A beam position monitor for the AWAKE experiment based on Cherenkov diffraction radiation

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JAI Fest

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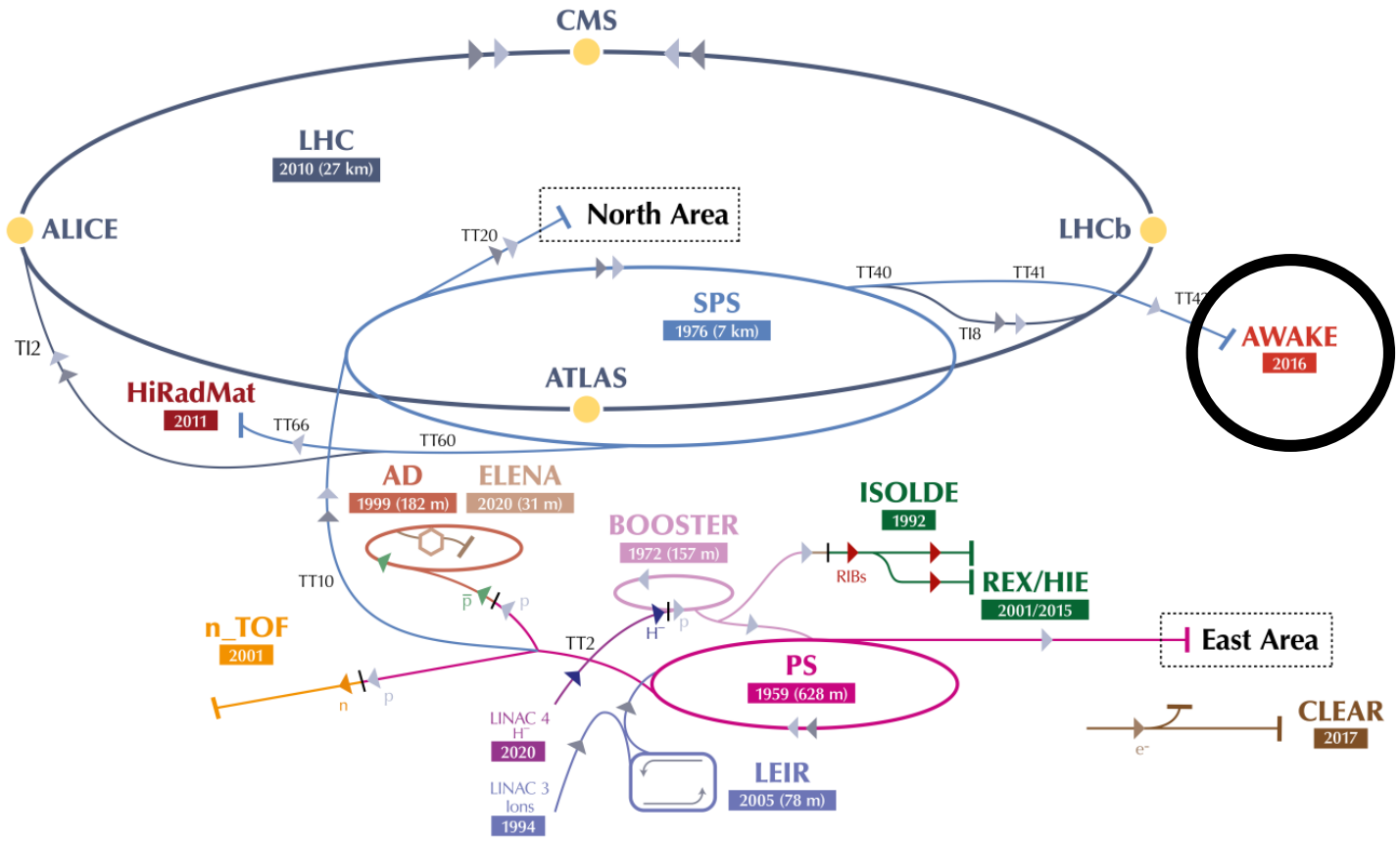
The AWAKE experiment

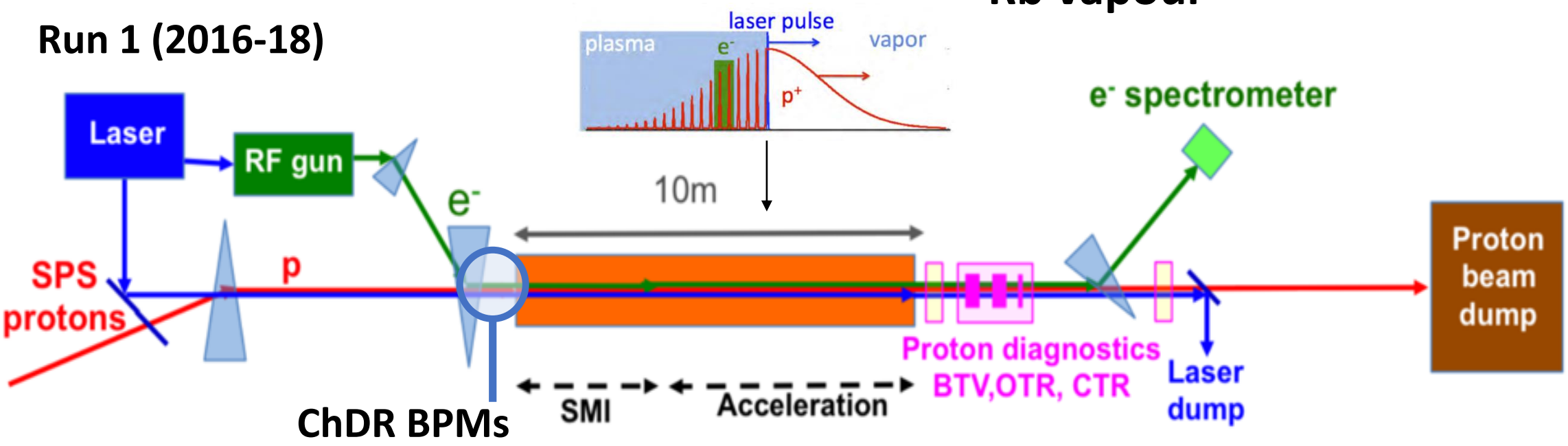
AWAKE: Advanced **Proton Driven** Plasma Wakefield Acceleration Experiment



The AWAKE experiment

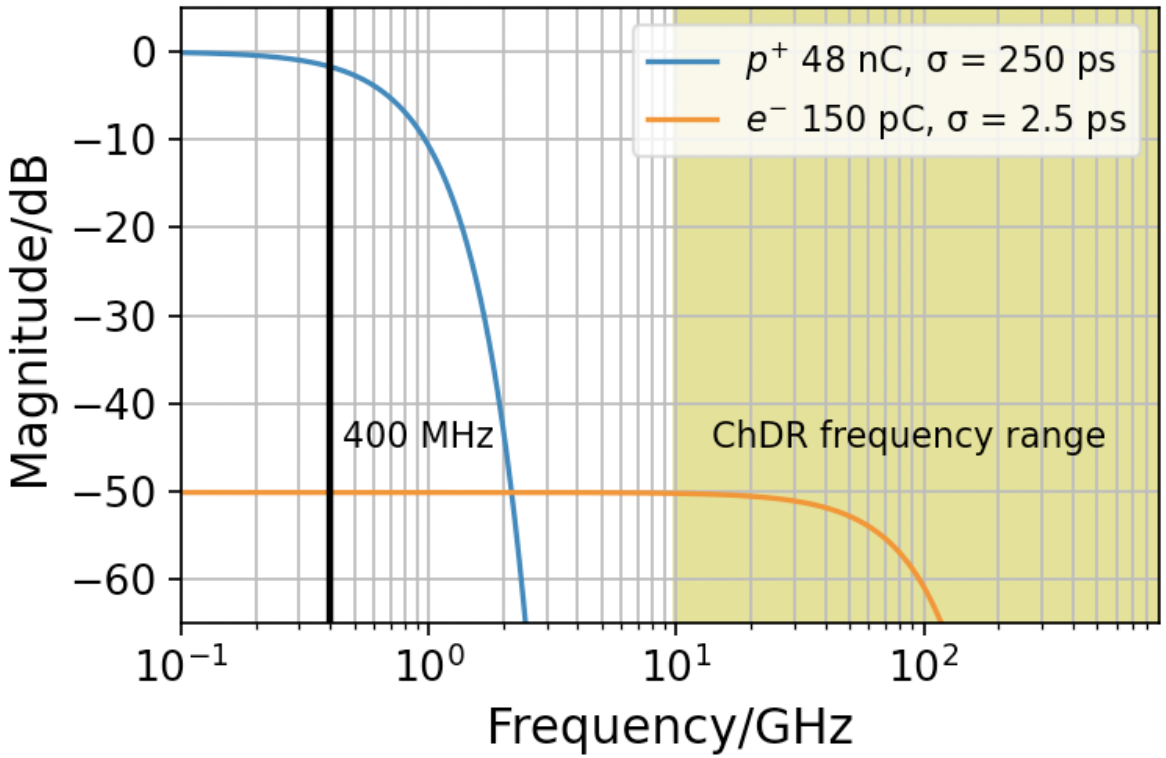
Protons 48 nC, 250 ps sigma
Electrons 150 pC, 2.5 ps sigma
Laser 120 fs, 450 mJ
Rb vapour

Run 1 (2016-18)



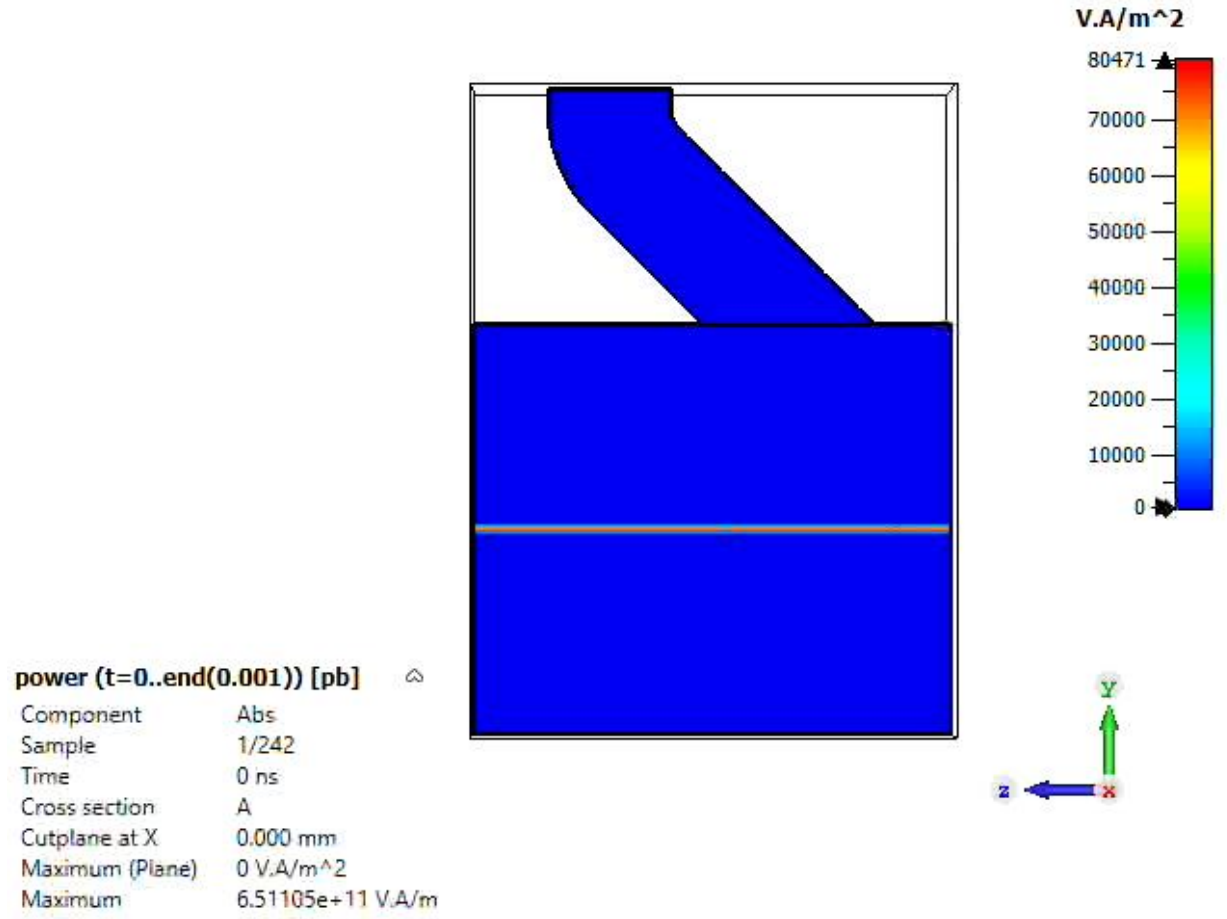
Motivation for ChDR BPM

- **Proton signal dominates** below 2 GHz
- Current system cannot measure electrons in presence of protons
- Exploit the **different bunch lengths**
- Operate at **high frequency**
- Very mechanically challenging for traditional electrostatic monitors

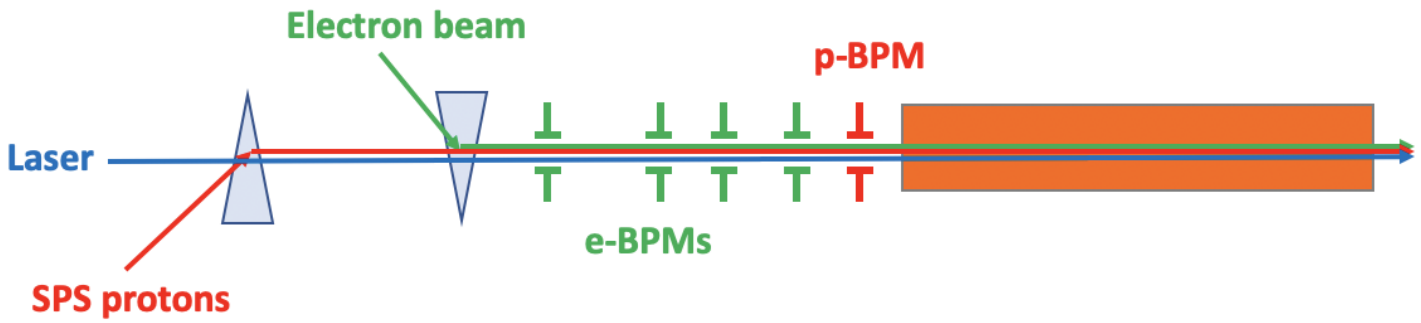


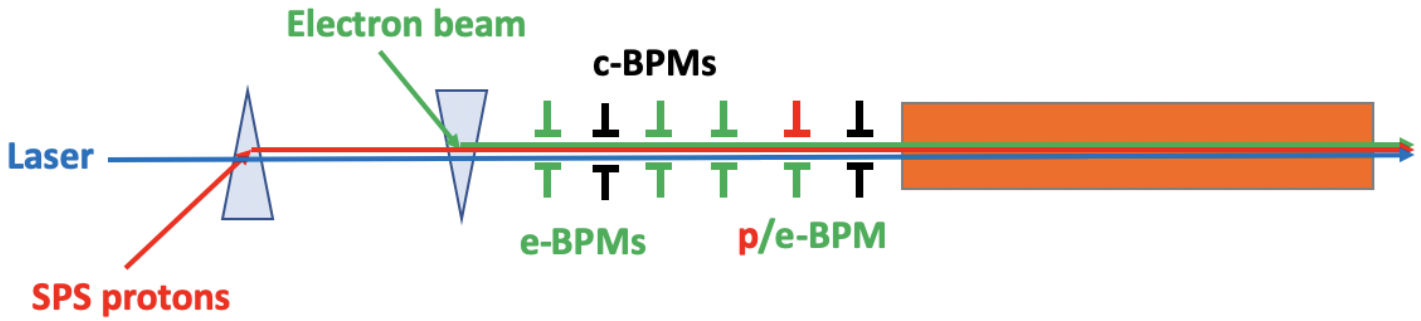
Motivation for ChDR BPM

- New technique based on **Cherenkov diffraction radiation**
- Polarization radiation produced when charged particle travels in **close proximity** to the surface of a dielectric target
  - Non-invasive measurement
  - Large emitted photon flux
  - Well-defined angular emission



Design for AWAKE





- Limited space available
- ChDR buttons designed to be **compatible with existing p-BPM body**

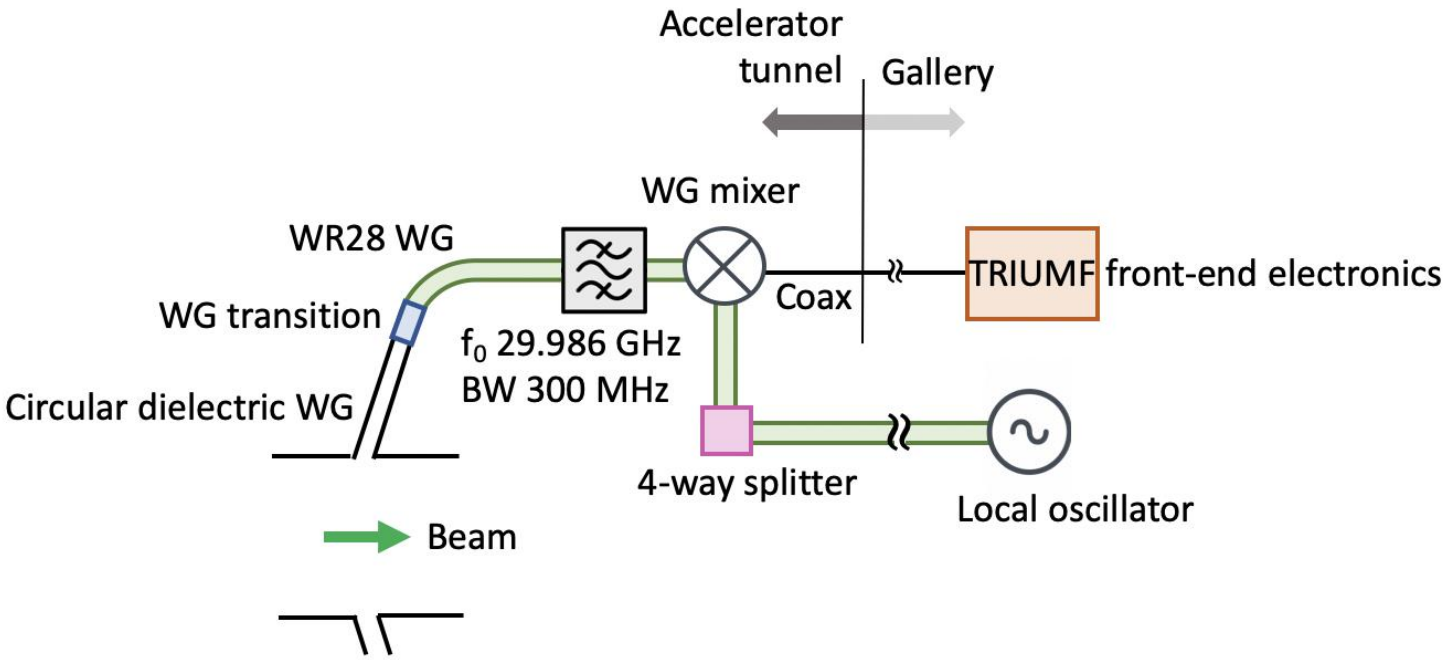
Plan:

1. Convert one p-BPM to c-BPM
2. Split signal of e-BPM to measure protons
3. Install additional c-BPM in drift space

Design for AWAKE

- Proton bunch **not gaussian**, spectrum extends to frequencies higher than expected
- Operating frequency in the range of 10s GHz means electron signal dominates
- 30 GHz chosen due to availability of waveguide (WG) components in house
- WR28 WG used with cutoff 21 GHz acting as high-pass filter
- Collaboration with TRIUMF for the front-end electronics

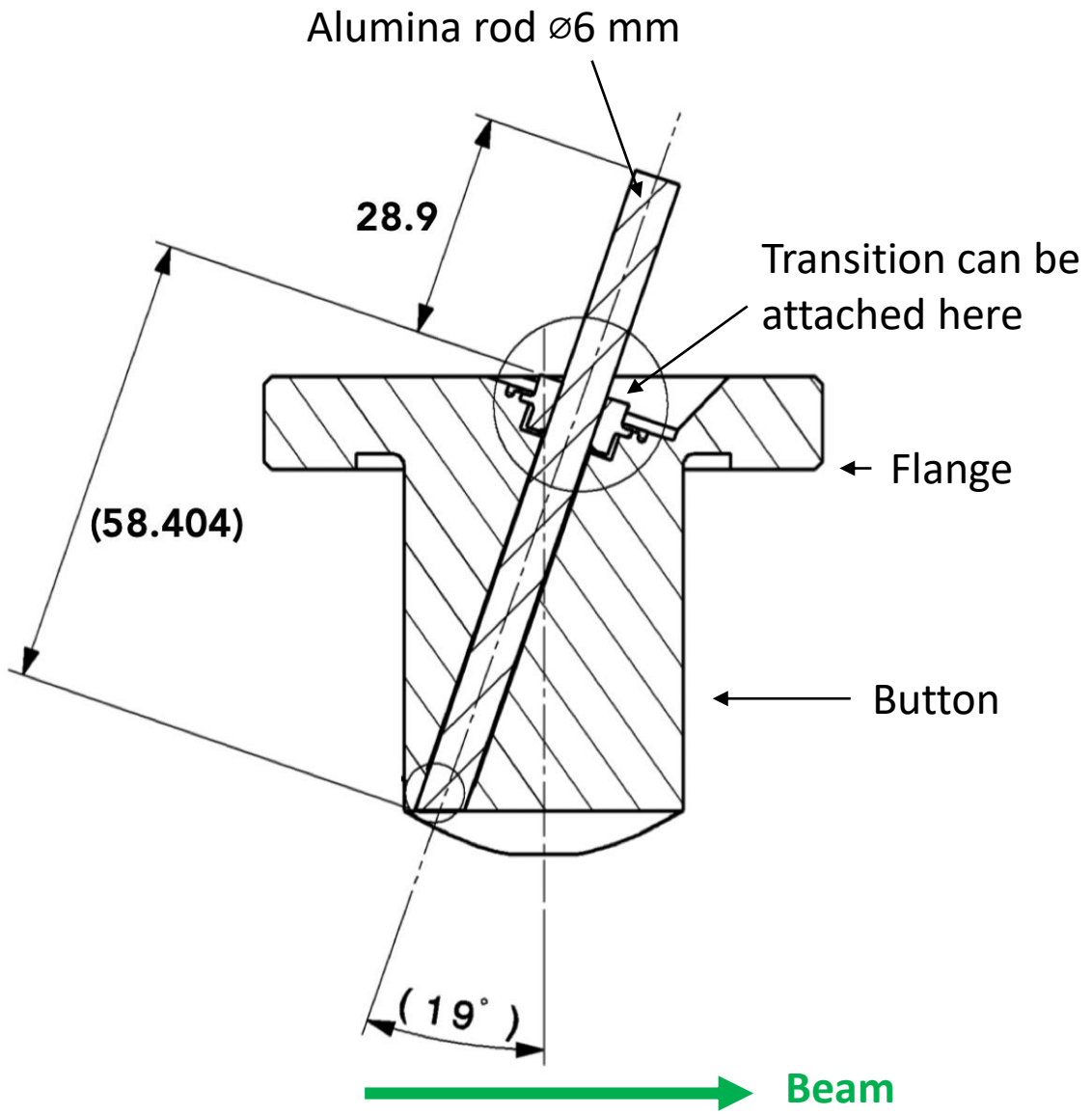
Schematic of entire ChDR BPM setup



Design for AWAKE

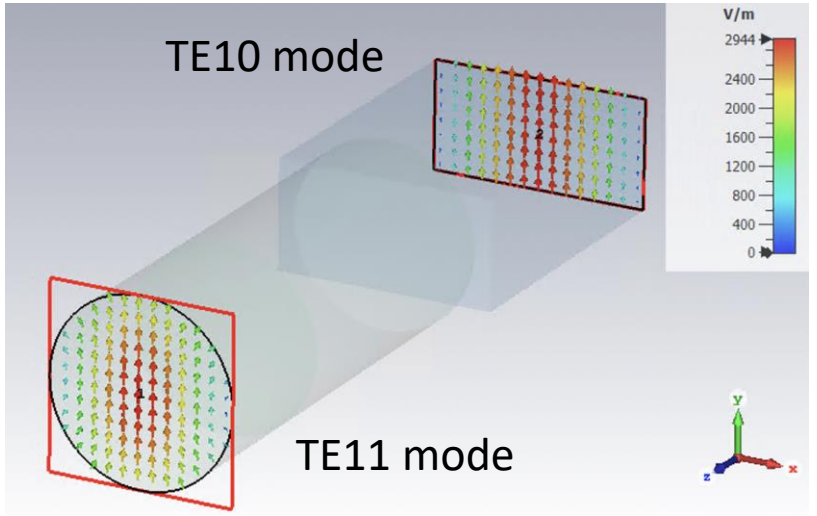
Mechanical design:

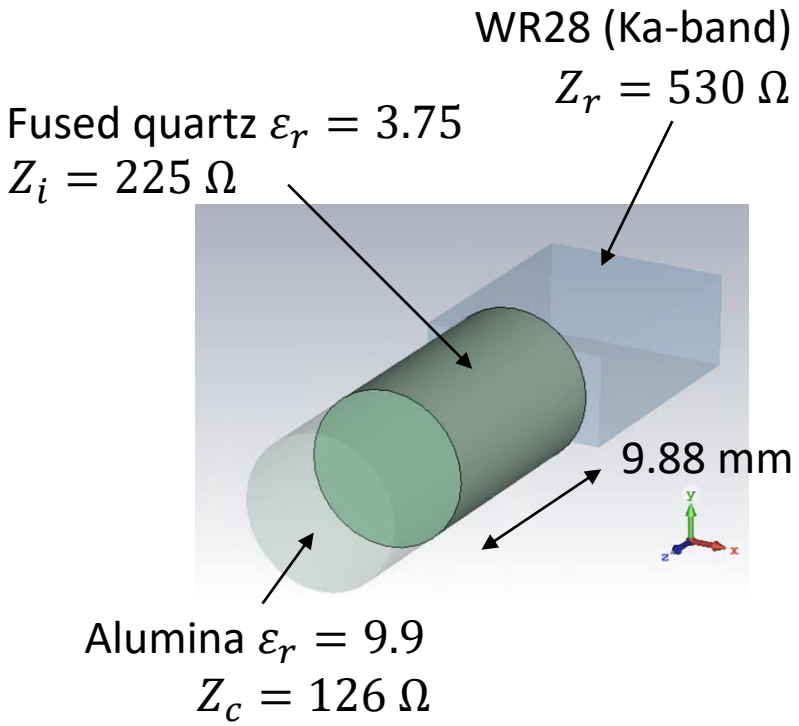
- ⌀6 mm alumina dielectric radiator oriented at Cherenkov angle ($\varepsilon_r = 9.9, \theta_{ch} = 71^{\circ}$)
- In metallic flanged button
- Cut flush on beampipe side and extended at the exit for attachment of a **matched-impedance transition** to an industry standard WR28 rectangular waveguide



WG transitions

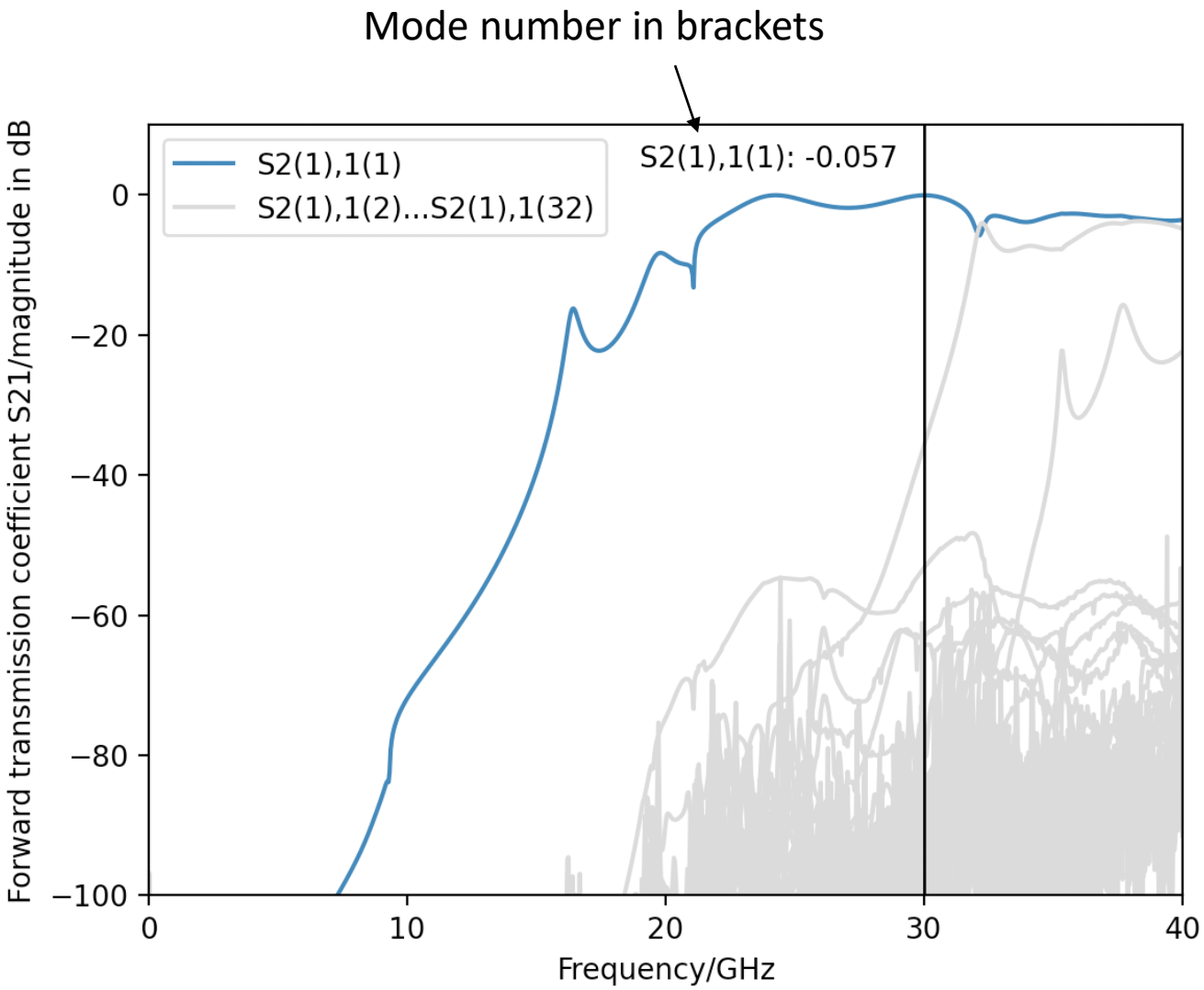
- Transition designed to **maximize power transfer** at 30 GHz between dominant modes of the waveguides
- Based **on quarter-wave impedance transformer**
- Section introduced with intermediate value of dielectric constant





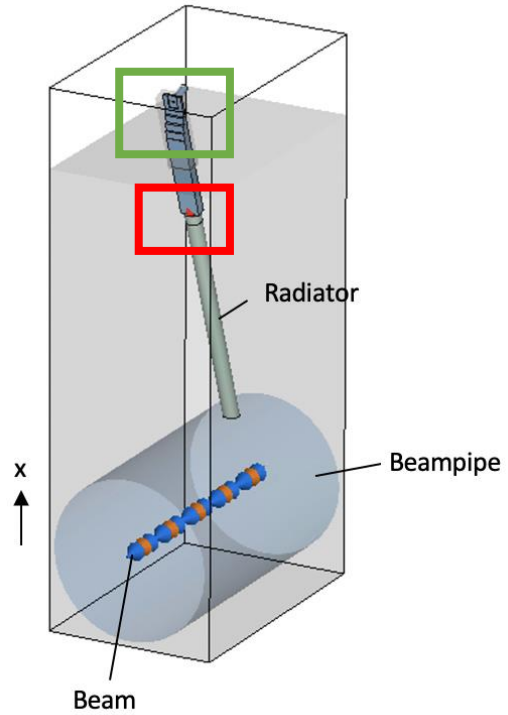
WG transitions

- Numerical analysis shows **forward transmission coefficient** for all modes below 40 GHz
- Length of intermediate section optimized to produce largest contribution of power from the fundamental mode of circular dielectric (TE11)
- S21^2 = 99% power transmission @ 30 GHz
- Contributions from all other modes in circular dielectric are suppressed

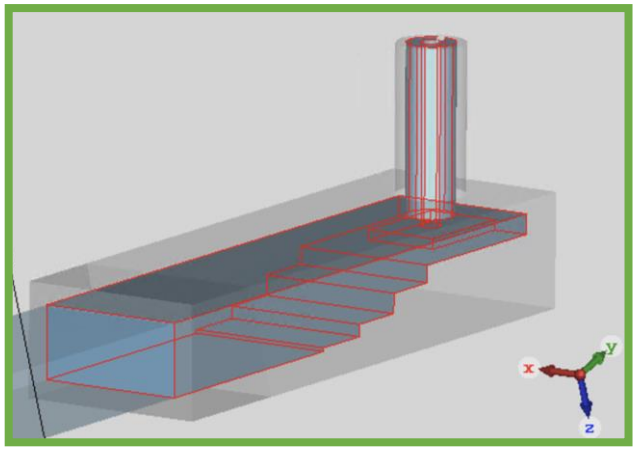


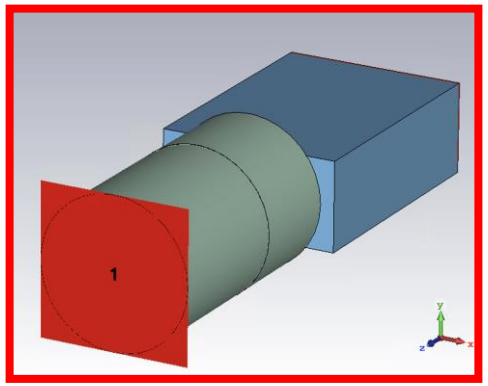
Numerical simulations

Full simulation with beam to investigate system behavior



R281A WR28 to 50 Ω coaxial adapter



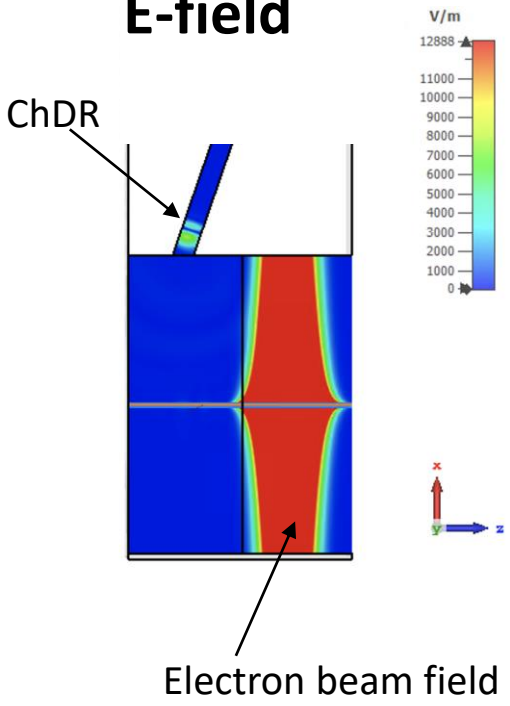


Circular to rectangular waveguide transition

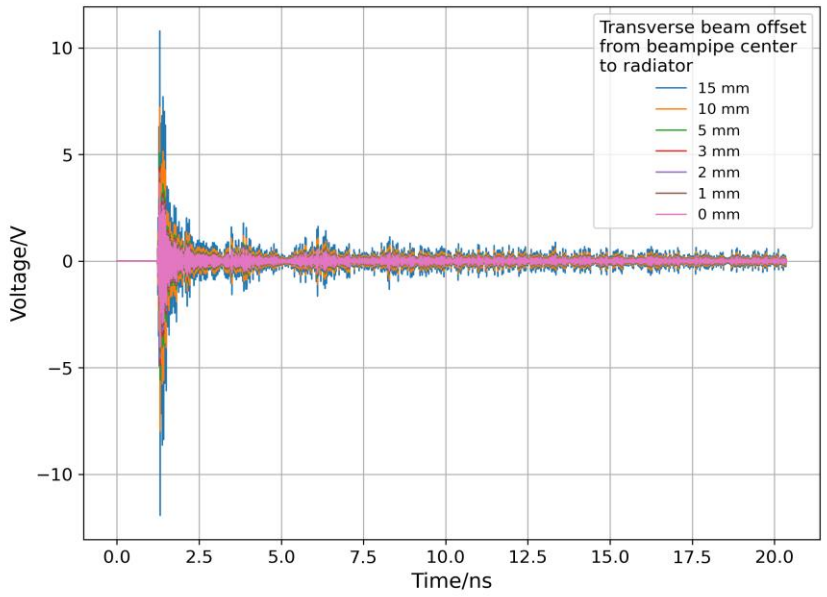
Parameter	Value
Bunch sigma	2.5 ps
Bunch charge	150 pC
Radiator angle	71˚
Radiator length	86.27 mm
Radiator dielectric constant (alumina 99.5% purity)	9.9
Mesh	10 mesh cells per wavelength
Total number of mesh cells	252 million
Average simulation time	Approx. 15 h
Beampipe diameter (AWAKE)	60 mm

Numerical simulations

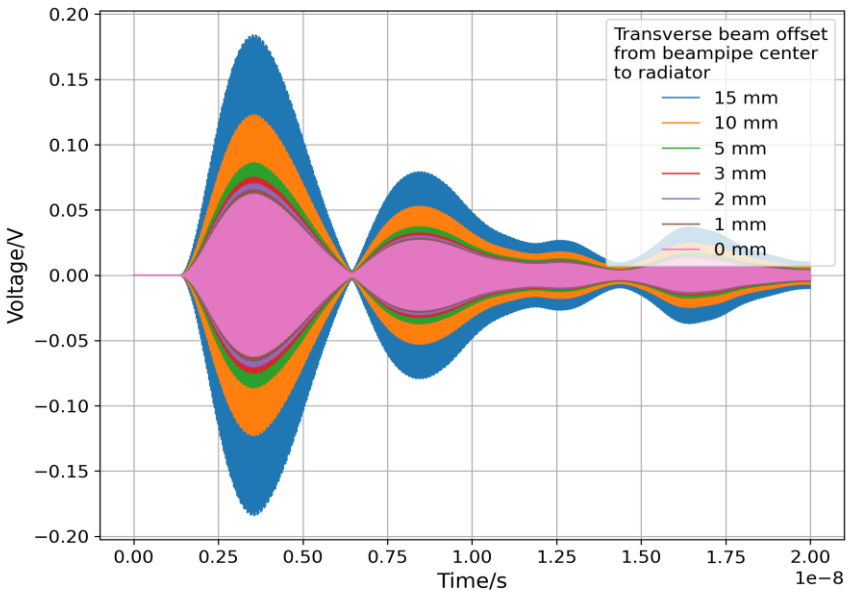
E-field



- Provides the **expected signal** output for different beam offsets
- Promising signal level out

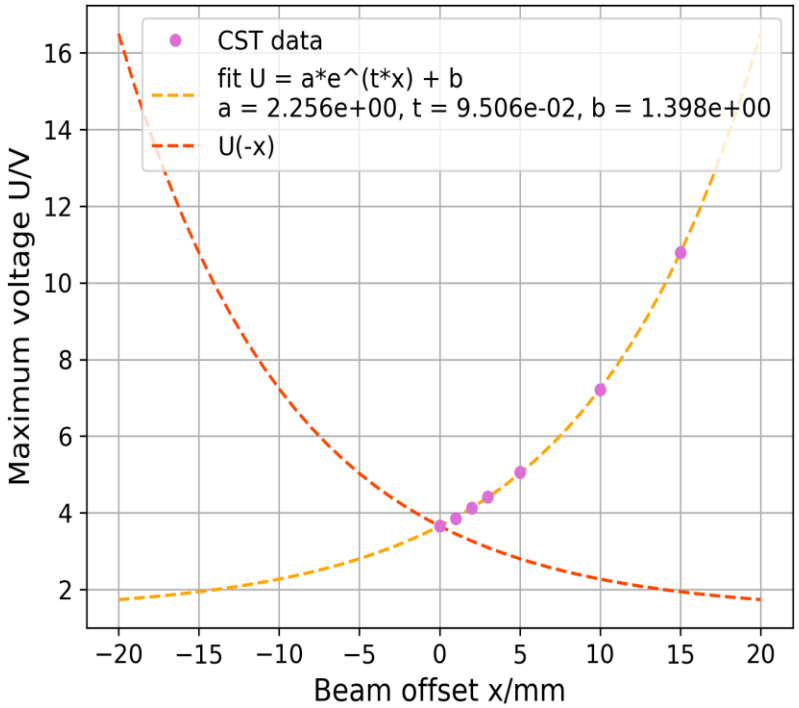


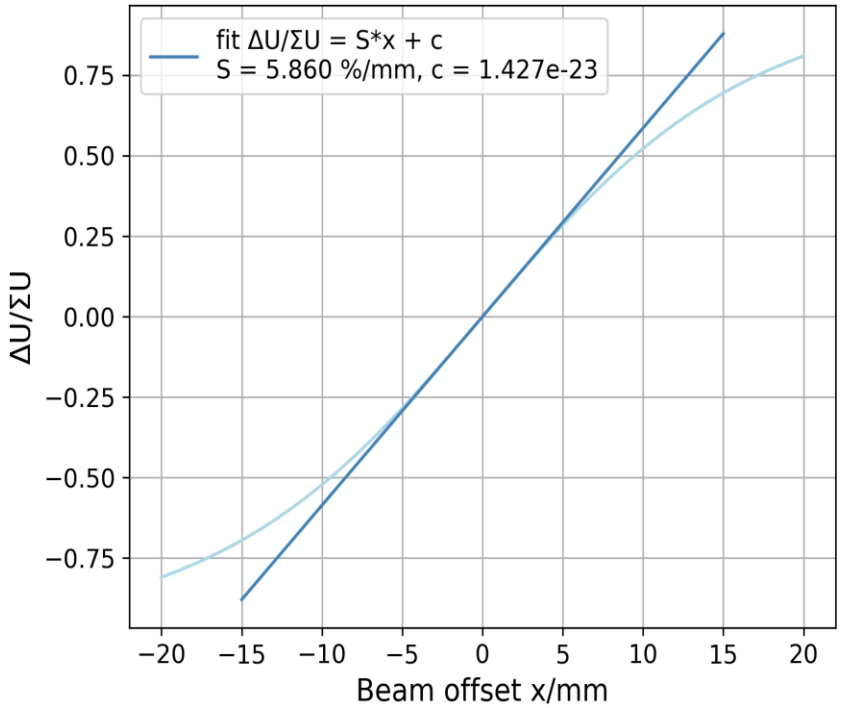
30 GHz, 300 MHz BW Butterworth filter



Numerical simulations

By taking the signal level at a given time for different beam offsets, provides **position response curve**





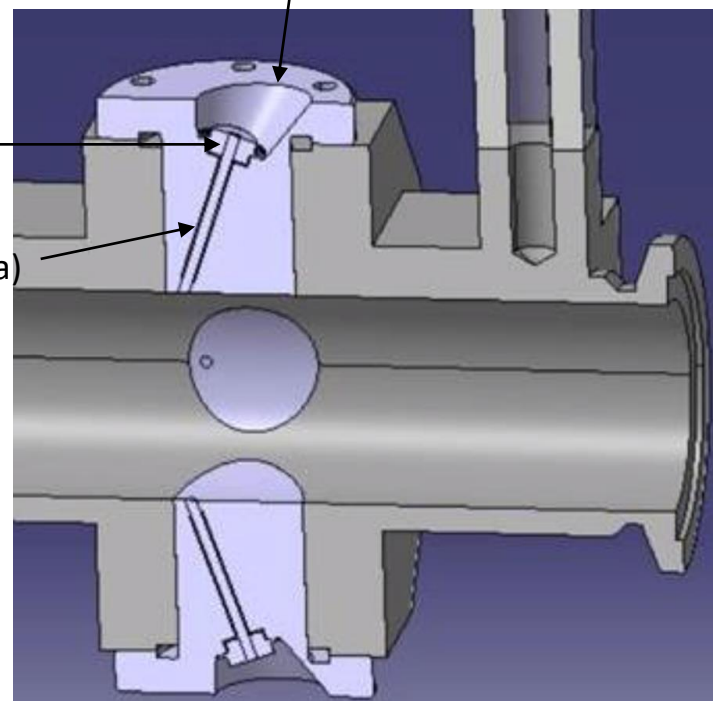
Summary of BPM specifications for 150 pC, 2.5 ps σ electron bunch

Parameter	Value
Position sensitivity	5.86 %/mm
Signal-to-noise ratio	Approx. 60/70 dB
Resolution	34.6 µm (300 MHz BW BPF)

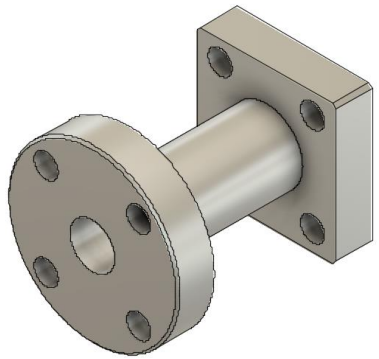
Useful system requirements for **development of front-end electronics** by TRIUMF

Status of BPM and future tests

- Alumina rods and fused quartz pieces should arrive in following weeks
- Allows for completion of manufacturing process of buttons and transitions
- Buttons to be tested in-vacuum at CLEAR once accelerator restarts in March 2022
- Installation of c-BPMs at AWAKE with TRIUMF electronics in **Summer 2022**



ChDR buttons in existing pBPM body



WG transition

Thank you for your attention!

Wish you all a Merry Christmas!