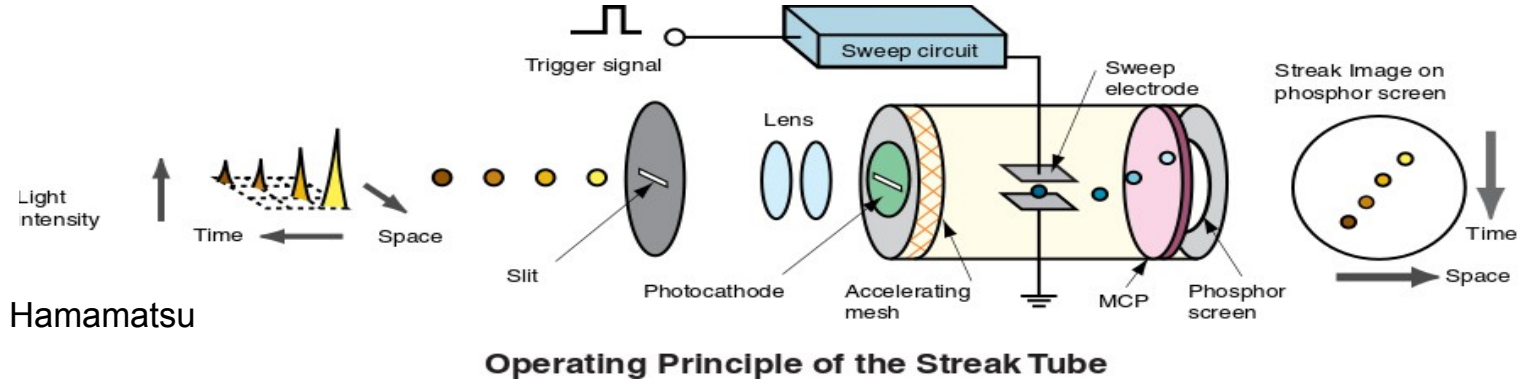


First goal of AWAKE @ CERN: Measure self-modulation of proton beam due to plasma wakefields

- Proton beam undergoes self-modulation in the plasma
- Use optical transition radiation to observe the self-modulation
- Use time resolved measurement of optical transition radiation (OTR)
- Frequency of modulation: 250 GHz

2. Streak camera working principle

Streak cameras are able to measure ~ ps long light pulses on a single event



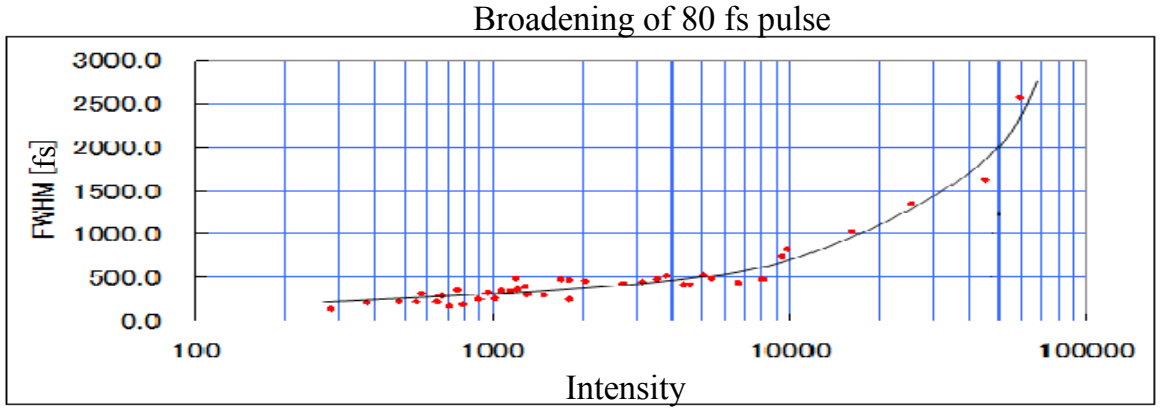
Picture by Hamamatsu

Operating Principle of the Streak Tube

- Measure light pulses by converting the light to electrons and deflecting the e^- with a time dependent voltage
- Streak cameras are normally used for short single pulse
- Highest resolution 200fs or 1-2ps

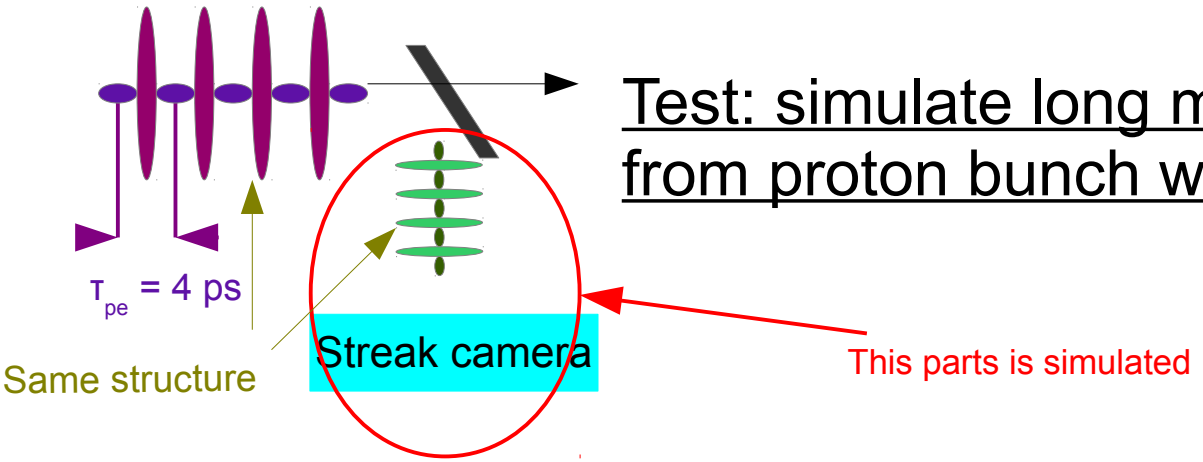
Limiting effect

Best resolution typically achieved with single, low intensity light pulse to minimize space charge effect in the streak tube



Picture by Hamamatsu

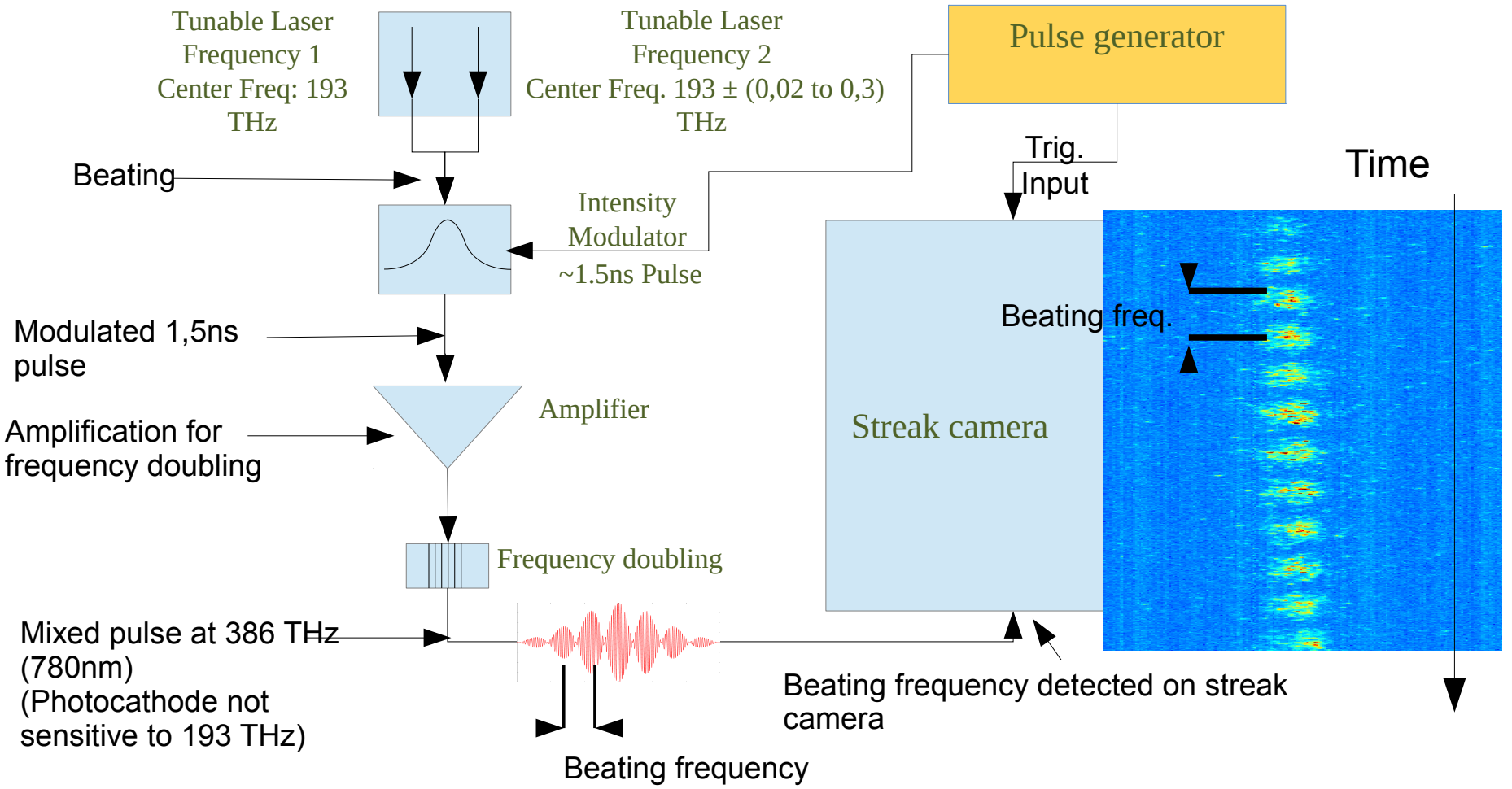
- What happens to resolution when the streak tube is filled with electrons from a long light pulse?



<u>Test: simulate long modulated OTR light pulse from proton bunch with laser light</u>

3.Experimental Setup

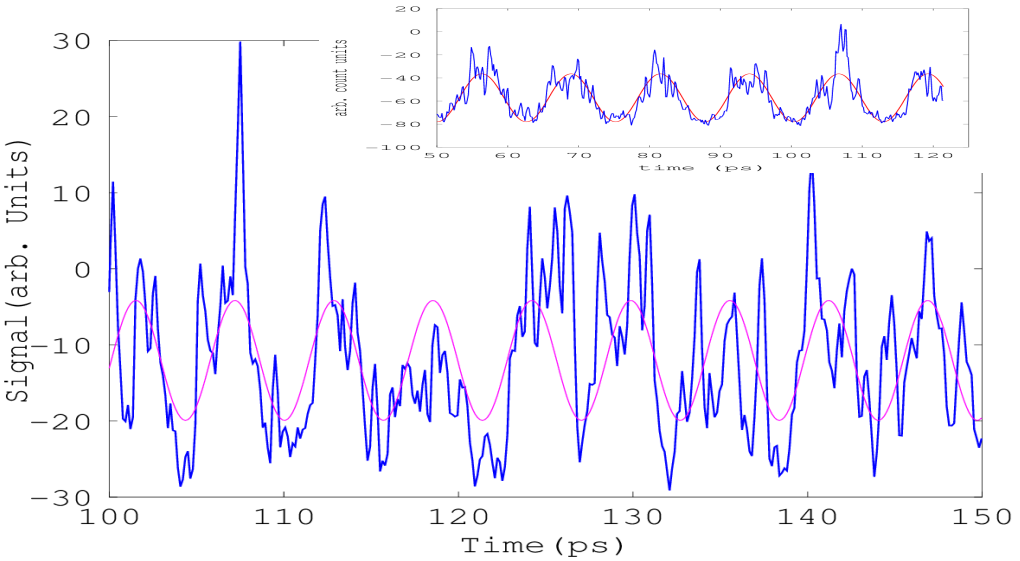
'Simulate' ~1 ns OTR light pulse with periodic laser pulse modulation

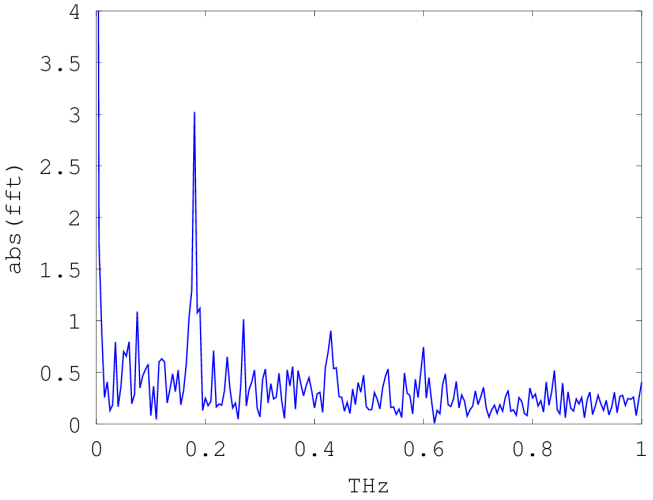


4. Results – up to 180 GHz

Streak camera is able to see modulations up to 180 GHz in a single event

- Simplest approach: fit a sine wave to signal and determine detected frequency by fit
- Detect imposed beating up to 180 GHz





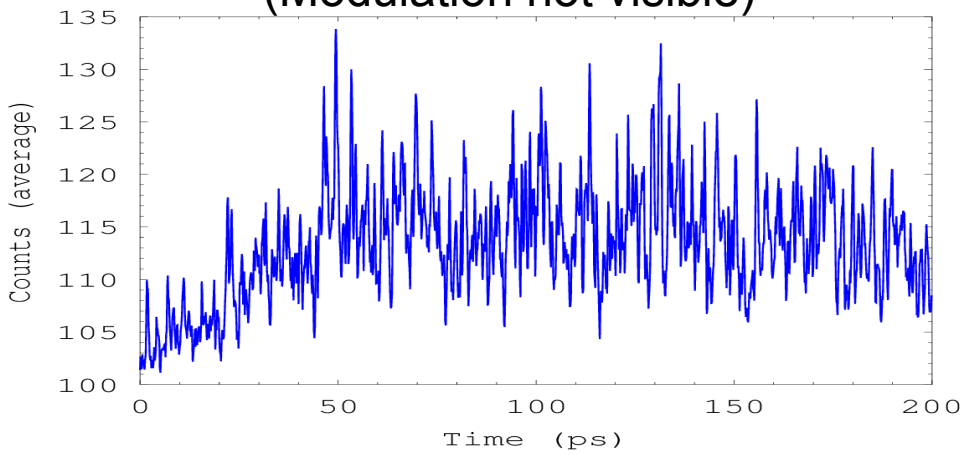
- Fourier Transform clearly has a peak at around 180 GHz, despite poor looking fit

Results up to 250 Ghz

Streak camera is able to see modulations up to 250 GHz in a single event (via a fast fourier transform)

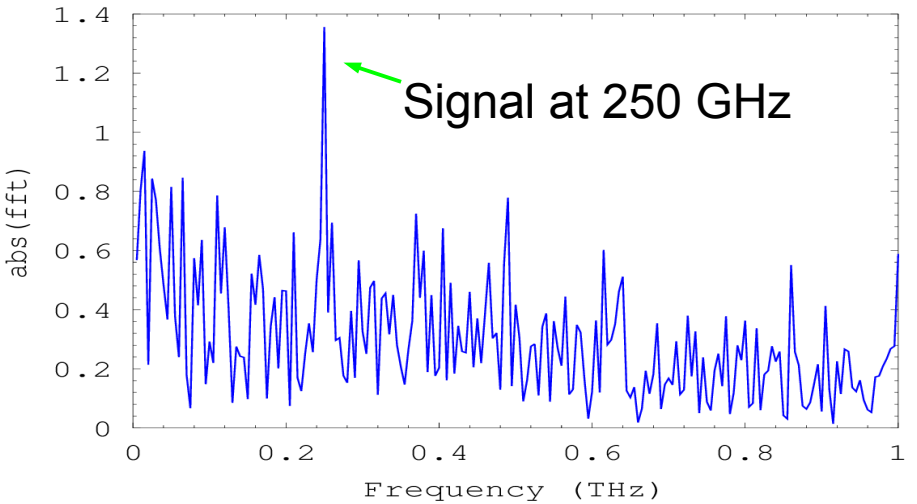
- Impose: beating frequency of up to 250 GHz on laser pulse
- Take FFT of signal
- Measure: peak in the frequency spectrum of the signal at imposed frequency
- Single event

Time Resolved Signal
(Modulation not visible)



FFT

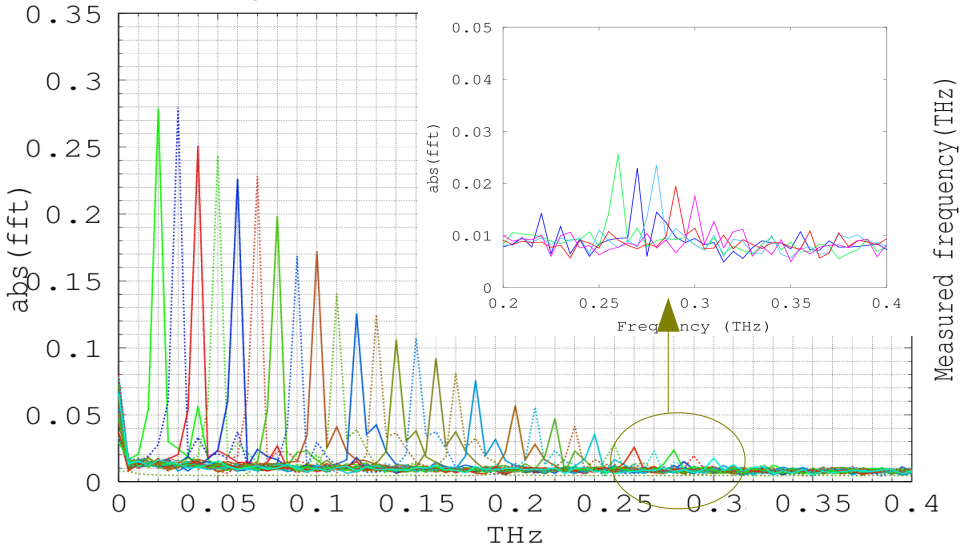
Amplitude spectrum of Signal



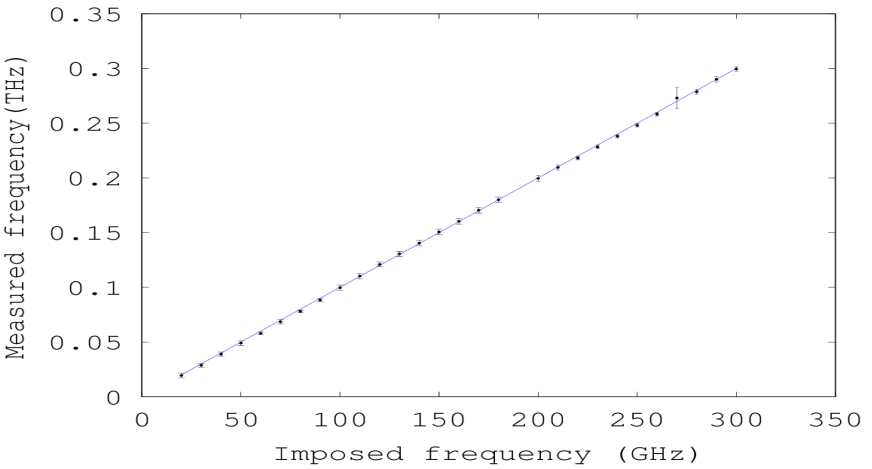
Results for averaged fft

Streak camera is able to see modulations up to 300 GHz by averaging over 10 events

Averaged FFT amplitude from 20 to 300 GHz



Measured vs Imposed frequency



- Fast fourier transform of each picture taken and average the amplitude spectra
- Modulation is seen up to 300 GHz
- AWAKE: Modulation of ~ 250 GHz expected (n_{pl}=7 * 10^{14}/cm^3)

5.Conclusion

Streak cameras can detect 1,5ns long pulses with ≥ 250 GHz modulation which is the maximum expected modulation of the proton bunch in the AWAKE experiment

With the modulated laser pulse simulating OTR light from the p^+ bunch we can detect modulation frequencies:

- Up to 180 GHz with a basic fit
- Up to 250 GHz from FFT of single event images
- Up to 300 GHz from averaging FFT amplitude spectra over 10 images

- Space charge is not destroying the modulation in the range of interest
- Challenge in AWAKE:

  Apply this OTR diagnostic to evidence and determine the frequency of the p^+ bunch self modulation, this includes Light capture efficiency, coupling to the camera, preserving the time structure (if in a fiber),...

Discussion

Questions and comments

End

Thank you for your attention!