Beam instrumentation R&D on CLEAR

T. Lefevre on behalf of the CLEAR beam instrumentation team

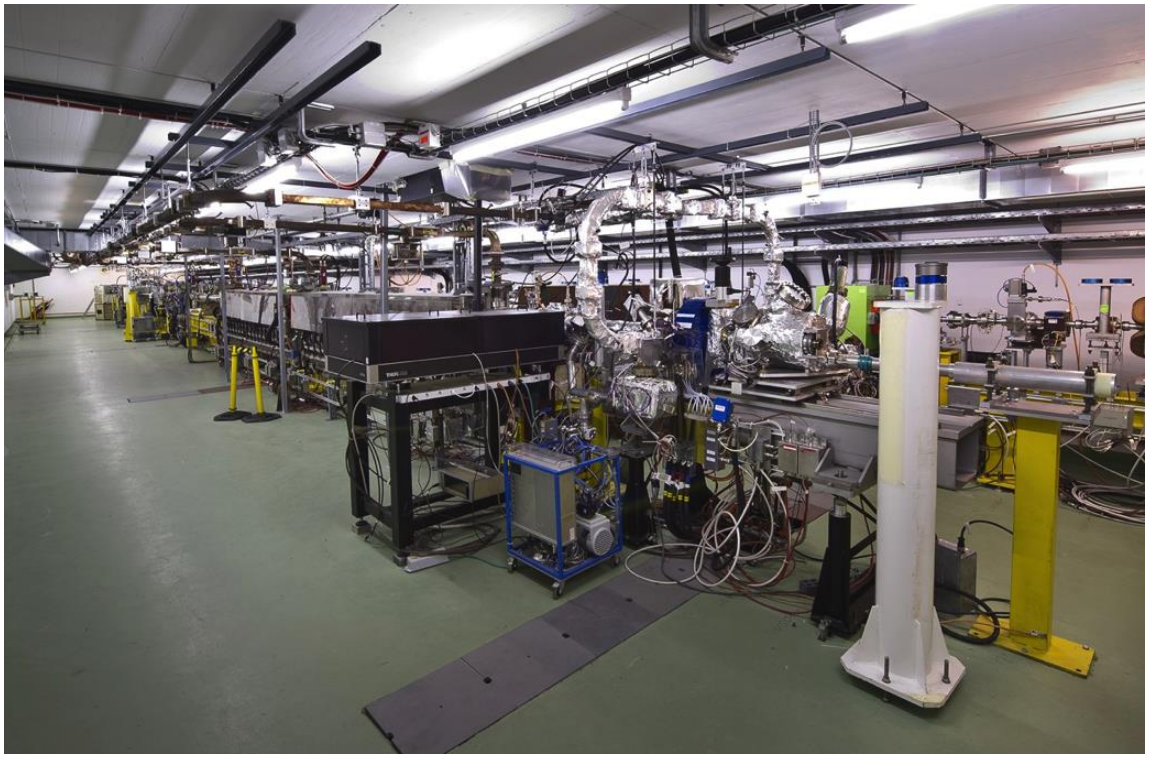
CLIC workshop, 21-25 January 2019, CERN

Outline

- **Testing beam instrumentation** on CLEAR
- **R&D** performed in **2018**
- **Planned R&D** for **2019-20**

Testing infrastructure

- What is a **dream** test facility for **beam instrumentation R&D** ?



Testing infrastructure

- What is a dream test facility for beam instrumentation R&D ?
  - **Machine easily accessible allowing fast Installation / changes** ?

Testing infrastructure

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  - **Machine easily accessible allowing fast Installation / changes** ?

    - Machine in access every Monday morning – including vacuum intervention
    - During beam tests, small radiation levels in CLEAR allow accessing machine several times a day if needed

Testing infrastructure

- What is a dream test facility for beam instrumentation R&D ?
  - **Flexible beam parameters** and **high beam quality and control** ?

Testing infrastructure

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  - **Flexible beam parameters** and **high beam quality and control** ?

Beam parameter (end of linac)	Value range
Energy	130 - 220 MeV (60 MeV with upgrade)
Bunch charge	0.01 - 1.5 nC
Normalized emittances	3 um for 0.05 nC per bunch, 20 um for 0.4 nC per bunch (in both planes)
Bunch length	ca. 500 um - 1.2 mm
Relative energy spread	< 0.2 % rms (< 1 MeV FWHM)
Repetition rate	1 - 5 Hz (25 Hz with upgrade)
Number of micro-bunches in train	Selectable between 1 and > 100
Micro-bunch spacing	1.5 GHz

- Low emittance :

Transverse beam size down to 10s microns

- Short bunches : sub-ps range

can possibly be shorter for new technology development (e.g. AWAKE)

- Would benefit from higher beam energies (e.g. 3GeV ≃ p^+@7TeV)
- Long term beam stability can be improved

Testing infrastructure

- What is a dream test facility for beam instrumentation R&D ?
  - Relying on **high quality beam instruments** for **cross-comparison ?**

Testing infrastructure

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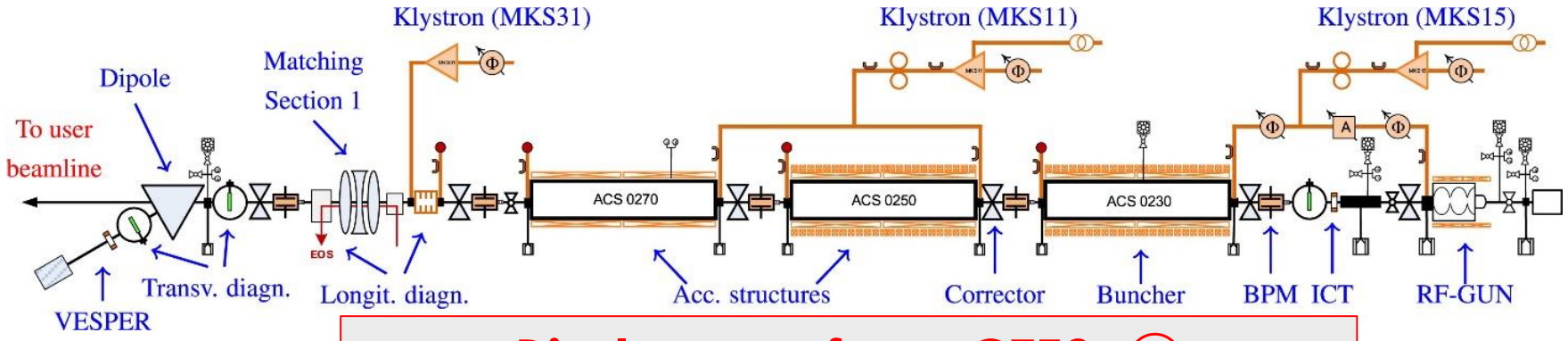
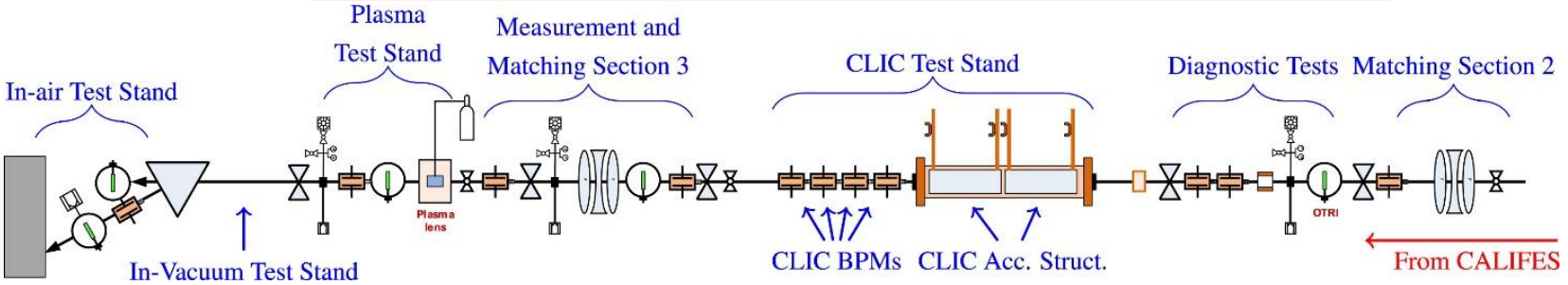


Big legacy from CTF3 😀



Testing infrastructure

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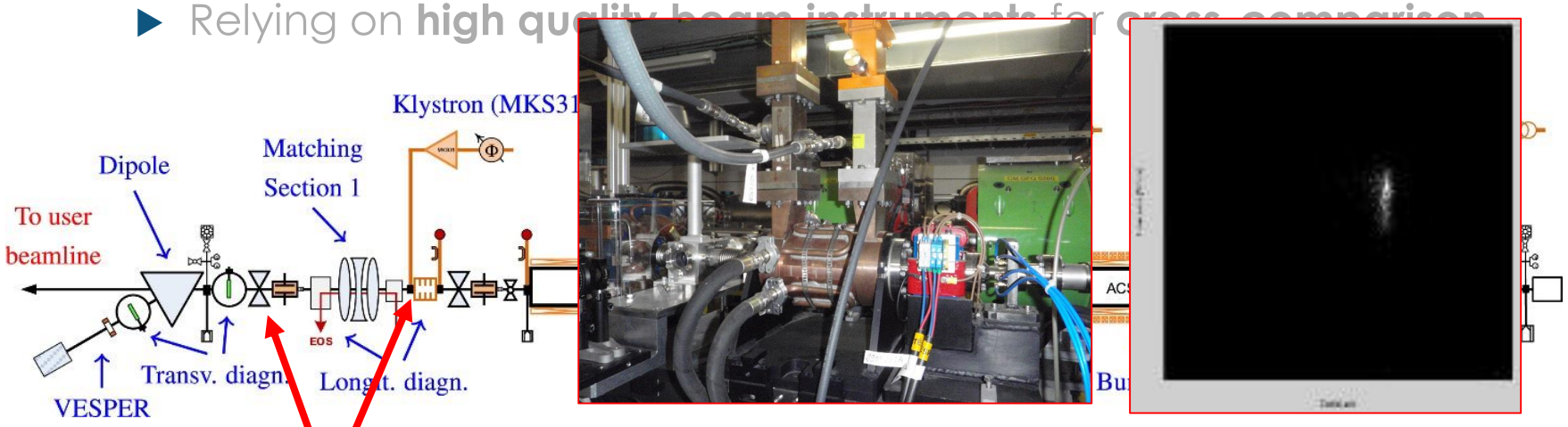


Transverse and Longitudinal diagnostics

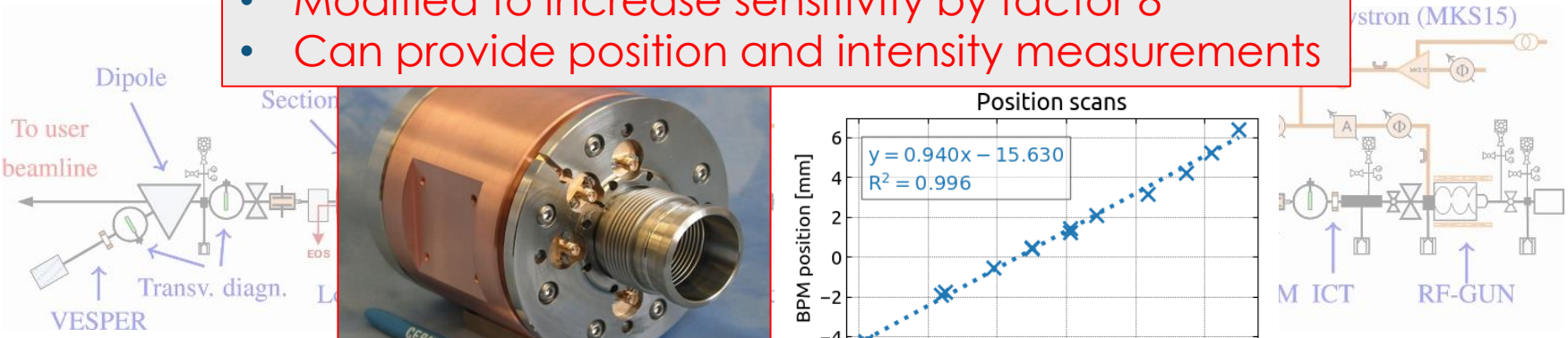
RF deflector, OTR screens (to Streak camera)

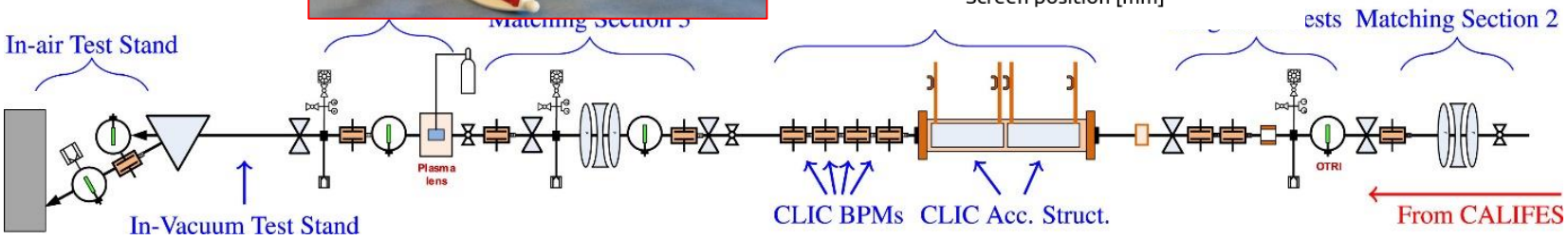
Testing infrastructure

- What is a **dream** test facility for **beam instrumentation R&D** ?
  - Re… …parison

Inductive BPMs

- Modified to increase sensitivity by factor 8
- Can provide position and intensity measurements



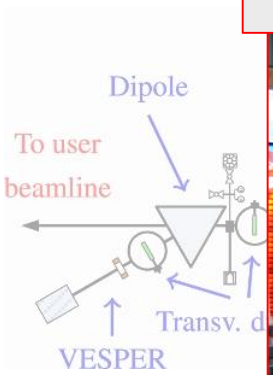


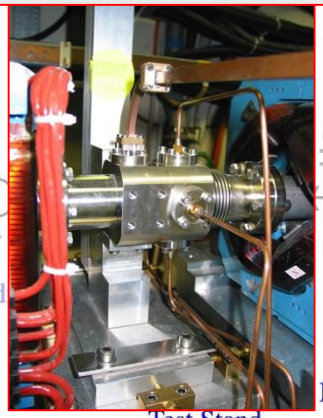
Testing infrastructure

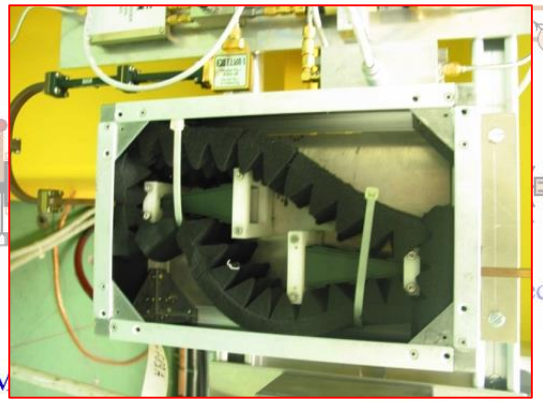
- Wha
  - R

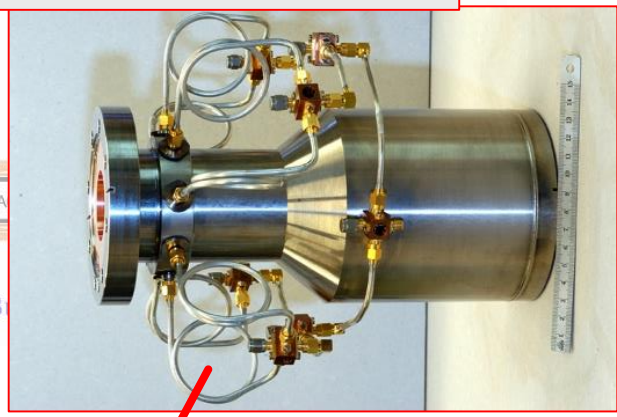
Longitudinal monitors

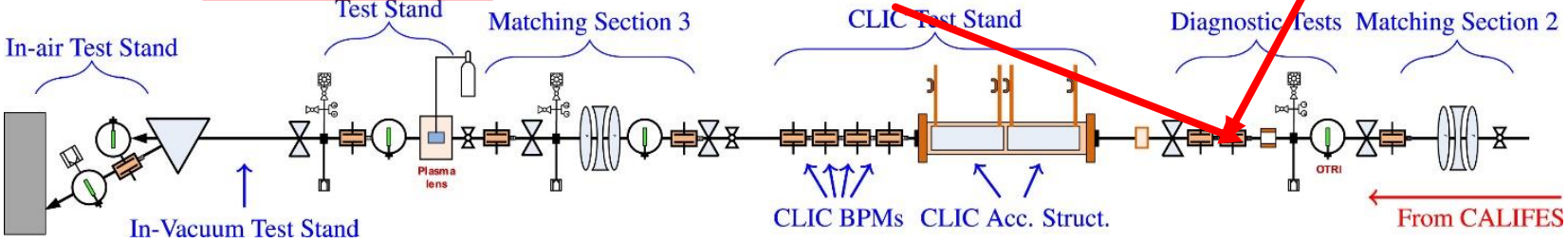
- WCMs -High bandwidth (10kHz-7GHz) and High sensitivity
- BPR's (Ka band power measurement)





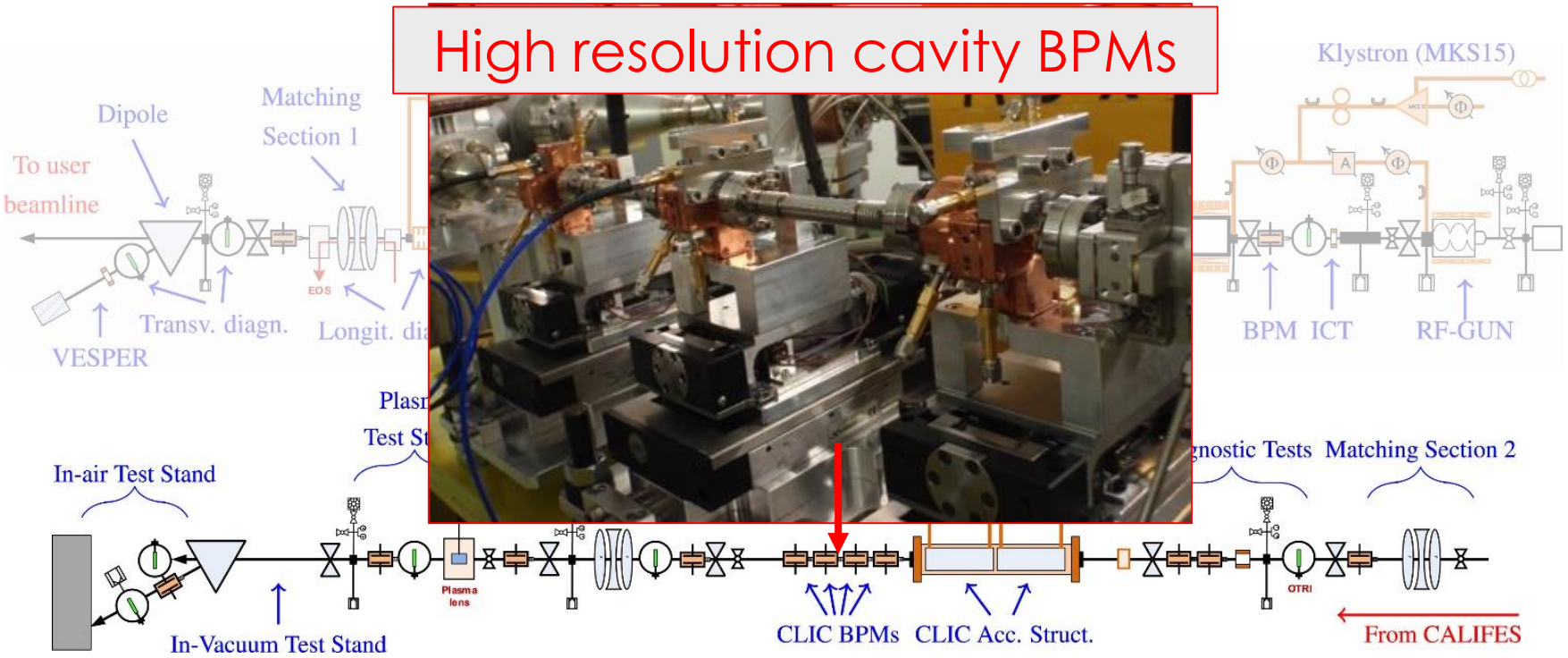






Testing infrastructure

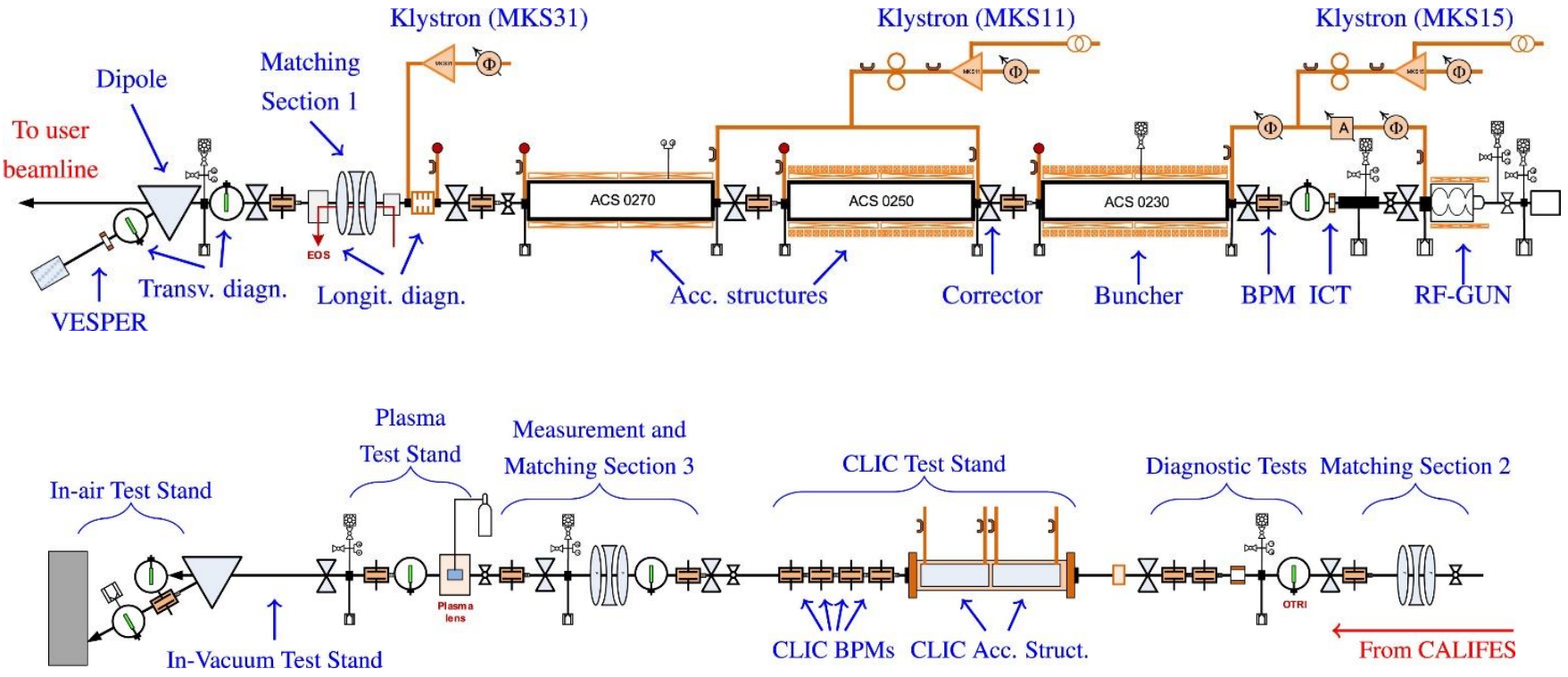
- What is a **dream** test facility for **beam instrumentation R&D** ?
  - Relying on **high quality beam instruments** for **cross-comparison**



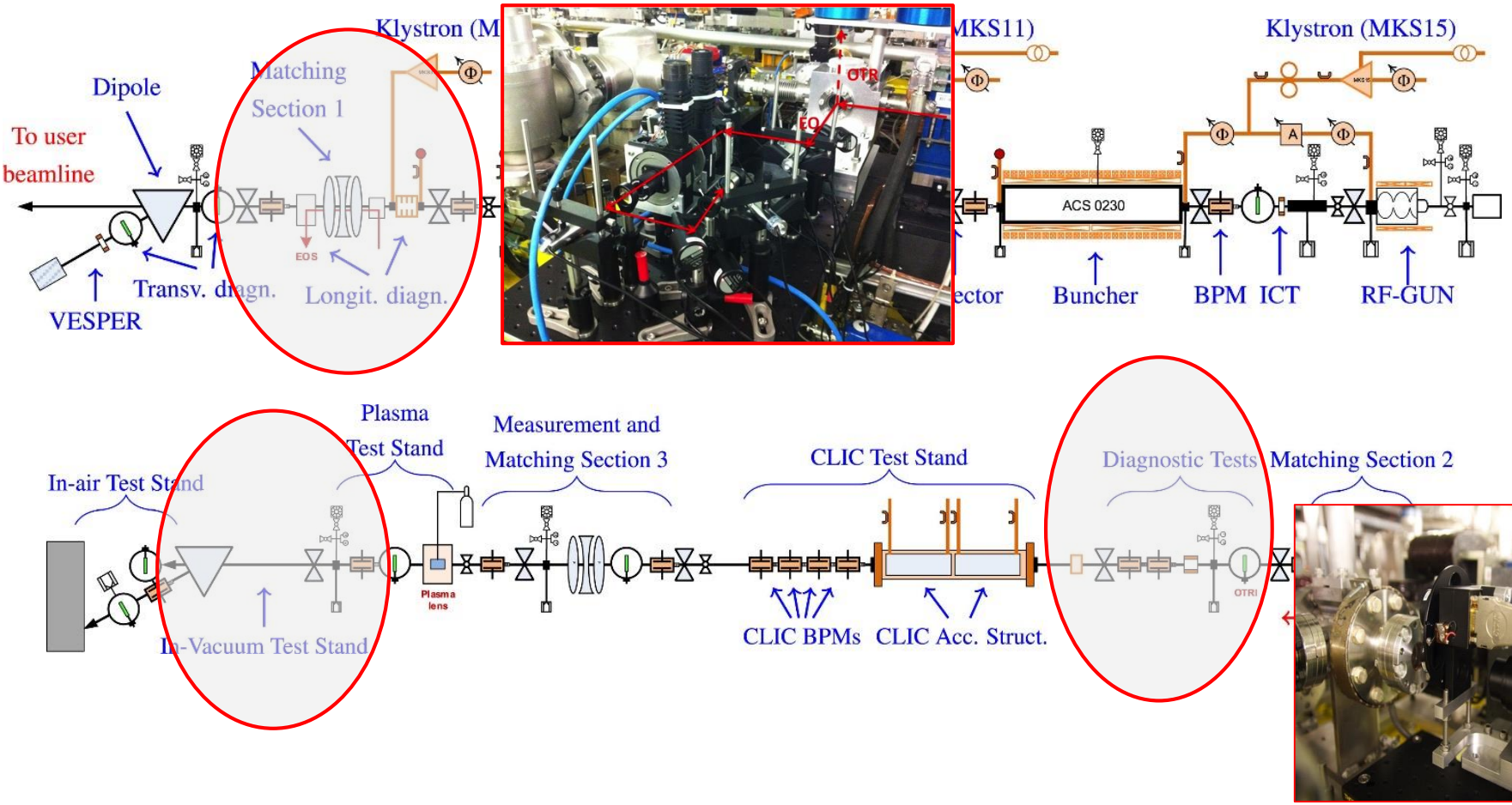
Testing infrastructure

- What is a **dream** test facility for **beam instrumentation R&D** ?
  - Machine easily accessible allowing fast Installation / changes 😀
  - Flexible beam parameters and high beam quality and control 😉
  - Relying on high quality beam instruments for cross-comparison 😀
    - Still some work to do on BI to make them operational

Different Testing Areas



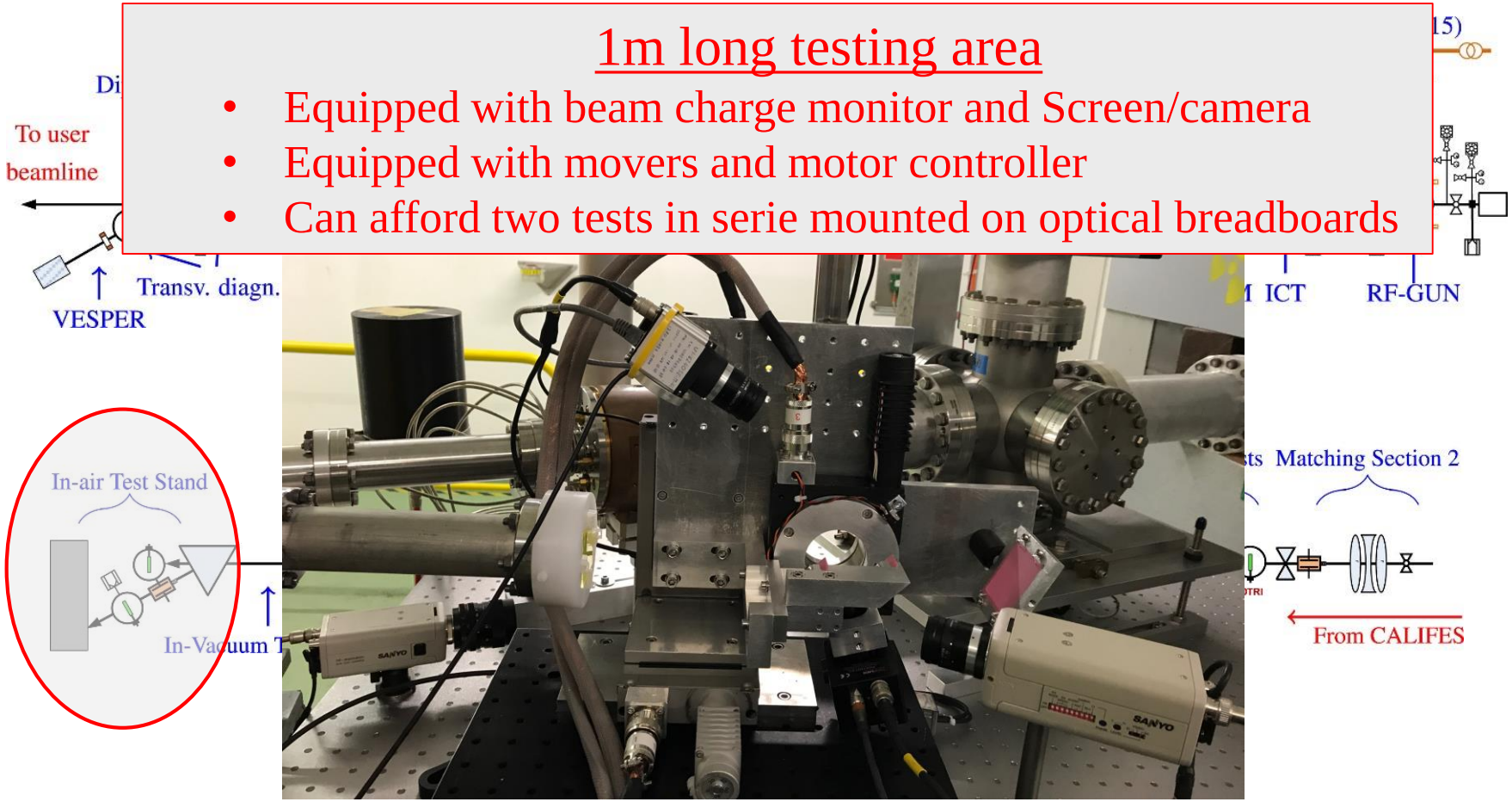
In-vacuum Testing Areas



In-air Testing Area

1m long testing area

- Equipped with beam charge monitor and Screen/camera
- Equipped with movers and motor controller
- Can afford two tests in serie mounted on optical breadboards



R&D performed in 2018

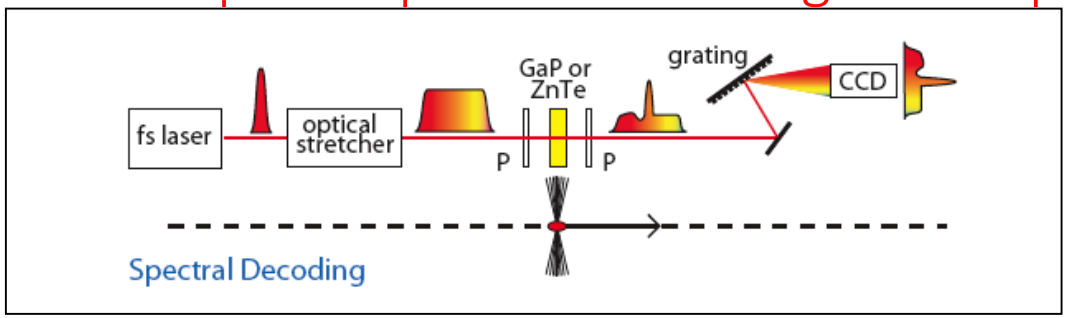
R&D performed in 2018

- **AWAKE run 2 diagnostics – Short bunch length monitors**

Single shot, non-destructive bunch length measurement

using

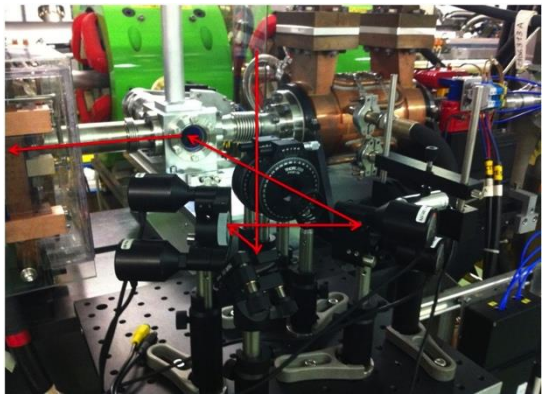
Electro- Optical Spectral Decoding Technique



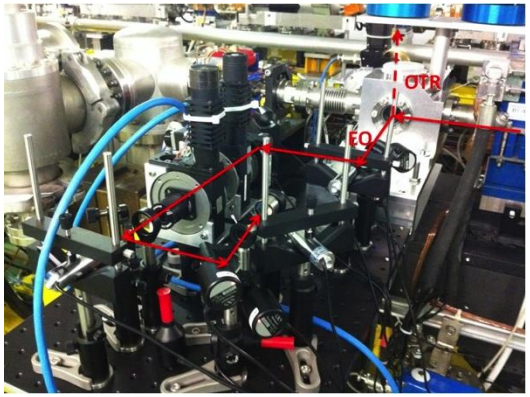
- Using beam induced bi-refringency in a non-linear crystal to encode the temporal profile of the beam field onto a chirped laser beam (time to frequency)
- Measuring the laser spectrum to decode the electron bunch length

R&D performed in 2018

- AWAKE run 2 diagnostics – Short bunch length monitors
- **Concept : Simplify and upgrade the existing EOS**
  - Re-uing laser and detection system
  - Replacing hardware configuration in the tunnel



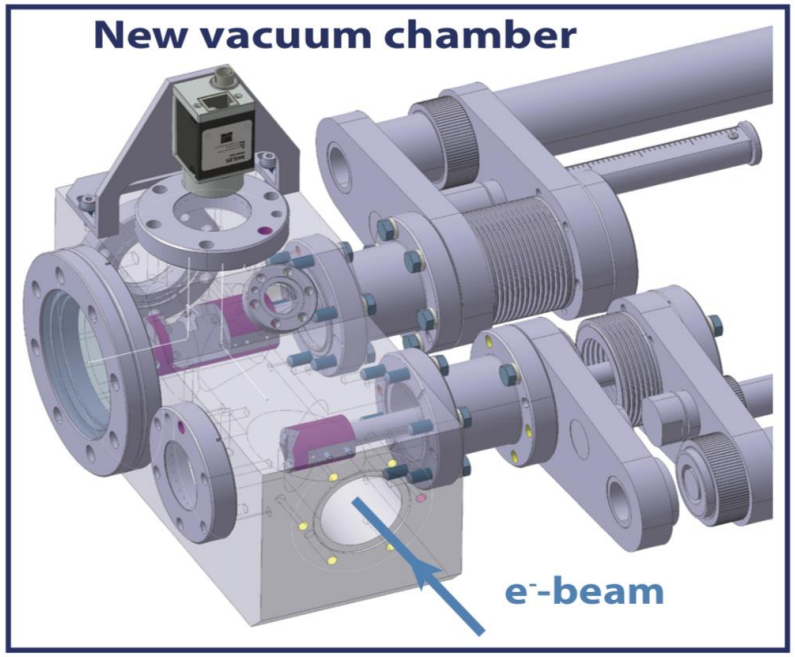
First polariser and
Laser injection Chamber

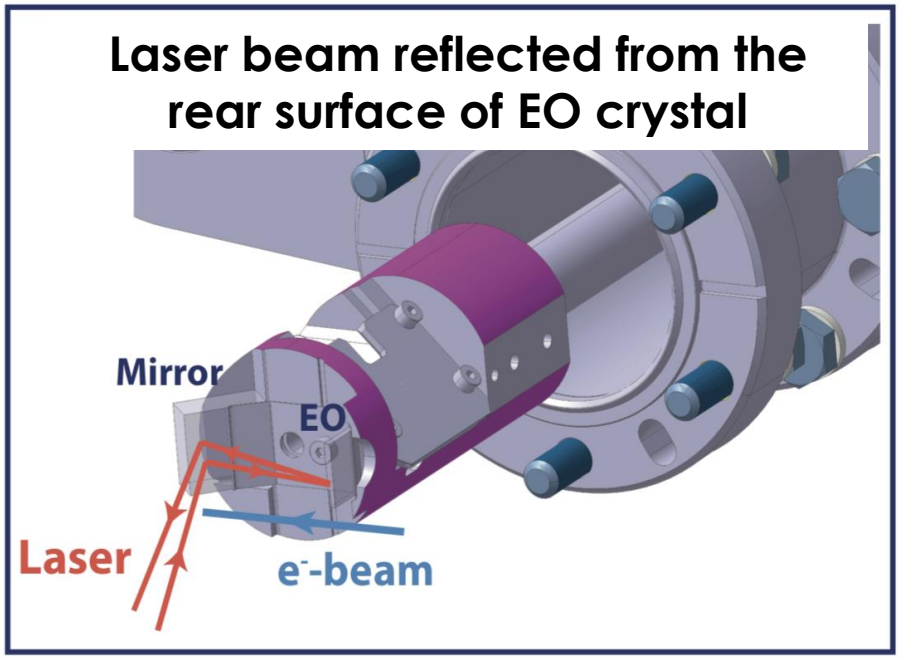


Crystal chamber (4mm ZnTe), crossed polariser and fiber coupling back to lab

R&D performed in 2018

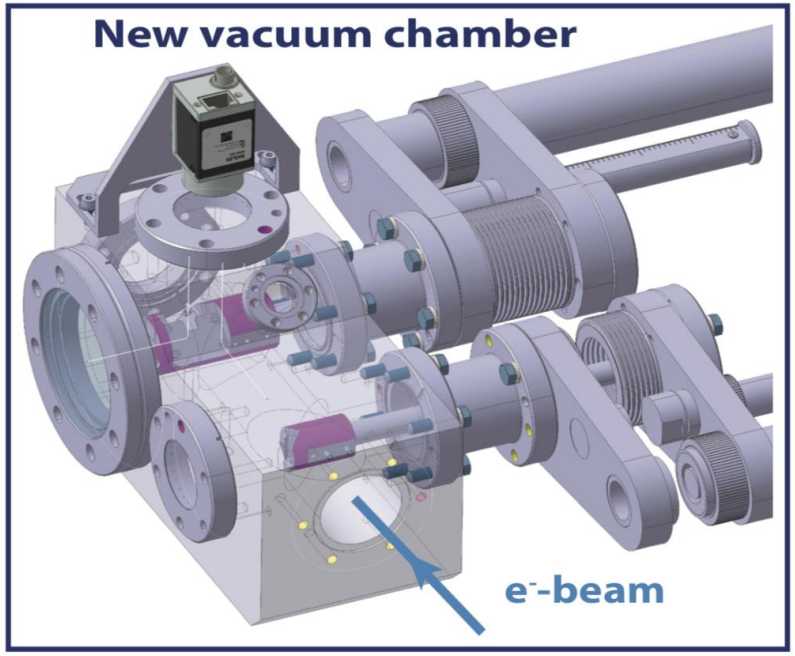
- AWAKE run 2 diagnostics – Short bunch length monitors
- **New Vacuum chamber :** Compact and easier to align and operate

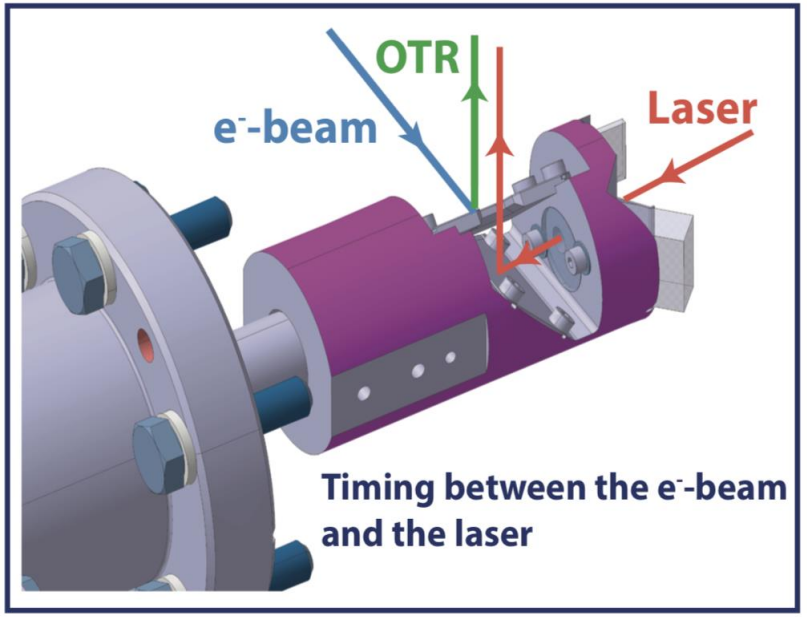




R&D performed in 2018

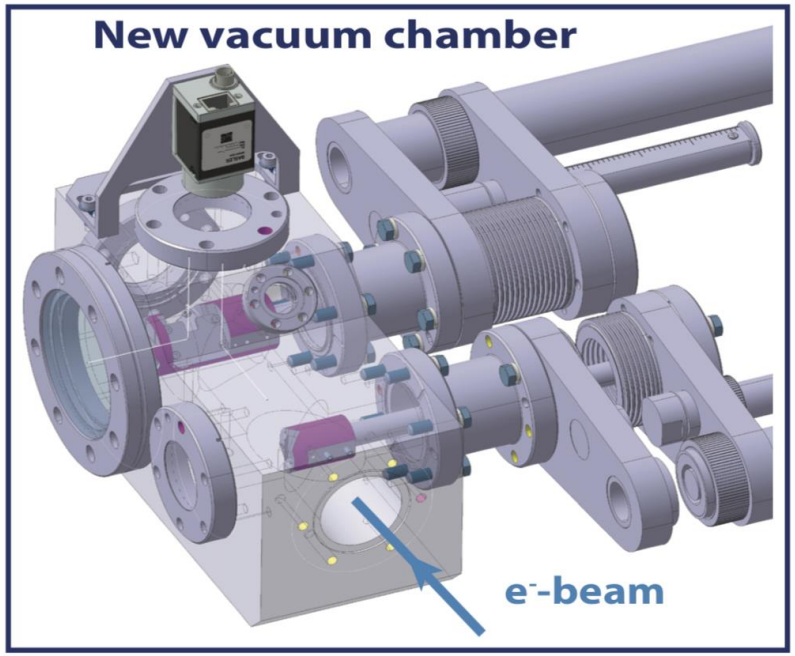
- AWAKE run 2 diagnostics – Short bunch length monitors
- **New Vacuum chamber :** Compact and easier to align and operate





R&D performed in 2018

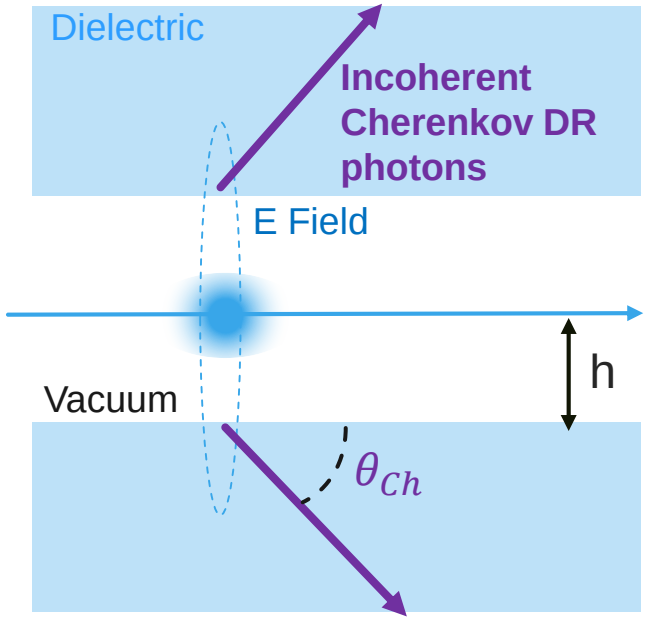
- AWAKE run 2 diagnostics – Short bunch length monitors
- **New Vacuum chamber :** Compact and easier to align and operate



- **The vacuum chamber is being built**
- **Installation planned on March-April 2019**
- **Full operation second half of 2019**

R&D performed in 2018

- Development of non-invasive beam instruments using **incoherent Cherenkov Diffraction Radiation in long dielectrics**

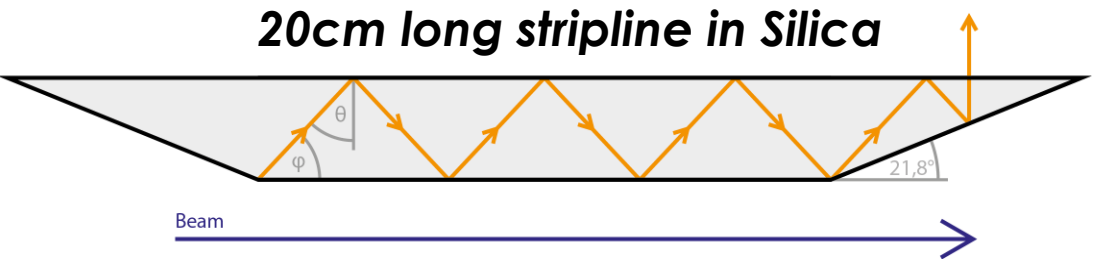


- In order to complement the studies performed at ATF2/Cornell/Diamond
- Aiming for applications at CERN accelerator complex (SPS / LHC)

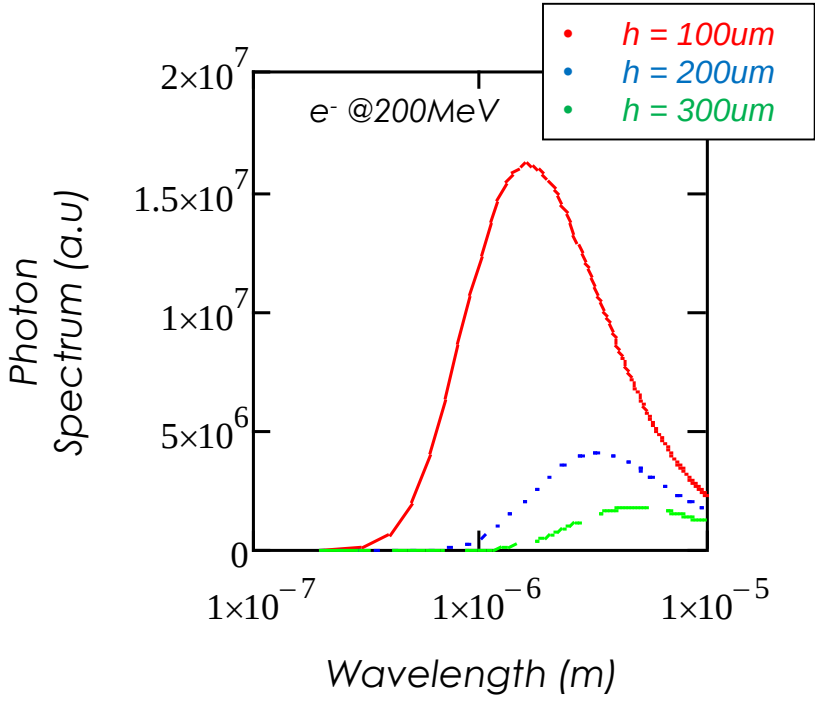
*R. Kieffer et al., "Direct Observation of Incoherent Cherenkov Diffraction Radiation in the Visible Range", PRL **121** (2018) 054802*

R&D performed in 2018

- Development of non-invasive beam instruments using incoherent Cherenkov Diffraction Radiation in long dielectrics

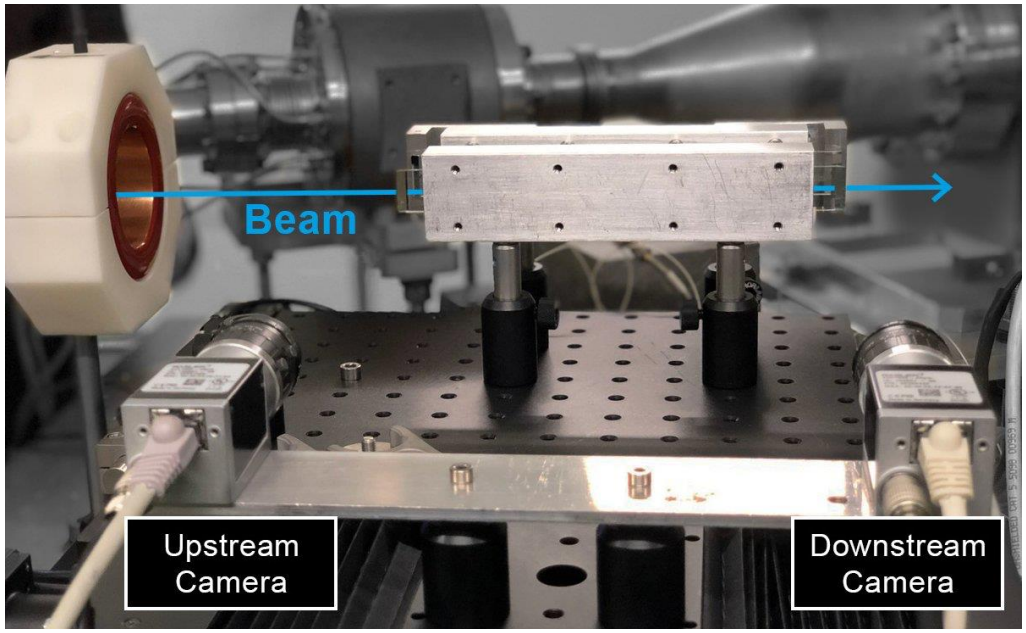


Investigating long(er) radiator (mm to 10s of cm) in order to increase the light yield and use those for low(er) beam energies and at large distances (few cm) from beams



R&D performed in 2018

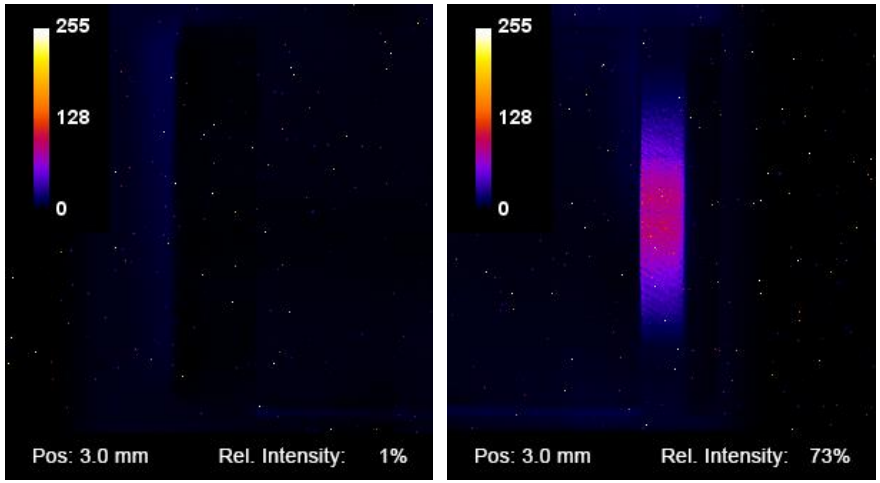
- Development of non-invasive beam instruments using incoherent Cherenkov Diffraction Radiation in long dielectrics



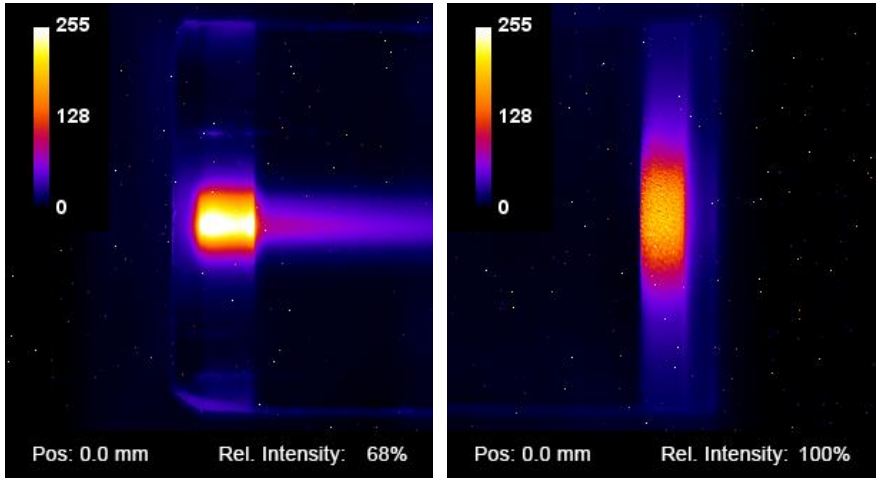
Measuring with cameras in visible range

R&D performed in 2018

- Development of non-invasive beam instruments using incoherent Cherenkov Diffraction Radiation in long dielectrics



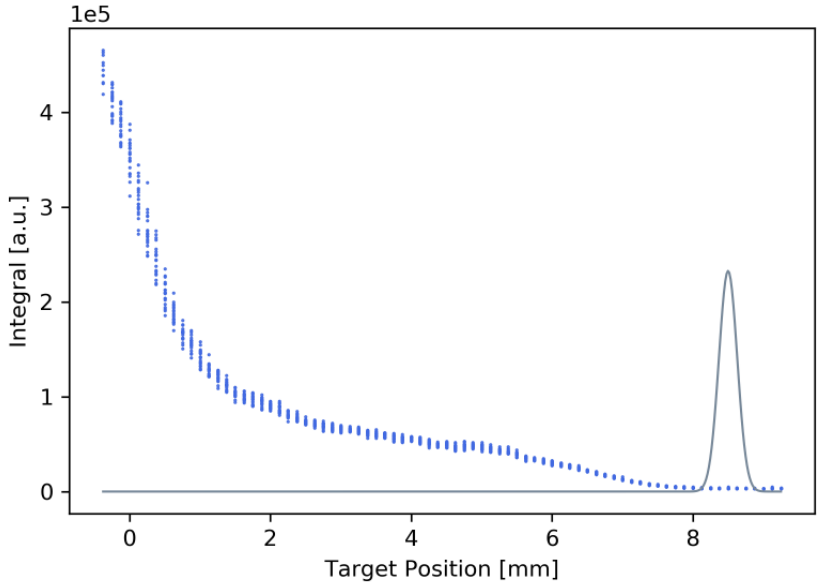
Beam at 3mm from surface of the dielectric



Beam touching the surface of the dielectric

R&D performed in 2018

- Development of non-invasive beam instruments using incoherent Cherenkov Diffraction Radiation in long dielectrics



Example of a position scan using a 50pC bunch

σ(BTV) = 130 μm. A 600 nm filter with a bandwidth of 10 nm was applied.

R&D performed in 2018

- Development of non-invasive beam instruments using incoherent Cherenkov Diffraction Radiation in long dielectrics
  - ***Long dielectrics*** *(20cm) enabled to provide a* ***large photon flux***
    - *Very encouraging results for BPM applications on protons at >450GeV*
    - *Possibly a way to get beam position for bunched and unbunched beams*
  - *Looking for* ***better engineered solution*** *to be tested in 2019-20 using optimised radiator and different wavelengths (visible and NIR)*
  - *Possibly trying* ***even longer detectors*** *to investigate the possibility of measuring* ***single particle*** *non-invasively*

Planned R&D in 2019-20

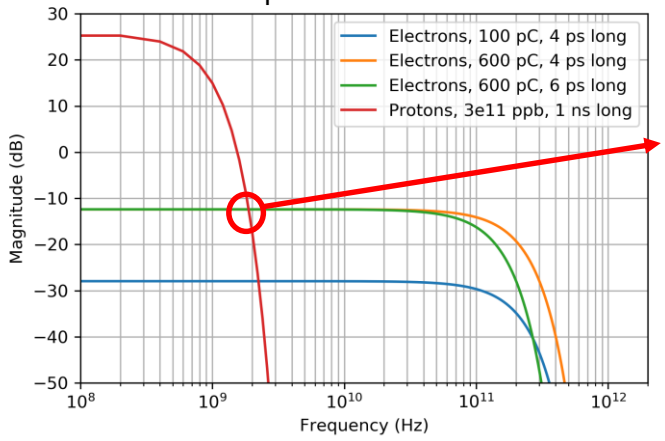
Planned R&D in 2019-20

- **AWAKE run 2 diagnostics – Electron BPM**

Planned R&D in 2019-20

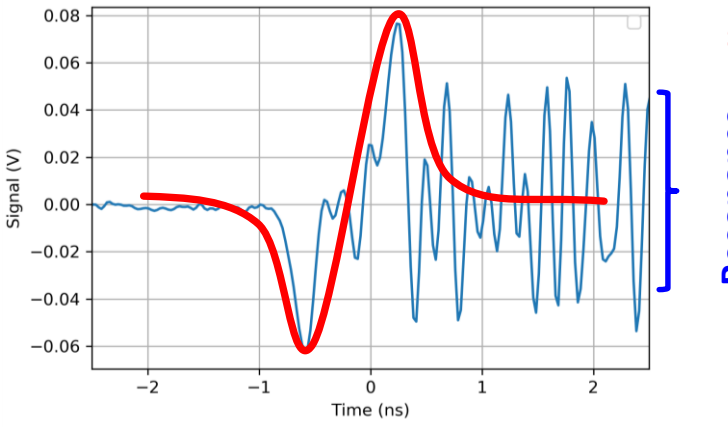
- **AWAKE run 2 diagnostics – Electron BPM**
  - **Issue :** A BPM capable of measuring low charge short electron bunch in presence of a high charge long proton bunch

Bunch spectrum



Same magnitude at ~2 GHz

AWAKE BPM response



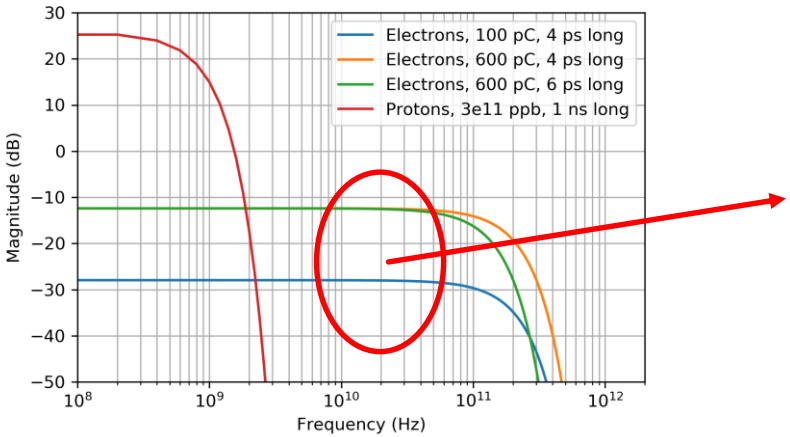
Electron bunch signal

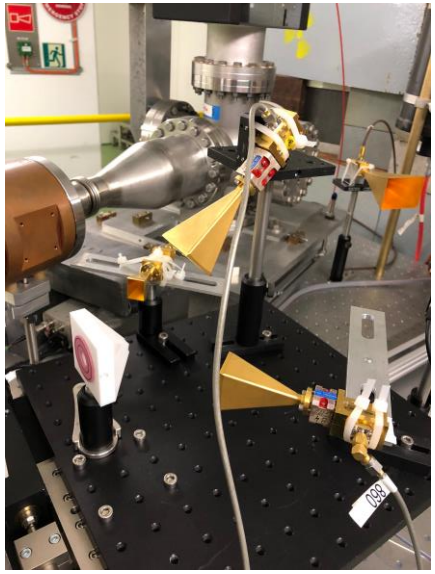
Resonance pattern

Measuring using the **present system** is problematic due to pickup resonances in the GHz range excited by the beam

Planned R&D in 2019-20

- **AWAKE run 2 diagnostics – Electron BPM**
  - **Concept :** Designing a BPM using Coherent Cherenkov radiation emitted at frequencies between 10-20GHz





As shown in Alessandro's talk

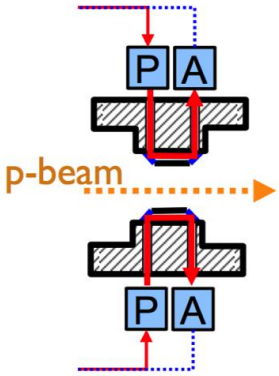
Need to develop a full engineered solution

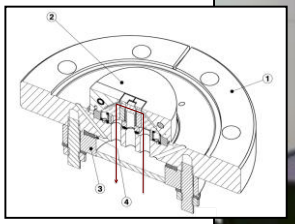
Planned R&D in 2019-20

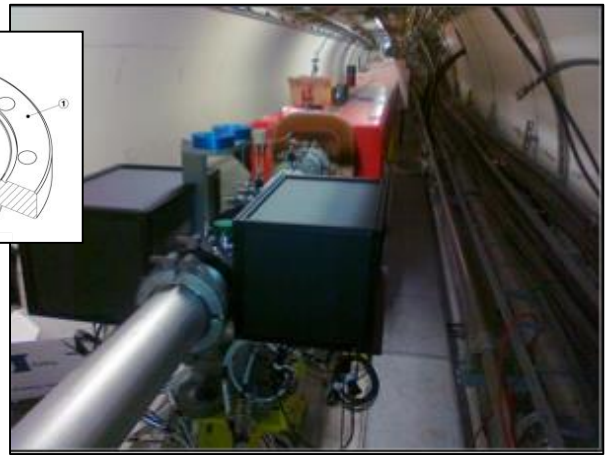
- Testing new monitors - **Electro-optical BPM for HL-LHC**

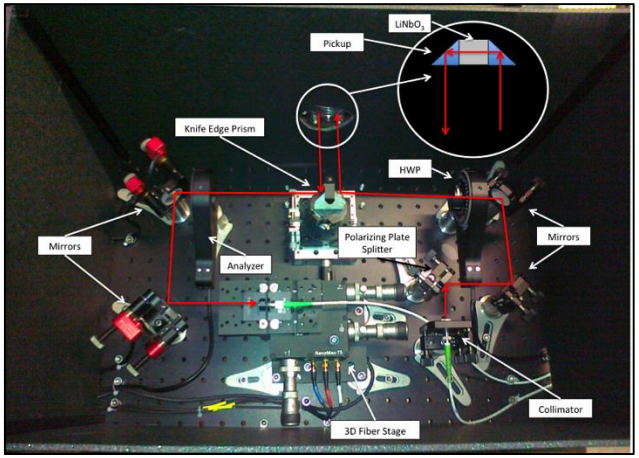
Planned R&D in 2019-20

- Testing new monitors - **Electro-optical BPM for HL-LHC**
  - Prepared the infrastructure in 2018 with installation of polarisation maintaining fibers in the in-air system
  - Testing the EO BPM recuperated from SPS



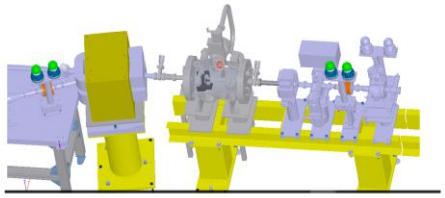


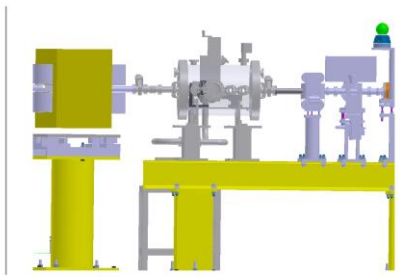


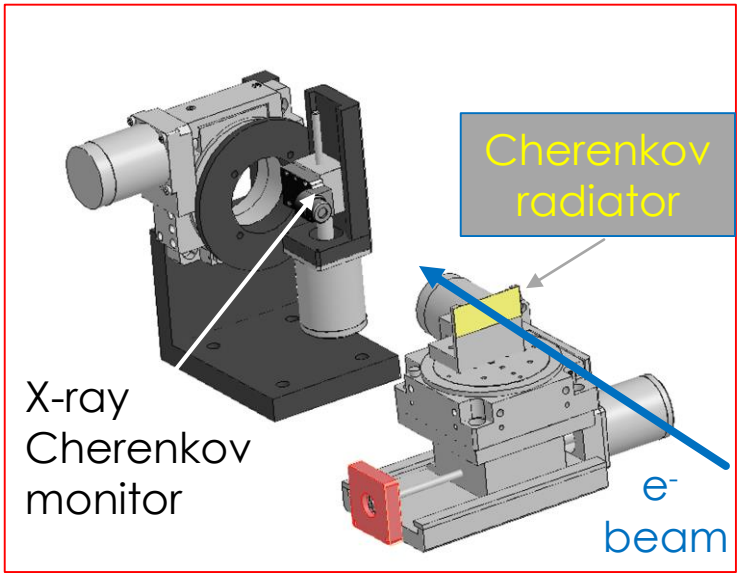


Planned R&D in 2019-20

- Testing new monitors - **Study on the production of X-ray Cherenkov radiation**
  - More fundamental physic study
  - Fully financed by Russian institute







Conclusions

- CLEAR has demonstrated its potential to allow efficient R&D for beam instrumentation in two steps :
  - In-air tests provide a solution for fast, flexible and efficient prototyping
  - In-vacuum test would then allow a final validation of well engineered solutions
- Developments for AWAKE, SPS and LHC are already showing promising results
- We would benefit from add. Beam lines to increase the testing capabilities both In-air/In vacuum

Thank you for listening

Many thanks to CLEAR BI team !!

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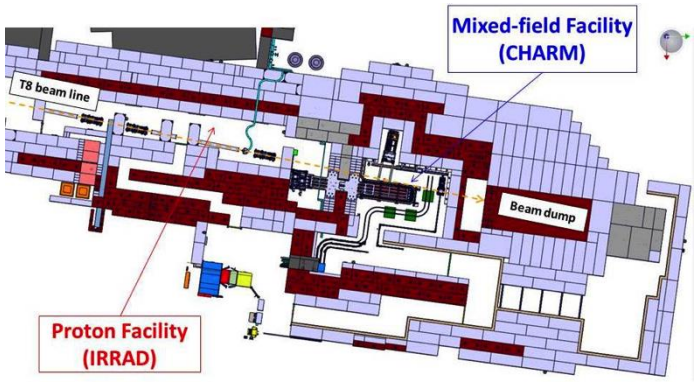
Developing Beam diagnostics at CERN

- Testing on **CERN PS Complex Area**
  - IRRAD – Proton irradiation (24GeV, max 5.10^{11} protons per spill, Up to 10^{18} protons)
    see https://irradiation.web.cern.ch/irradiation/
  - CHARM (CERN High-energy AcceleRator Mixed field facility) : mimic radiation environment found in the accelerator chain
    see https://charm.web.cern.ch/CHARM/



- Testing on **CERN SPS Area**
  - High Radiation to Material – 450GeV Protons with up to 288 Bunches with 25ns spacing (3 10^{13} protons per pulse)

see https://espace.cern.ch/hiradmat-sps/Wiki%20Pages/Home.aspx

  - Gamma Irradiation Facility in NA with a 15 TBq ^{137}Cs source

see https://gif-irrad.web.cern.ch/gif-irrad/

Developing Beam diagnostics at CERN

- Testing directly on the Operational Machines themselves
  - It works..but may lead to unpleasant surprises
    - *e.g. Beam position dependency of CERN Fast Beam Current Transformer on LHC*
  - Limited time for hardware installation/modification in the tunnel (i.e. Technical stops)
  - Limited beam time available for tests during MDs
  - R&D is not always compatible with the strict requirements for Operational Machines

e.g. Testing gas jet monitor and their performance as function of gas pressure would conflict with vacuum requirements