A beam position monitor for co-propagating beams at the AWAKE experiment

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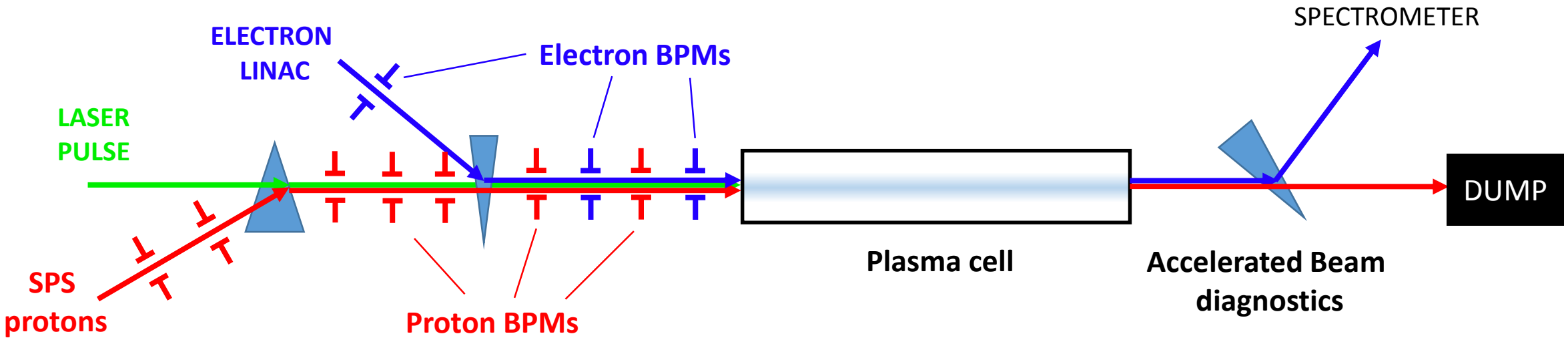
Outline

- The AWAKE experiment
- Co-propagating beams
- Cherenkov Diffraction Radiation
- In-air tests
- Outlook to the future

AWAKE in a nutshell

AWAKE: **proton driven** plasma wakefield acceleration



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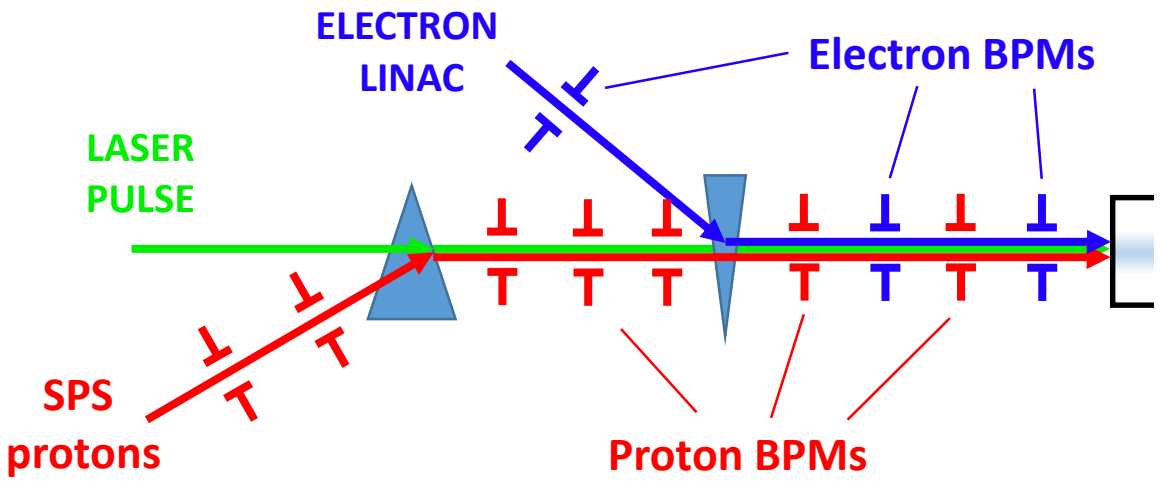
1 INJECTORS



The AWAKE recipe

- **Proton beam** 48 nC, 250 ps-σ
- **Electron beam** 600 pC, 4 ps-σ
- **Laser beam** 120 fs, 450 mJ
- **Rb vapour** (later)

AWAKE in a nutshell

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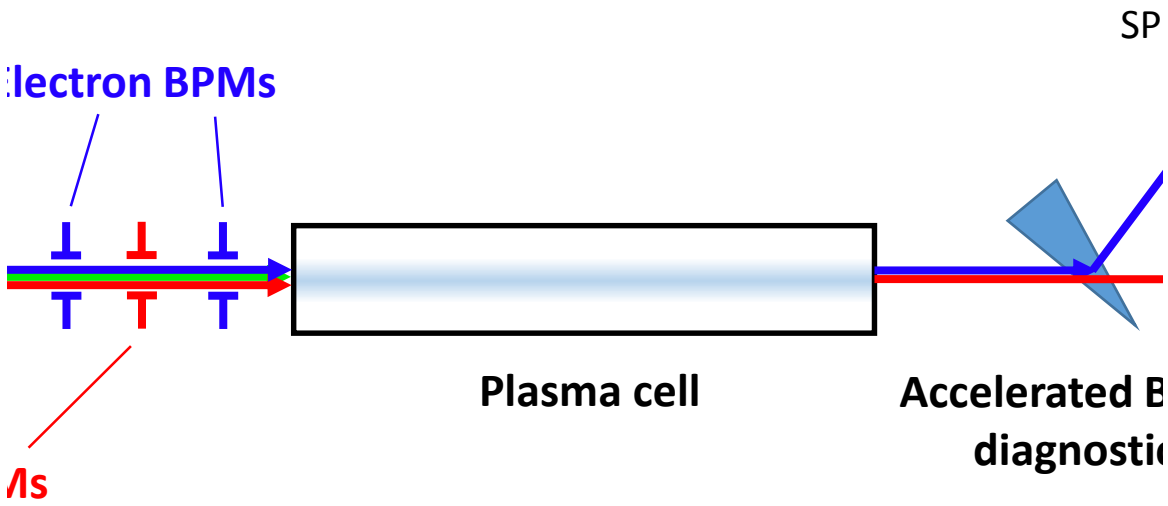
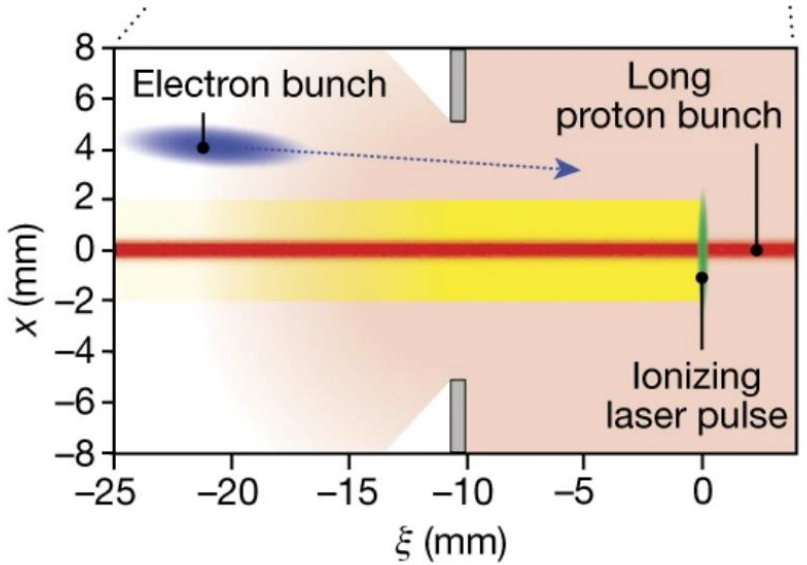
2 SELF-MODULATION



The **proton** bunch is broken into a **train of microbunches** via the self modulation process in the plasma



See AWAKE Collab., Phys. Rev. Lett. **122**, 054802 (2019)

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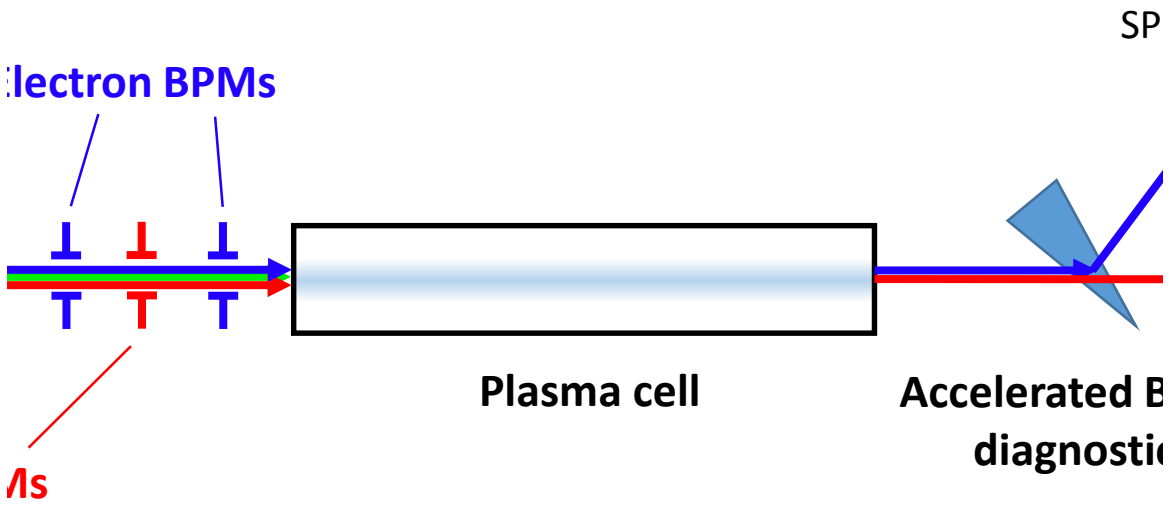

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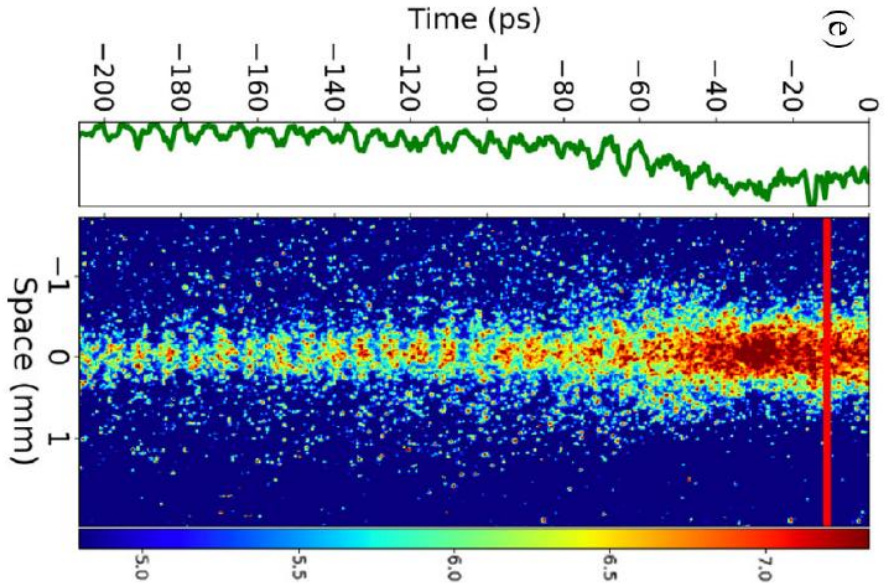

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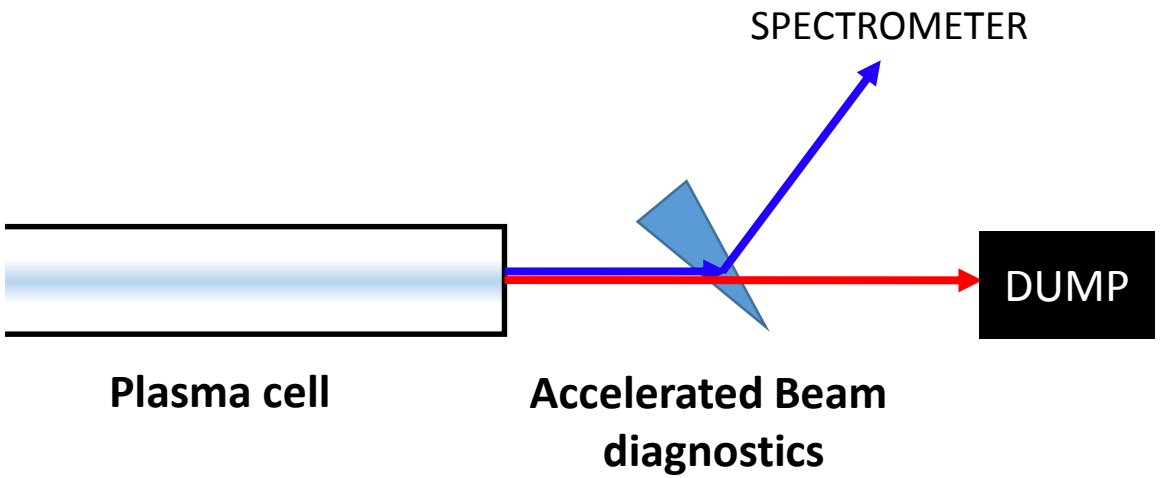
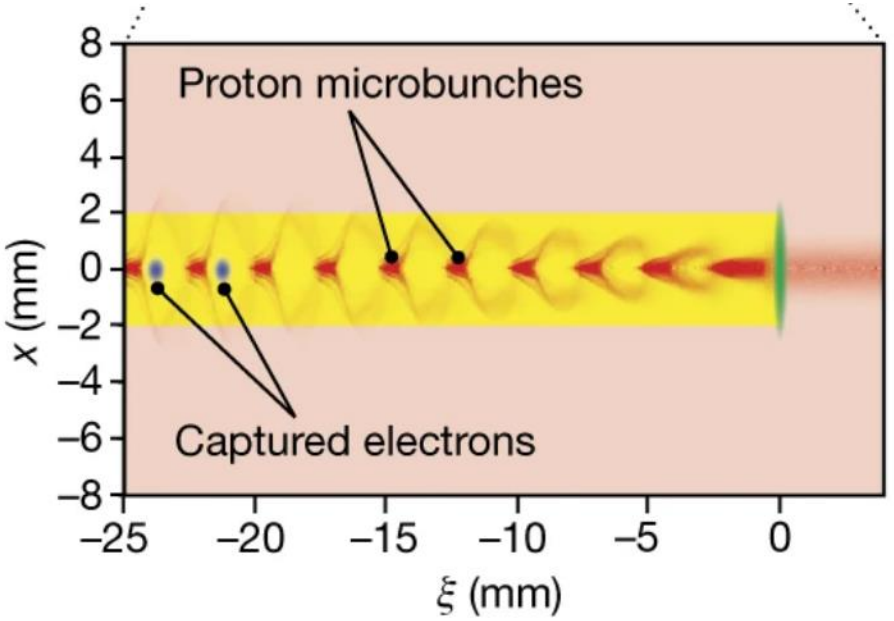
AWAKE: **proton driven** plasma wakefield acceleration

3 ACCELERATION

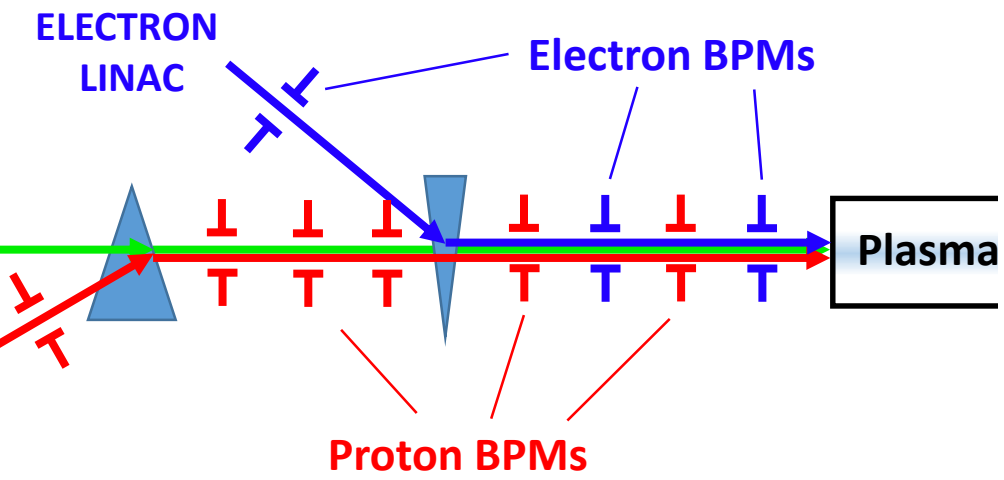


The electrons are captured in the plasma wakefield and accelerated after the self-modulation



See AWAKE Collab., Nature **561**, 363-367 (2018)

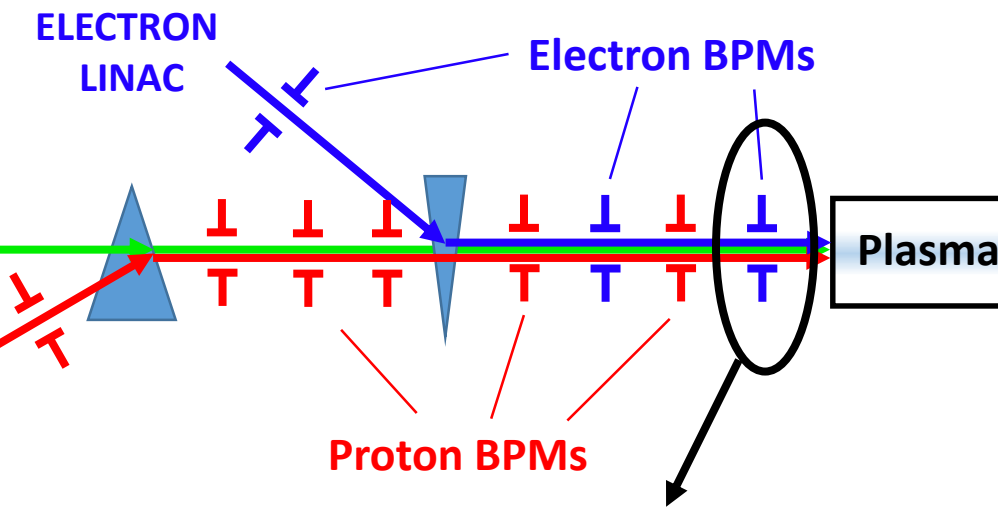
Co-propagating beams

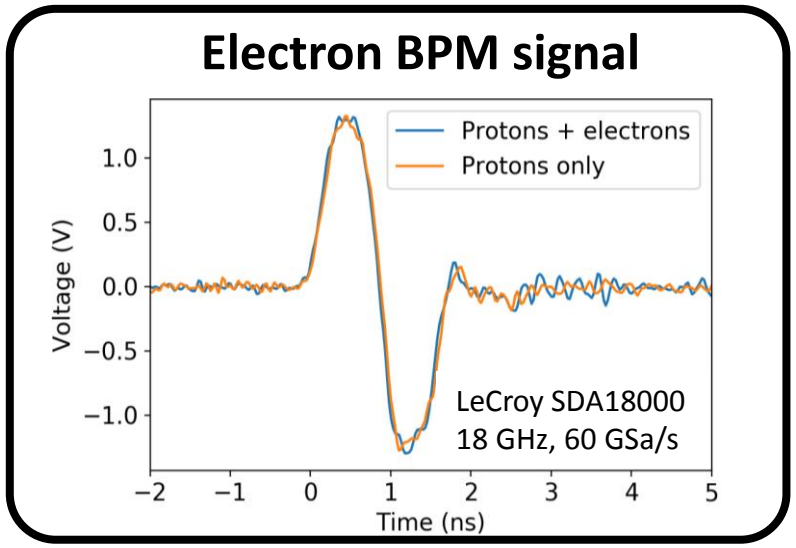


Instrumentation problem:
e^- and p^+ beams in the same beampipe, and very different beam parameters

p^+ beam 48 nC, 250 ps-σ
e^- beam 600 pC, 4 ps-σ

Co-propagating beams





Instrumentation problem:
e^- and p^+ beams in the same beampipe, and very different beam parameters

p^+ beam 48 nC, 250 ps-σ
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The **electron beam instrumentation** is **saturated by proton** signal

Beam spectrum

Is it impossible to measure the electrons with protons ?

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e^- beam 600 pC, 4 ps-σ

Beam spectrum

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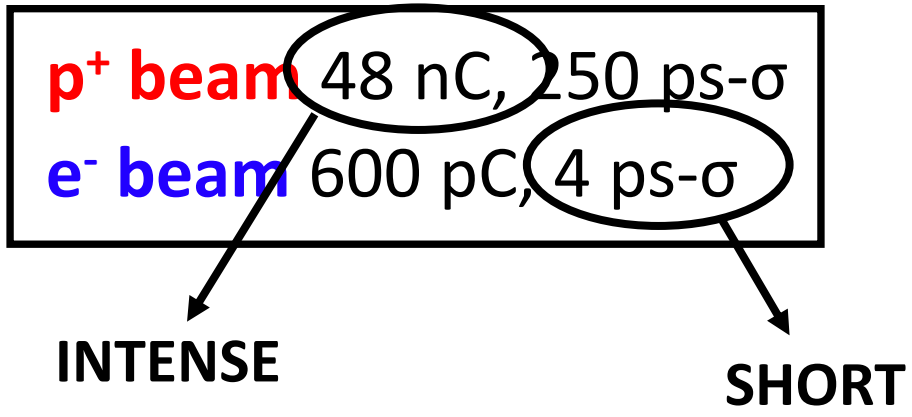
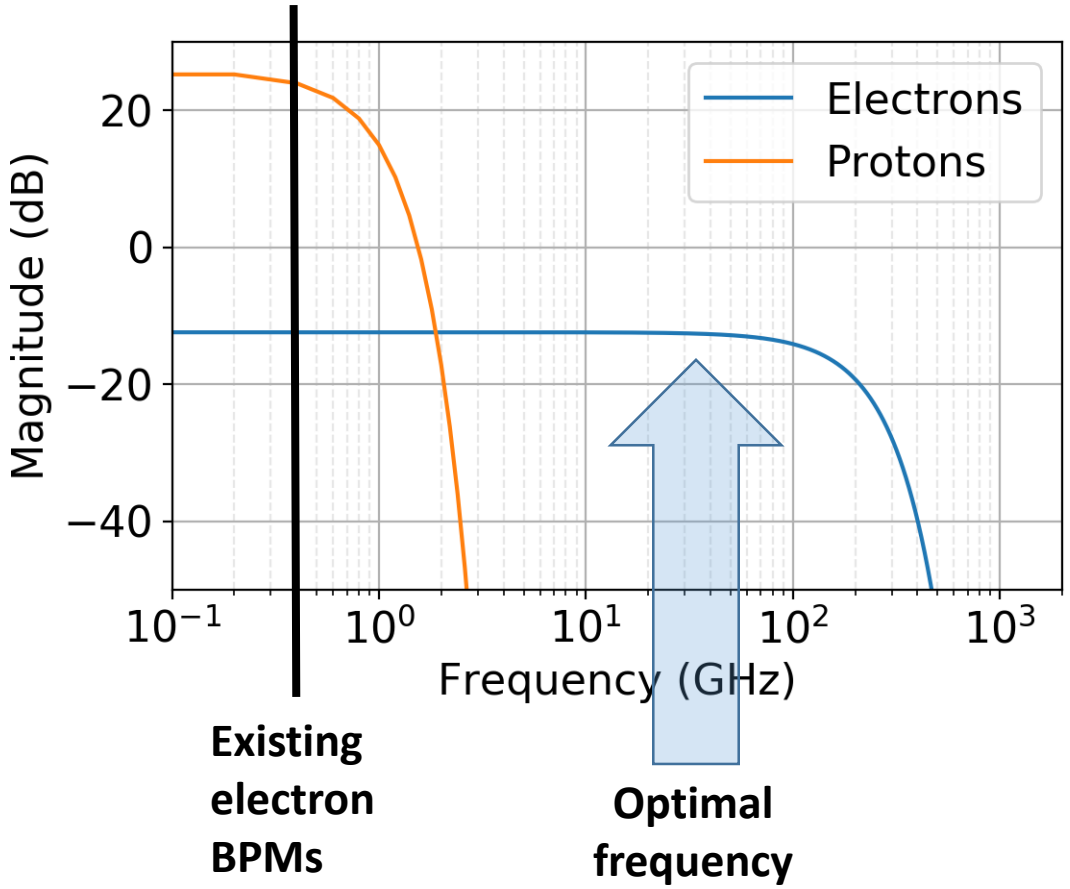


Approach the problem **in the frequency domain !**

Beam spectrum

Is it impossible to measure the electrons with protons ?



Approach the problem **in the frequency domain !**

p^+ stronger below 2 GHz

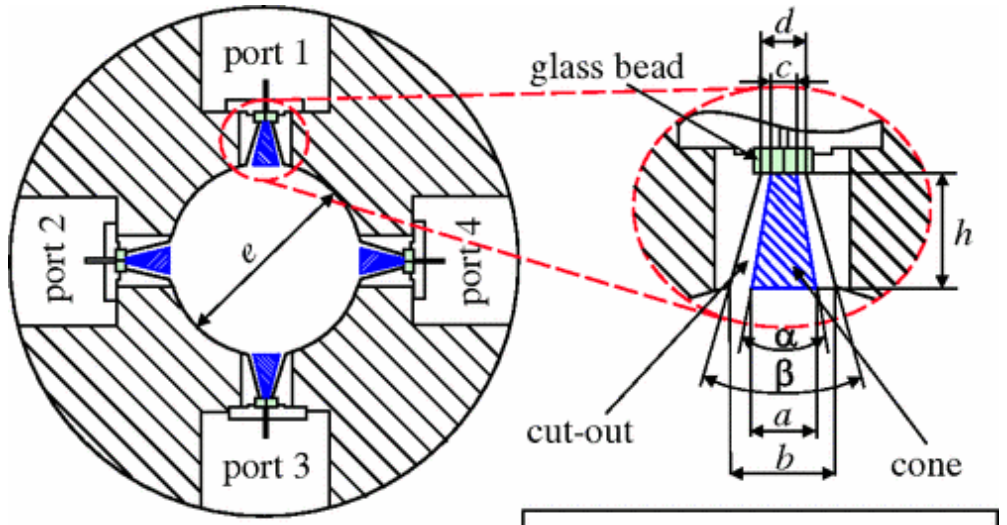
e^- stronger above 2 GHz

Gaussian beams assumed here …
Life is not that easy in the real world …

Cherenkov Diffraction Radiation

A high-bandwidth monitor is necessary, working at 10s of GHz !

- **'Traditional' approach:** electrostatic monitor
  - Conical buttons
  - Up to 40 GHz
  - Very challenging mechanics



$a = 2.42$ mm	$c = 0.70$ mm
$b = 5.60$ mm	$d = 1.62$ mm
$e = 40.50$ mm	$h = 6$ mm
$\alpha = 16°$	$\beta = 36.6°$

See A. Angelovski et al., Phys. Rev. ST Accel. Beams **15**, 112803 (2012)

Cherenkov Diffraction Radiation

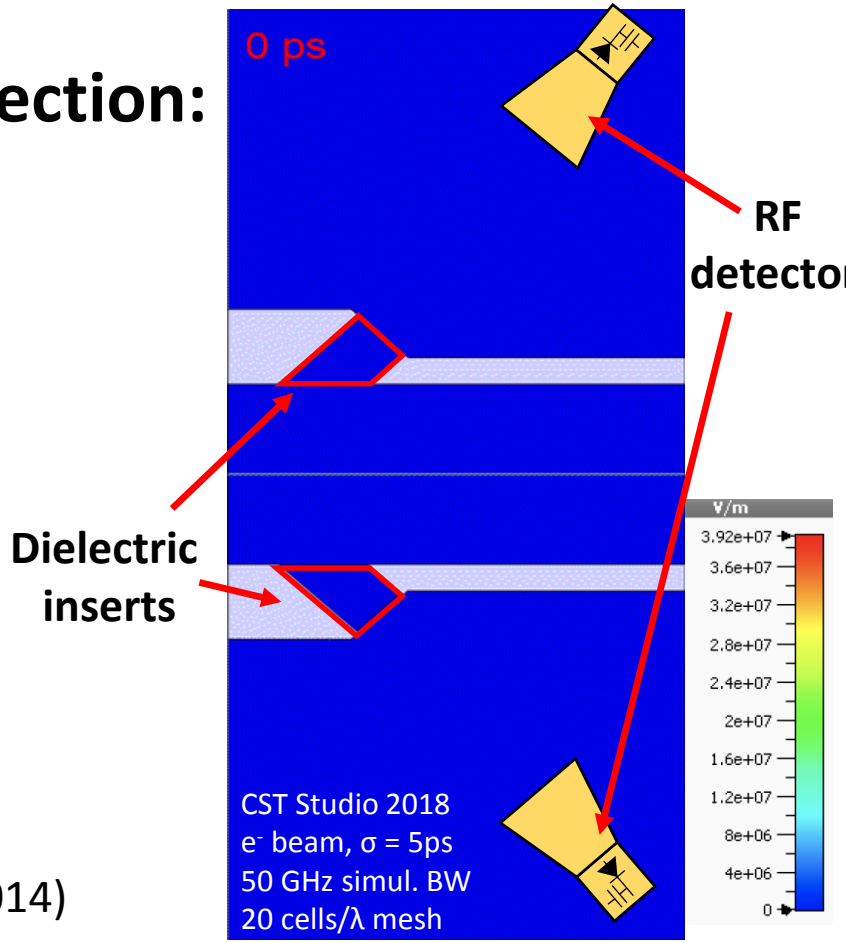
A high-bandwidth monitor is necessary, working at 10s of GHz !

Cherenkov Diffraction Radiation (ChDR) detection:

ChDR is polarisation radiation induced by a charged beam passing next to a dielectric target and emitted at the Cherenkov angle

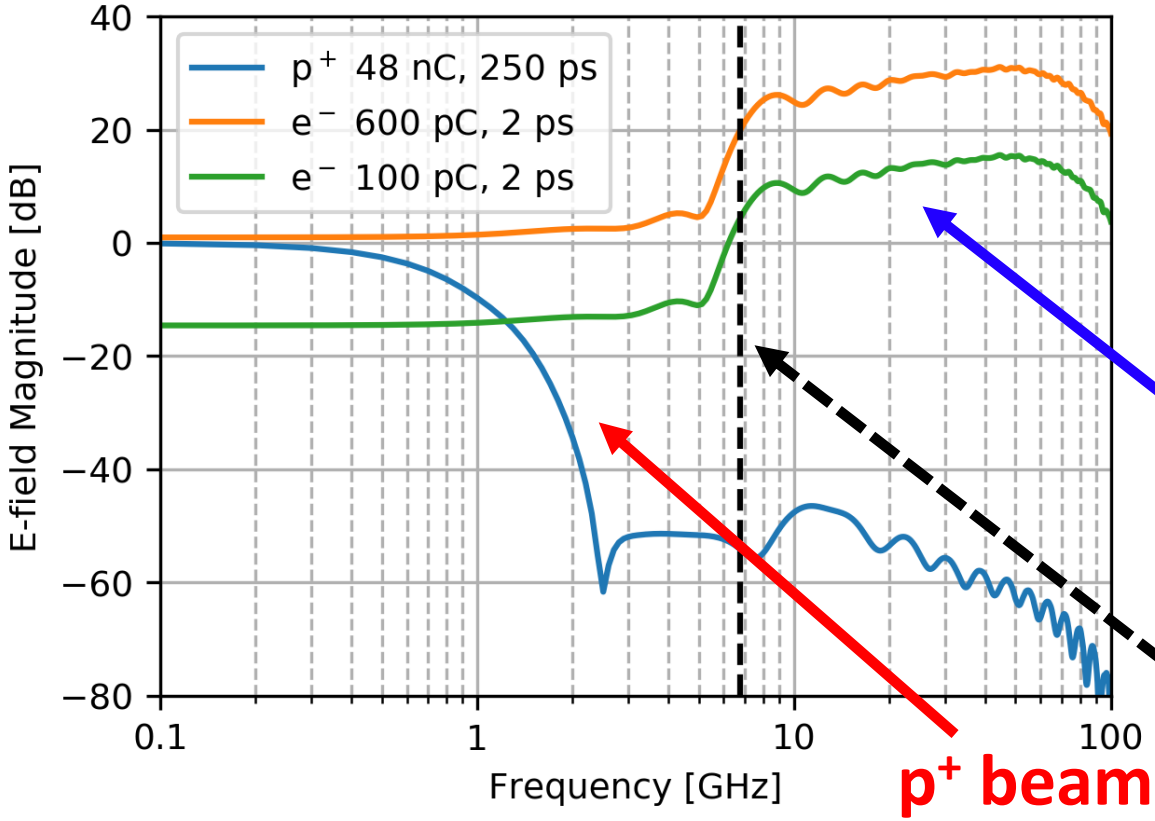
PROPERTIES

- Large emitted photon flux
- Very well defined angular emission
- Non invasive measurement
- Broadband at the emitting surface



See M. V. Shevelev and A. S. Konkov, JETP **118**, 501-511 (2014)

Cherenkov Diffraction Radiation



The ChDR is produced broadband

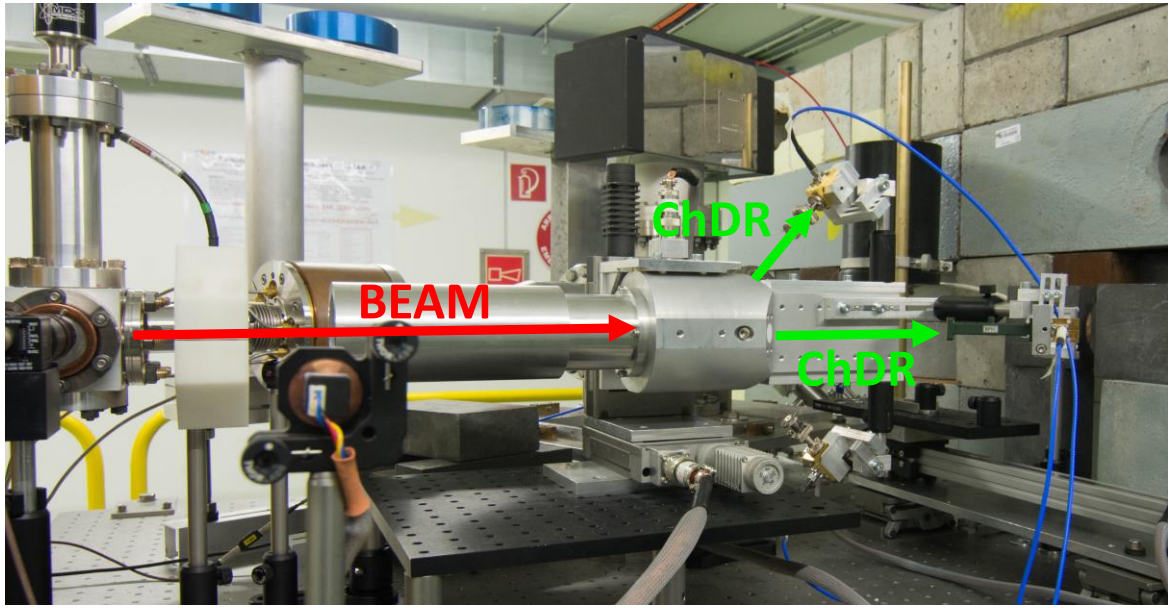
The radiator highpass the emission,
behaving like a loaded waveguide

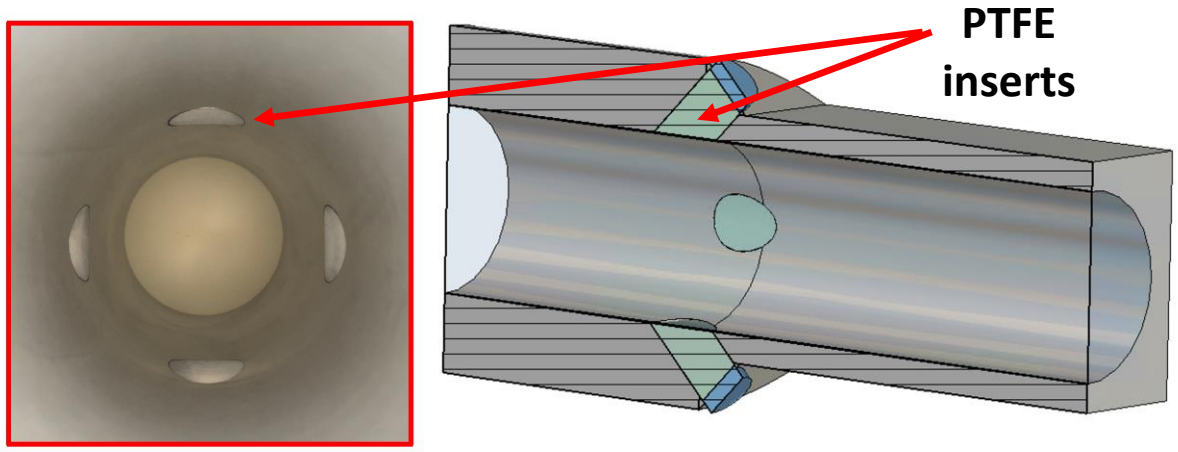
e^- beam
COUPLED AT HF

p^+ beam
DEPRESSED

Radiator
Cutoff frequency

In-air tests at the CLEAR facility



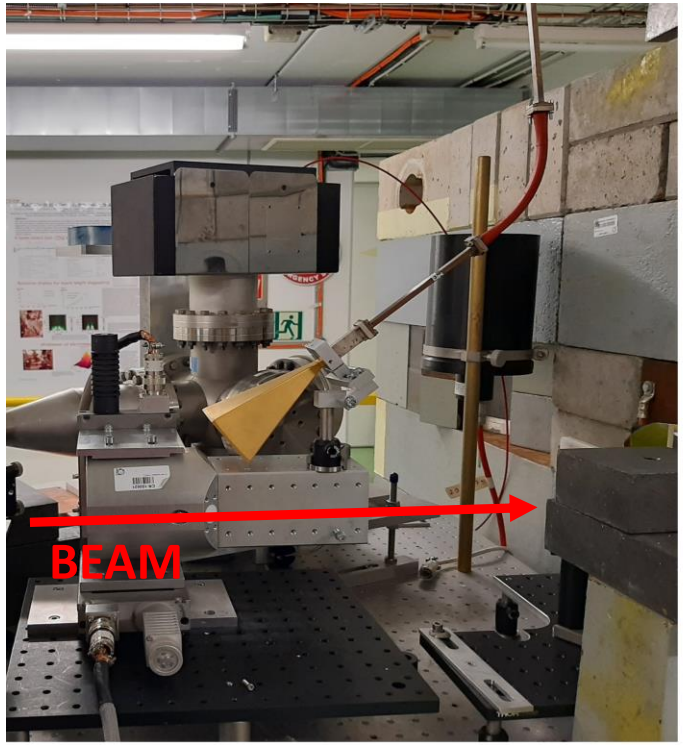


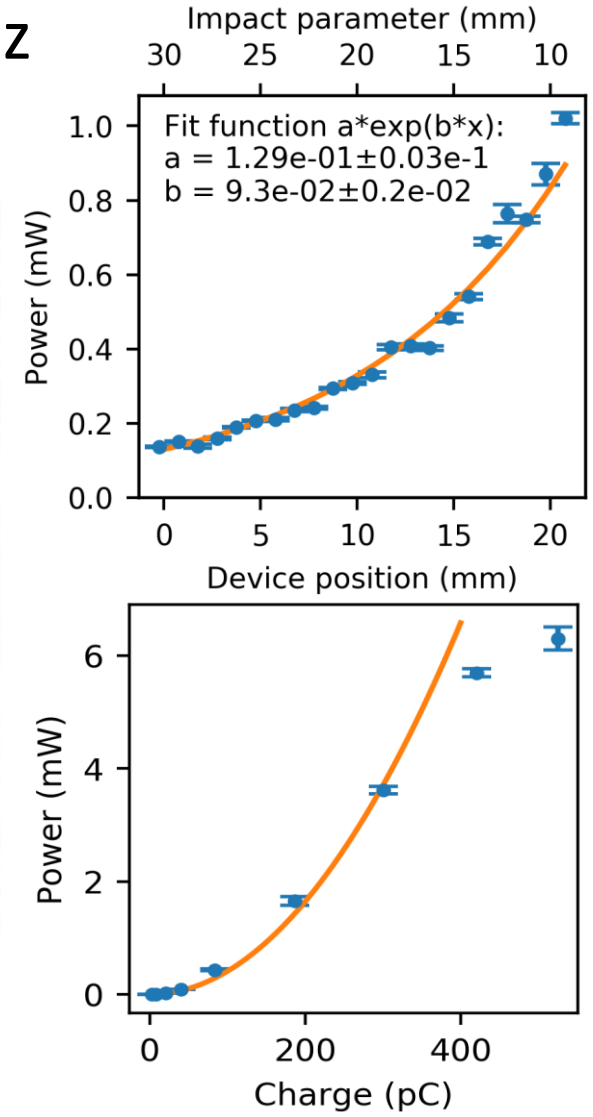
Prototype in-air test:

- **60 mm** diameter **aperture** (AWAKE)
- **PTFE** radiators
- Emission at 45°
- In-air detection for flexibility
- **Zero-bias RF schottky diode detectors** in the Ka-band
- Motorised support, move the device, not the beam

Radiation characteristics

f_0 = 36 GHz, BW = 1 GHz

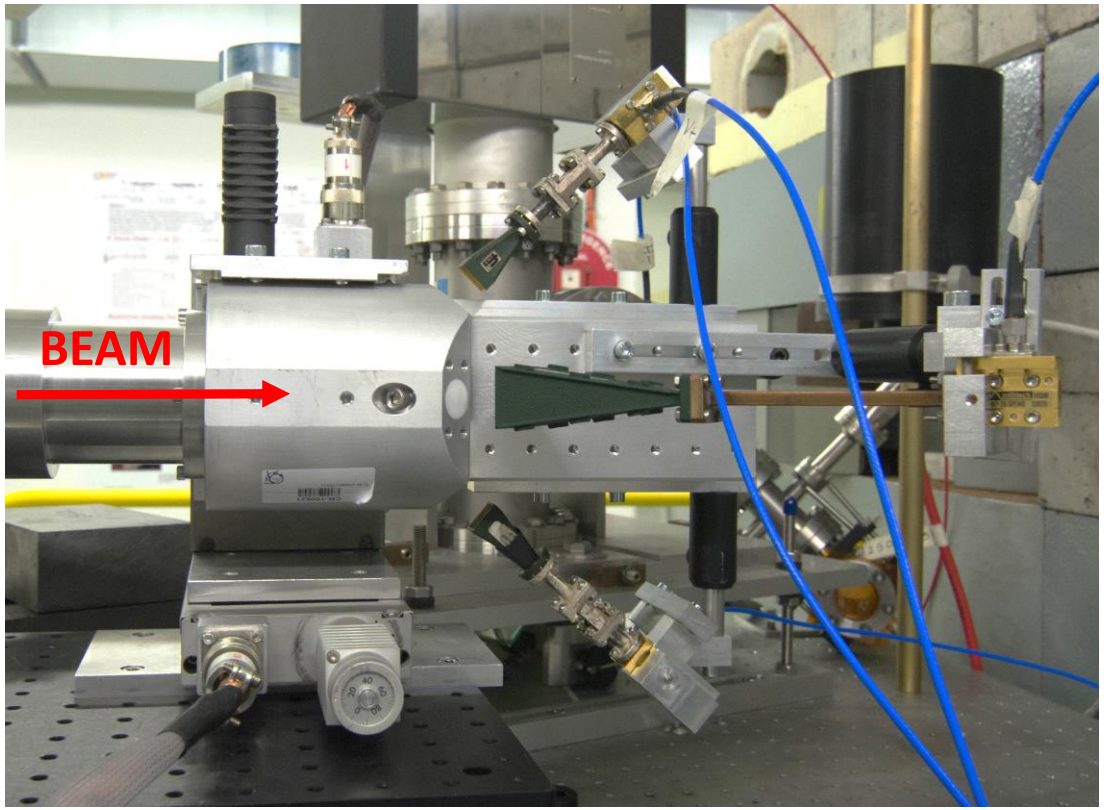


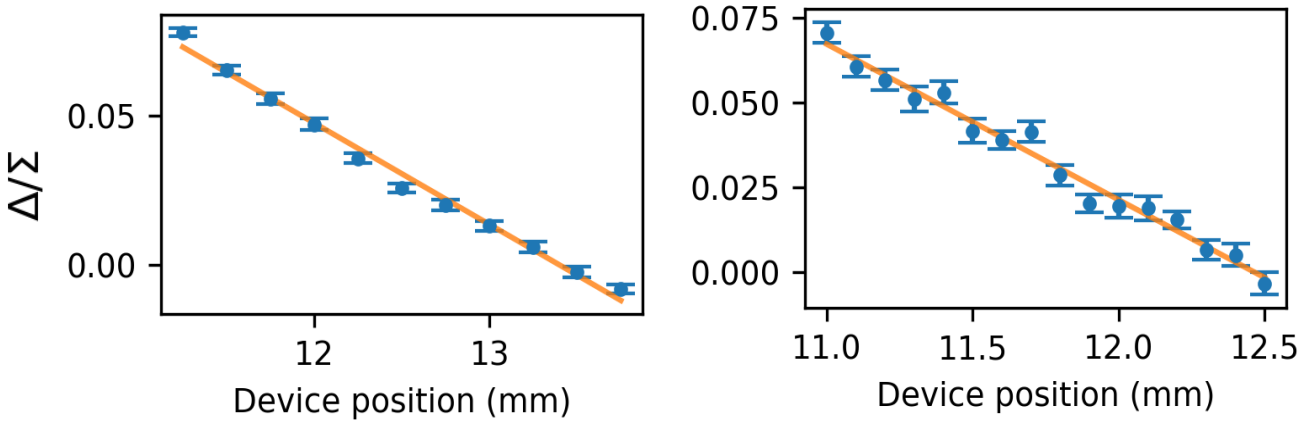


Output of one radiator:

- The **radiated power** has an exponential dependence with the **beam position**
- And quadratic dependence with the **beam charge** (coherent radiation)

Beam position measurement





Beam position measurement

Sensing the **power emitted** by **opposite radiators** to calculate **Δ/Σ**

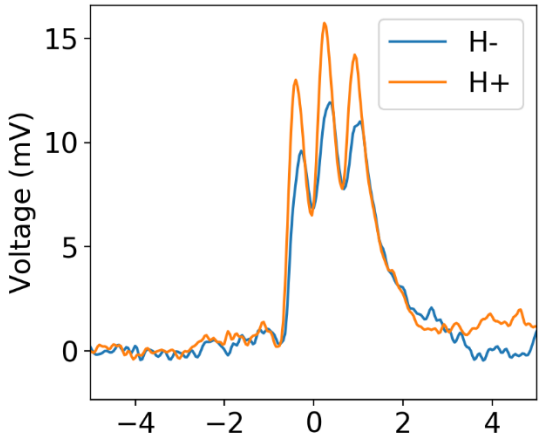
- **Linear** response around the **centre**

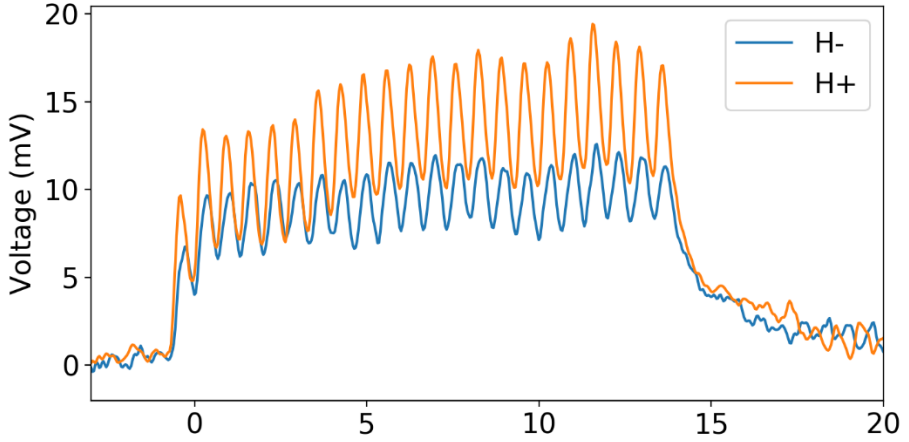
Bunch-by-bunch capability

- The **bunch structure is visible** in the signal. Leakage is present due to slow detection
- The **bunch spacing** is consistent with the high-frequency wall current monitor and RF period

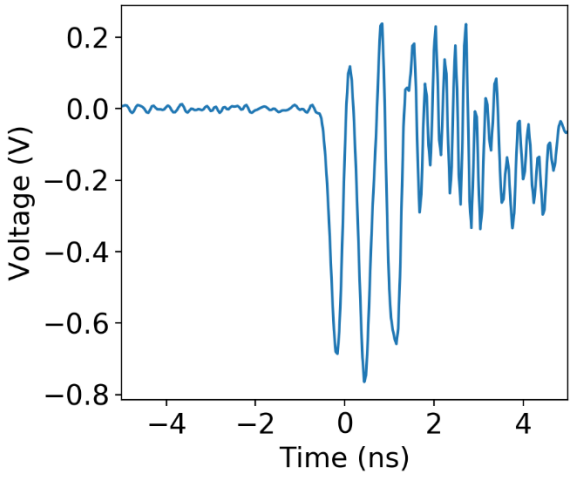
3 BUNCH TRAINS | **20 BUNCH TRAINS**

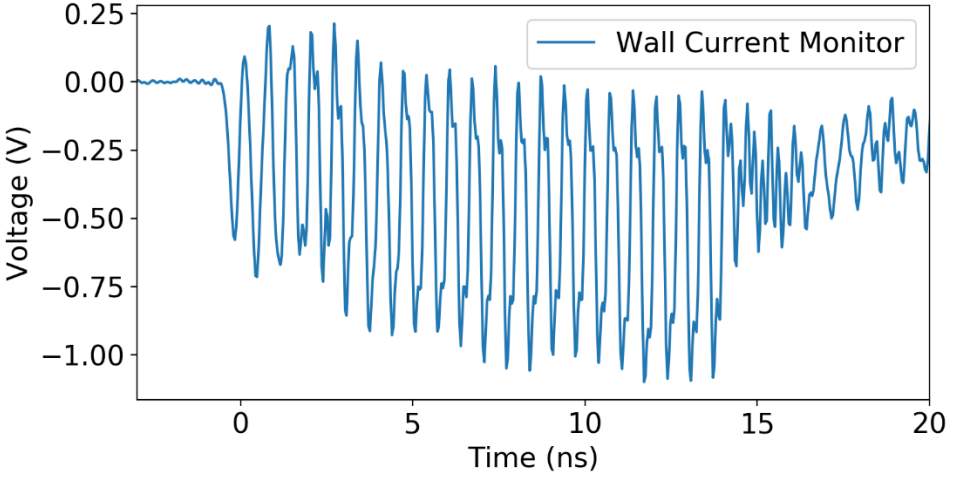
CHERENKOV RESPONSE





WALL CURRENT MONITOR





The future

ChDR-based radiators are interesting for **diagnostics** in the **GHz** range

- **AWAKE** plans to install two **ChDR BPMs** to point the electron beam when the protons are present.
- Presently working on **vacuum compatible** designs with Alumina circular radiators

The future

ChDR-based radiators are interesting for **diagnostics** in the **GHz** range

Possible applications:

- Short bunch accelerators (FELs, PWFA)
- Longitudinal diagnostics

See A. Curcio et al., Phys. Rev. ST Accel. Beams **23**, 022802 (2020)

See D. Alveset al., Cherenkov Diffraction Radiation as a Tool for Beam Diagnostics, Conf. Proc. of IBIC 2019, Malmö, Sweden

Thanks for your attention !