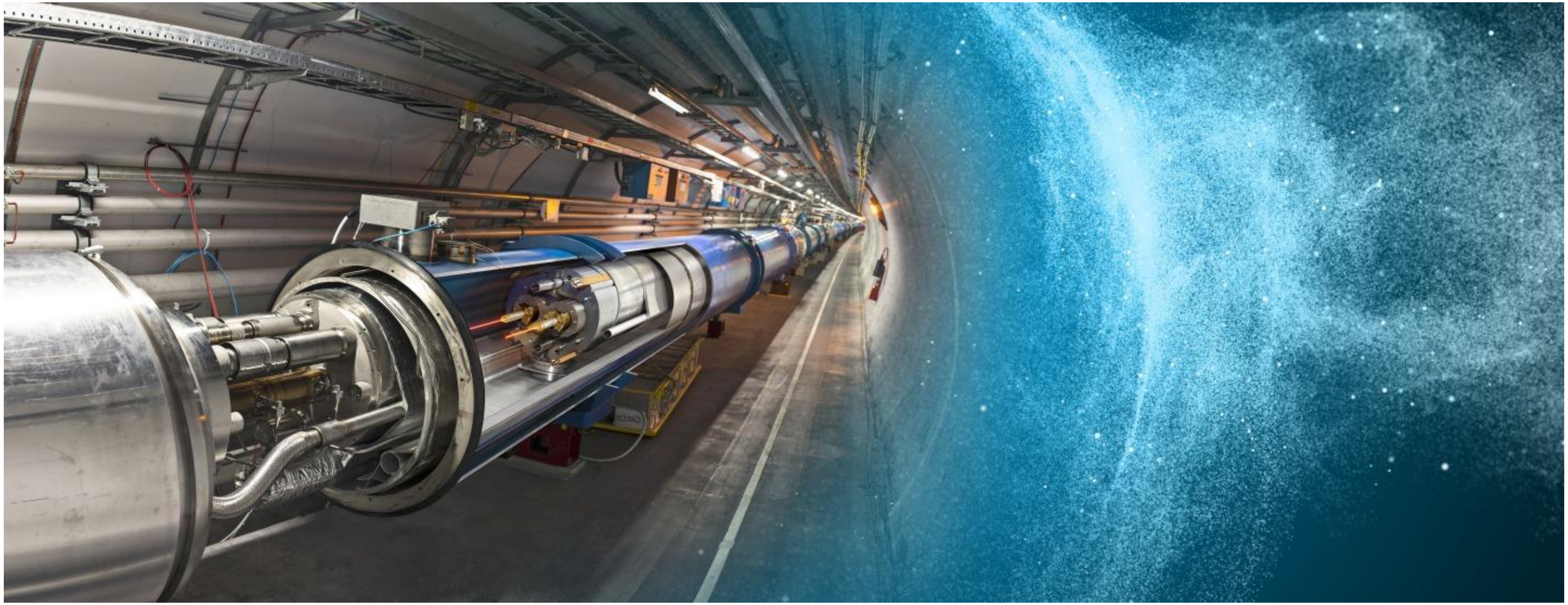
CLEAR BEAM TRAINING

Have a chance to operate a real accelerator at CERN

Antonio Gilardi - Wilfrid Farabolini

OUTLINE:

- Introduction
- Nuclear Irradiation
- Plasma lens
- X-Band ACS
- Proposed activity



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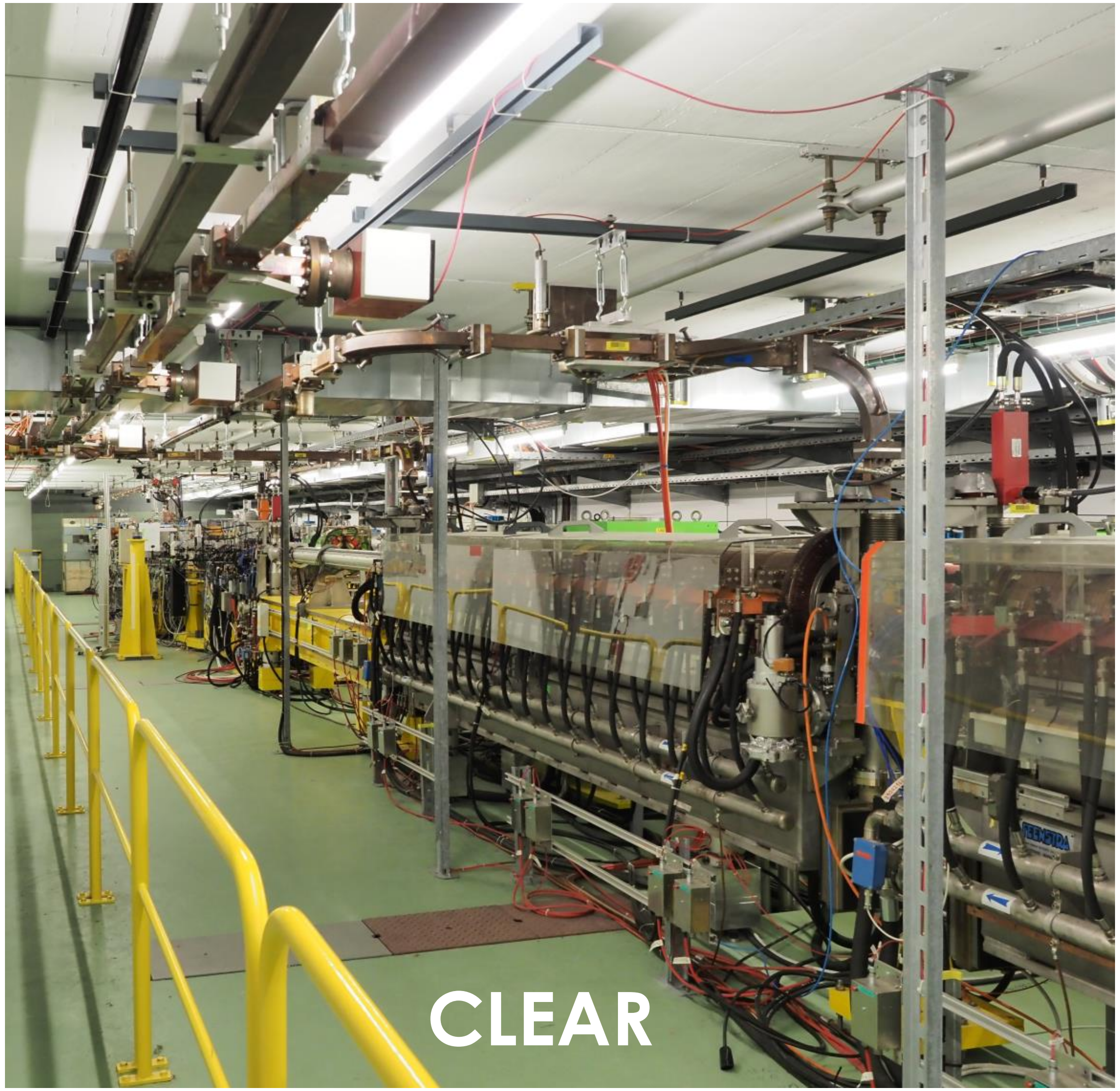
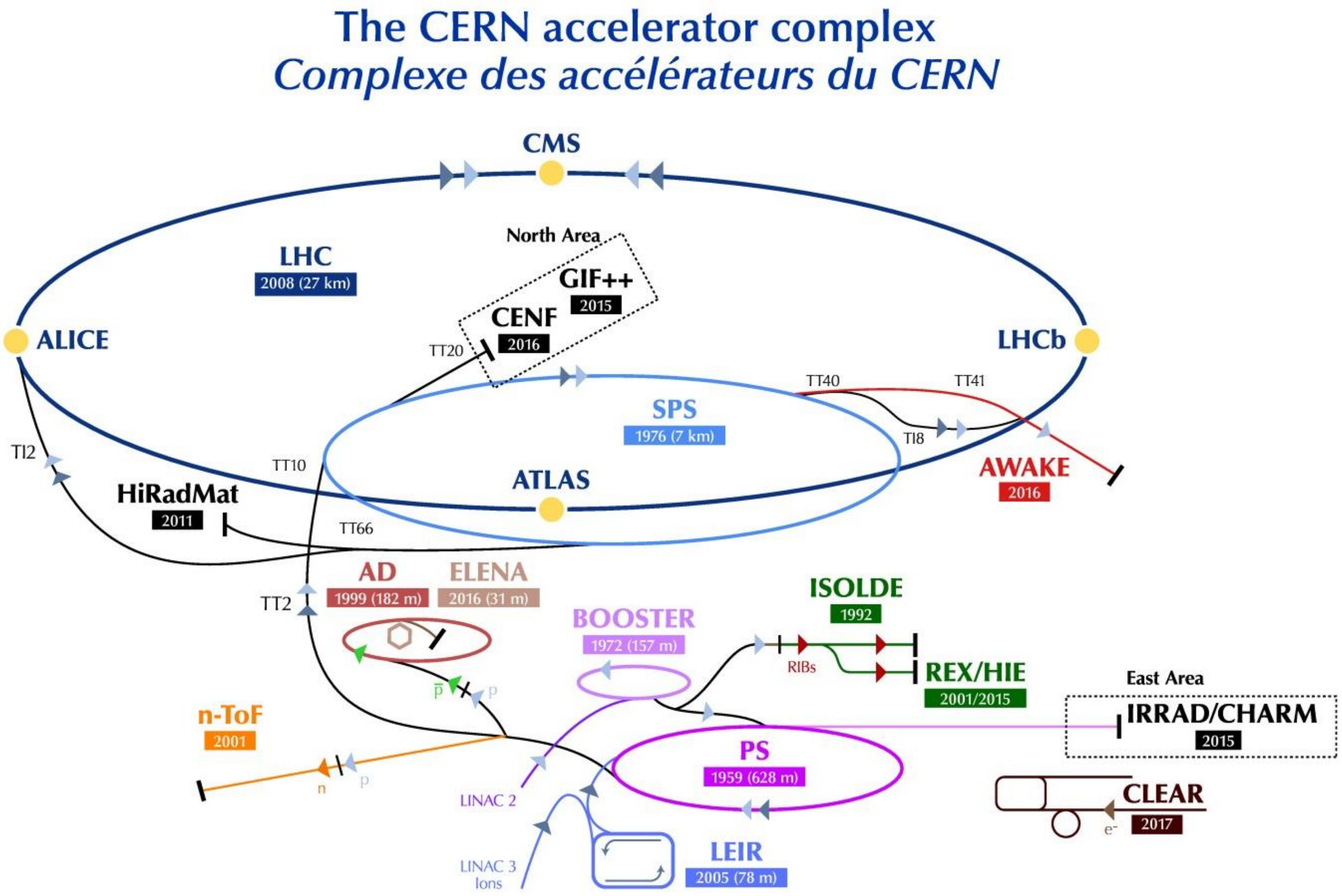


Accelerator overview



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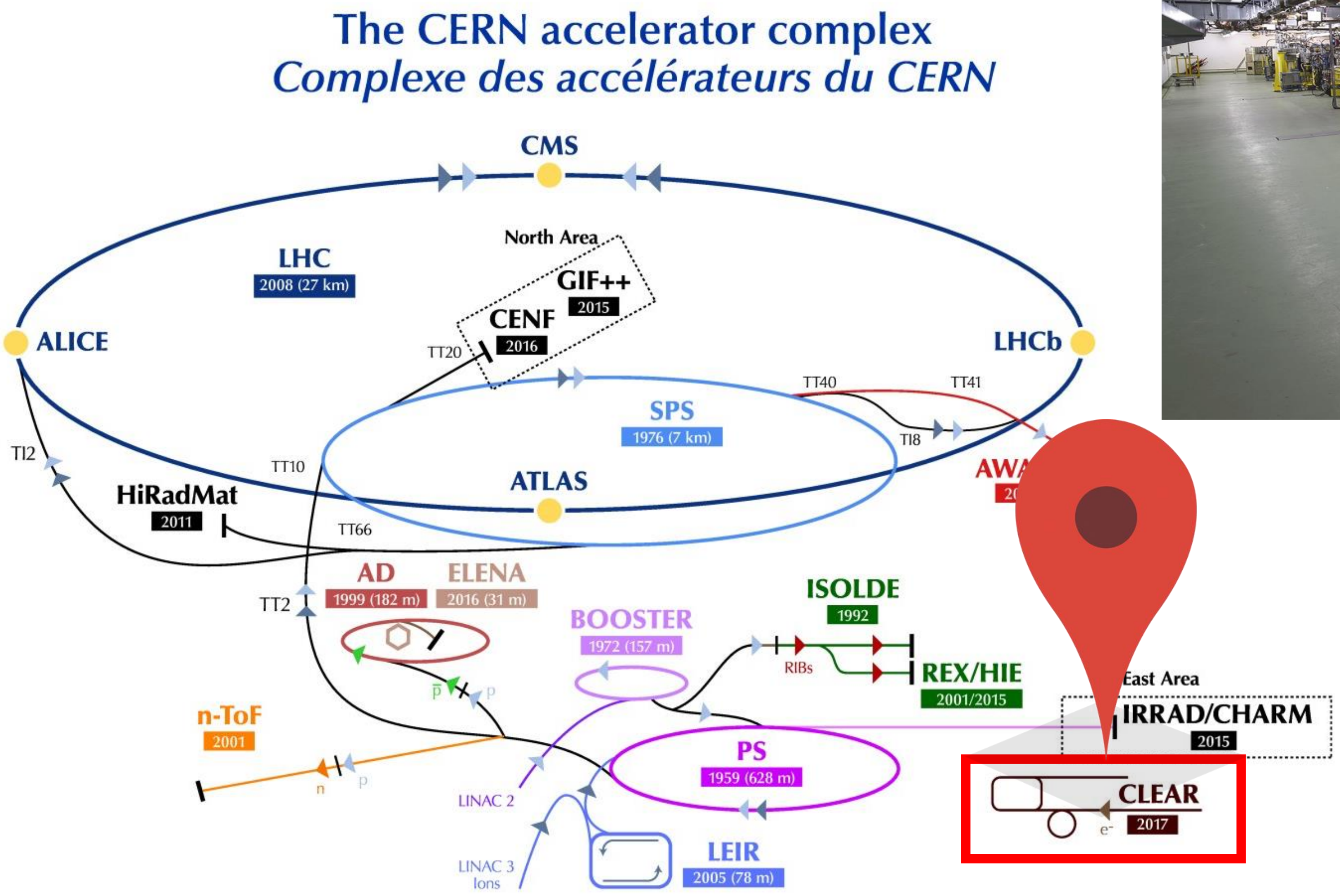
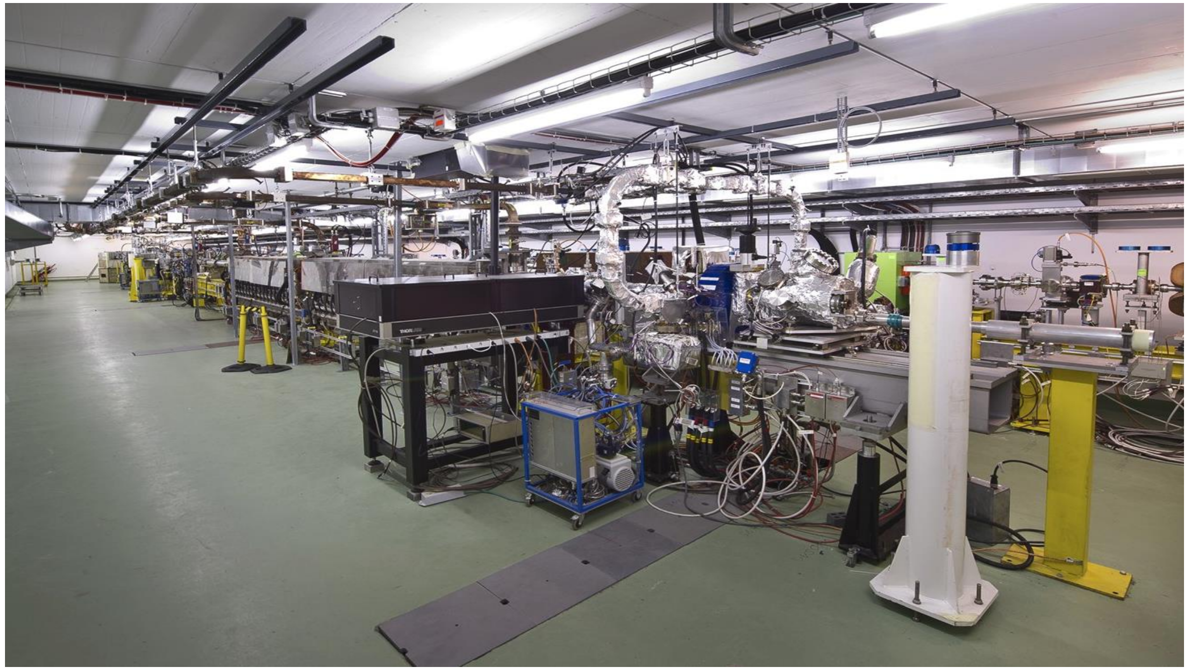
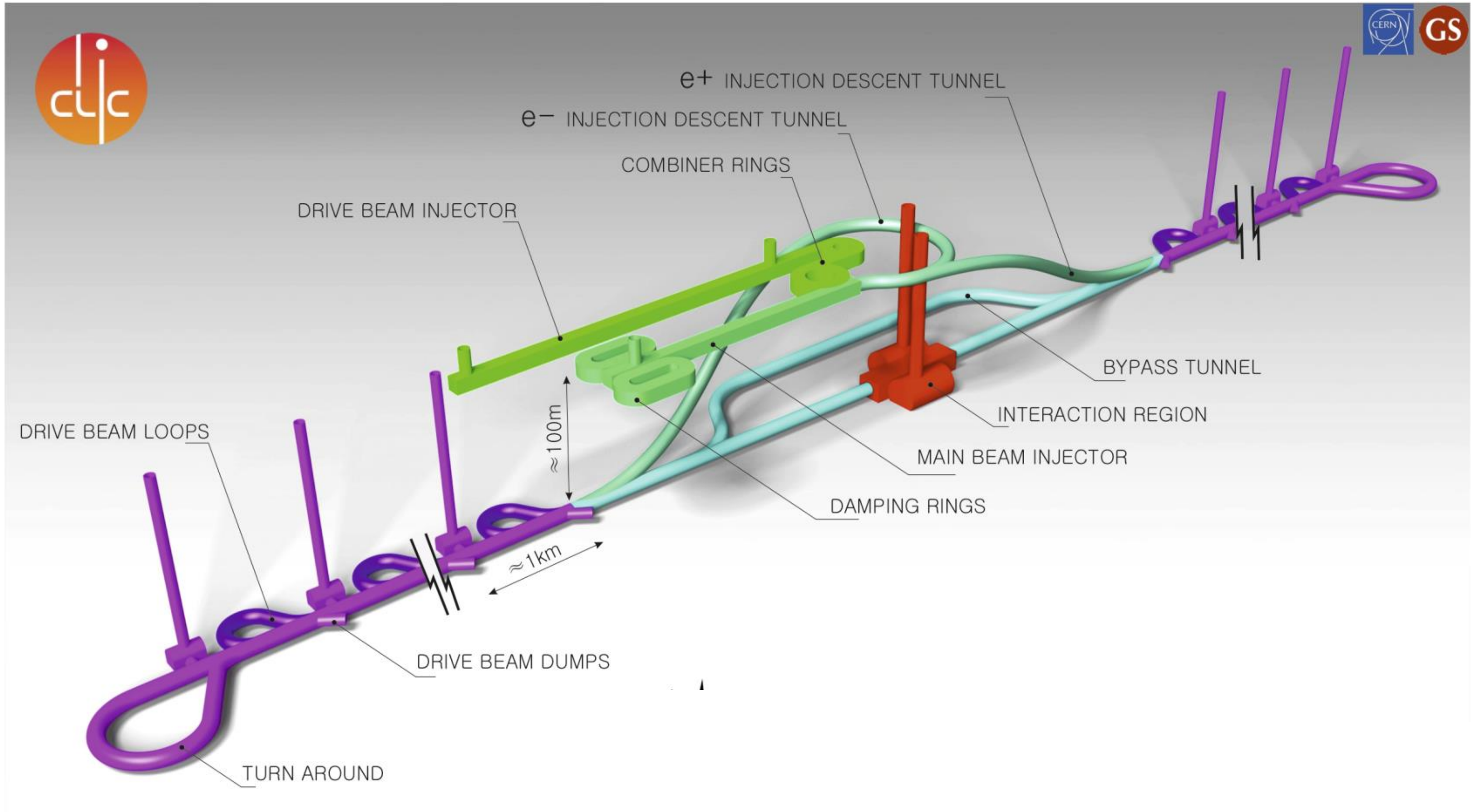




CLIC – Compact Linear Collider



Innovative concept!

Two different beam:

Probe beam → Feed RF power in the ACcelerating Structure (ACS)

Test beam → To carry out experiment!

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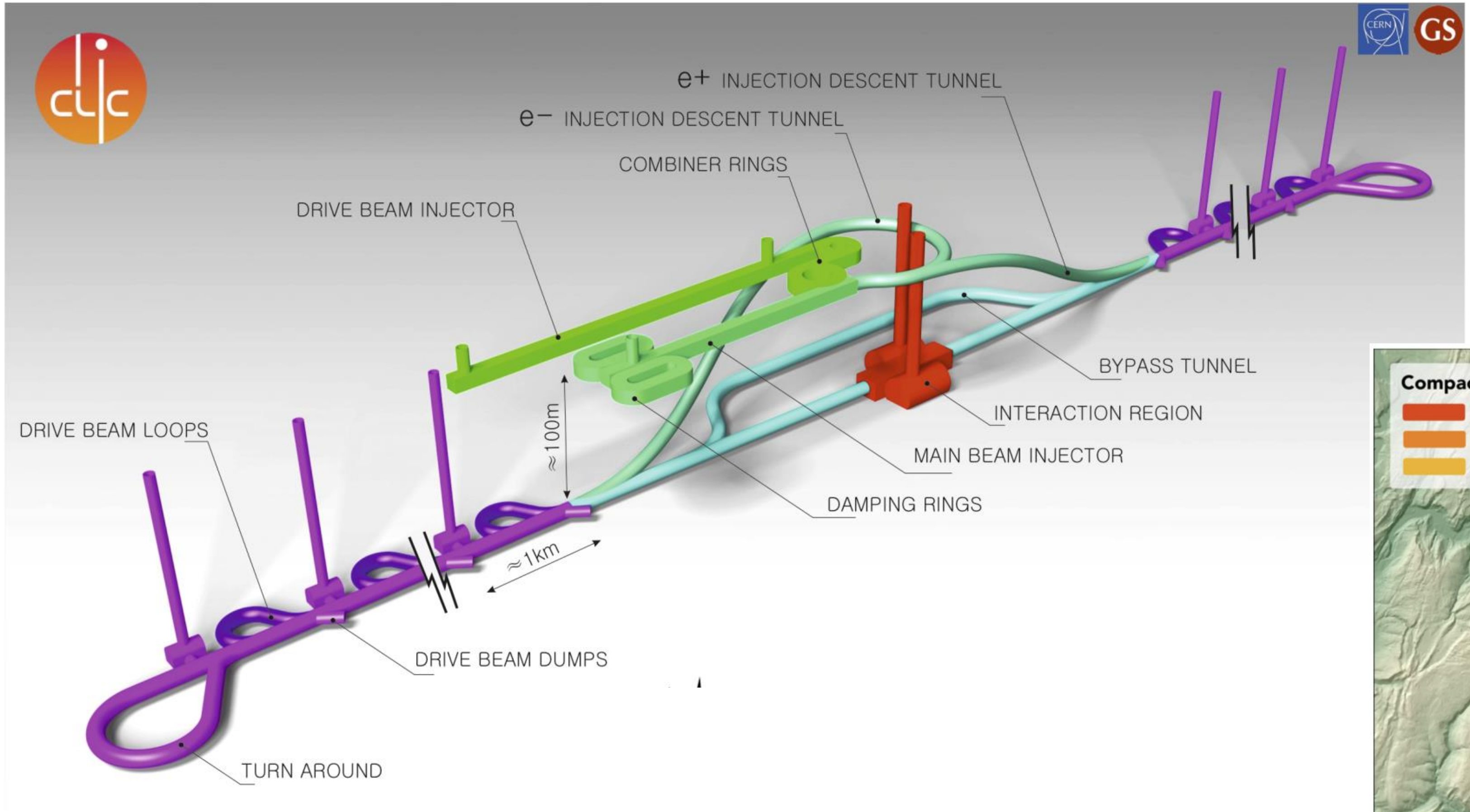

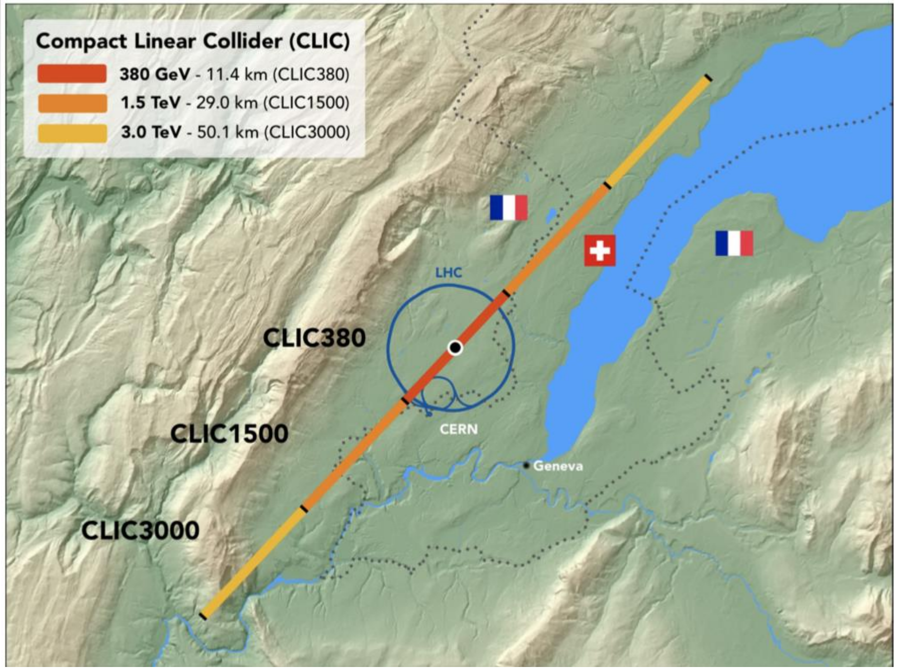

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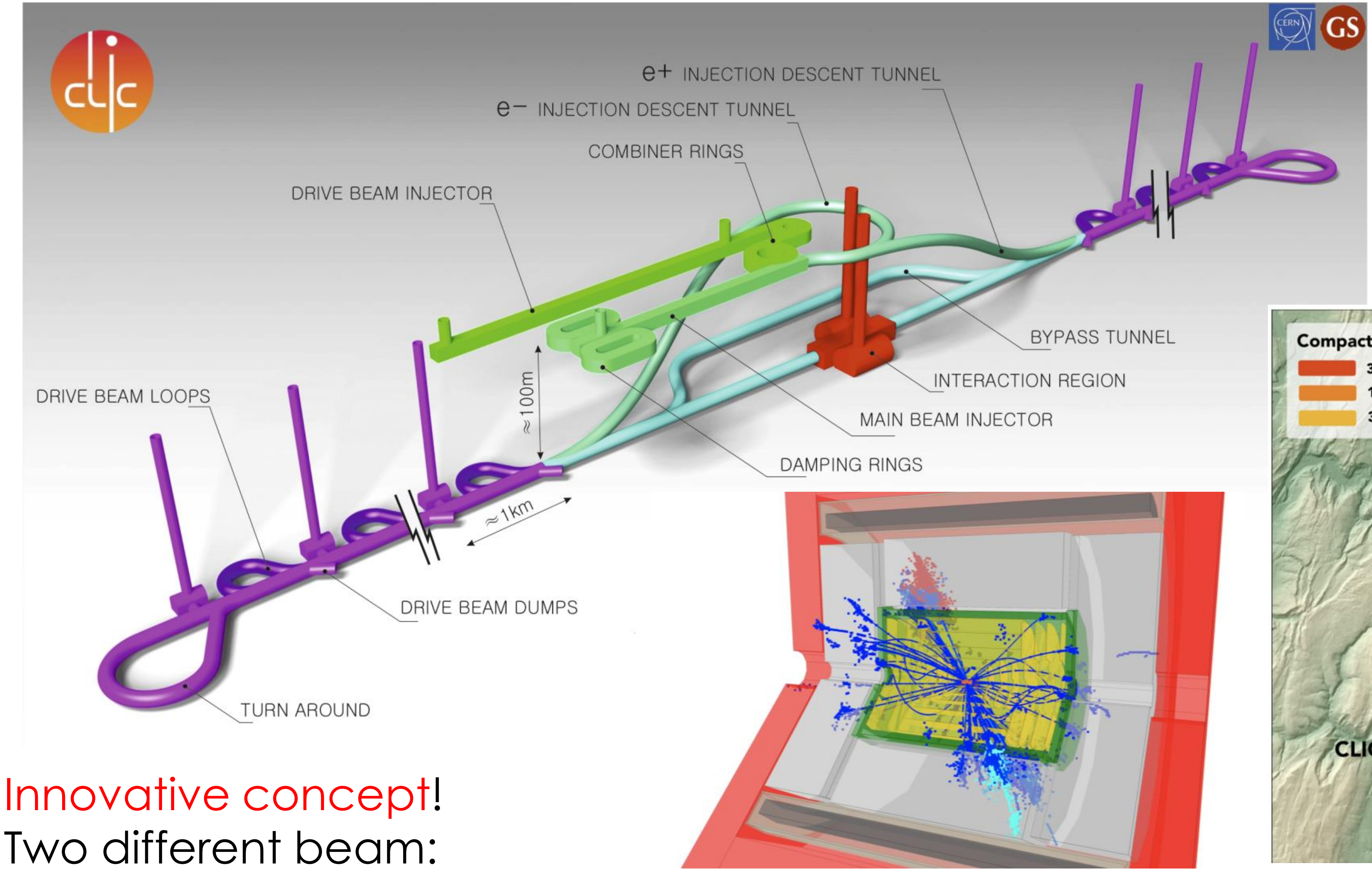
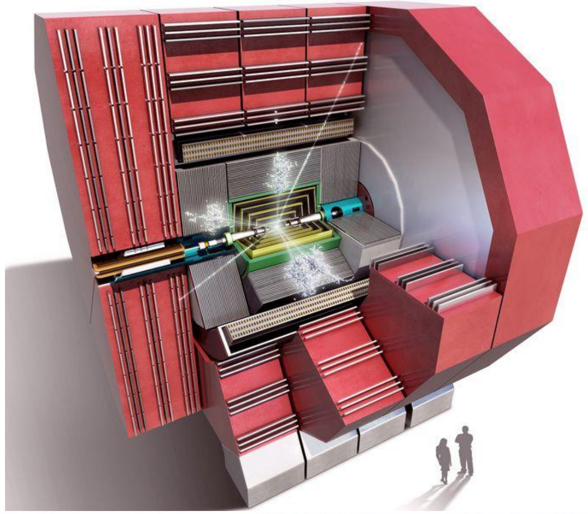
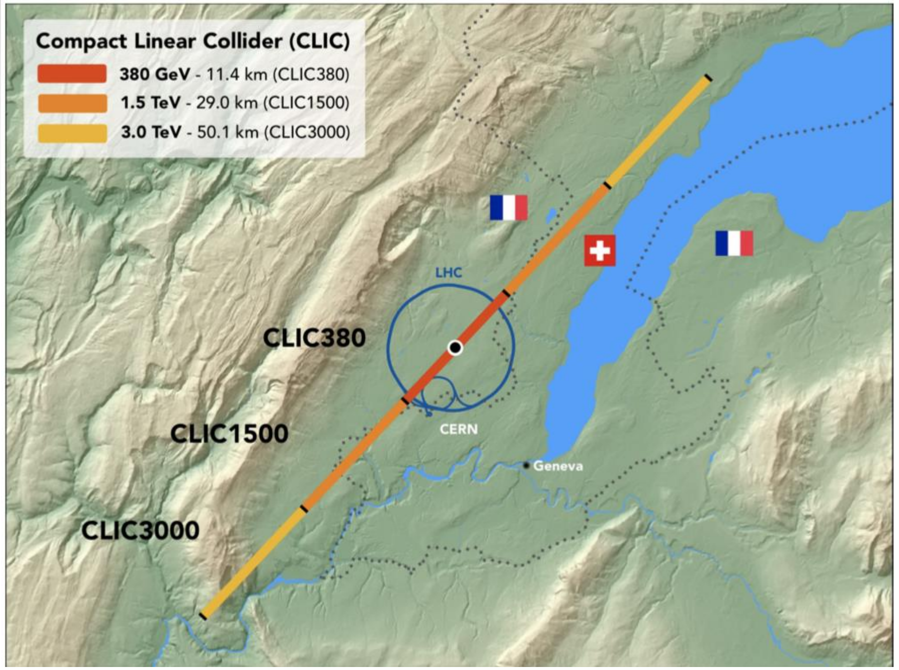


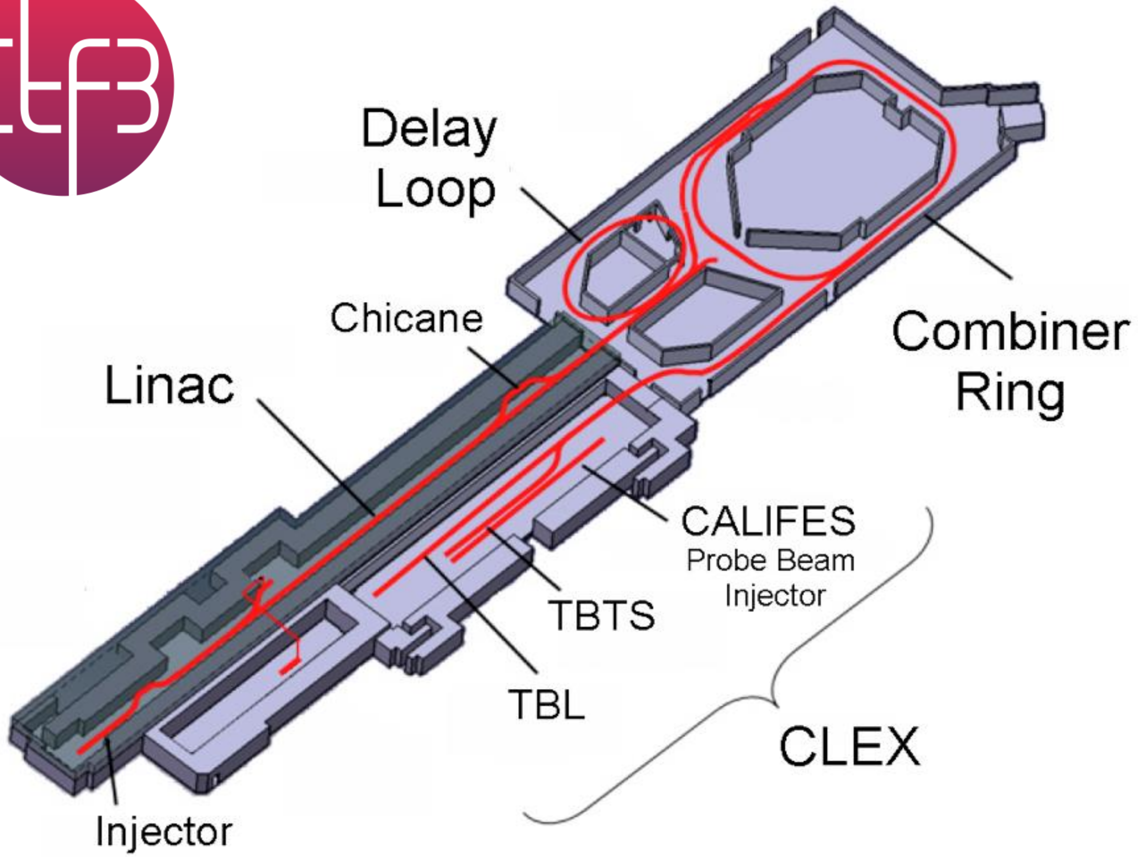




Innovative concept!
Two different beam:

Probe beam → Feed RF power in the ACcelerating Structure (ACS)
Test beam → To carry out experiment!

Test are needed (CTF3)



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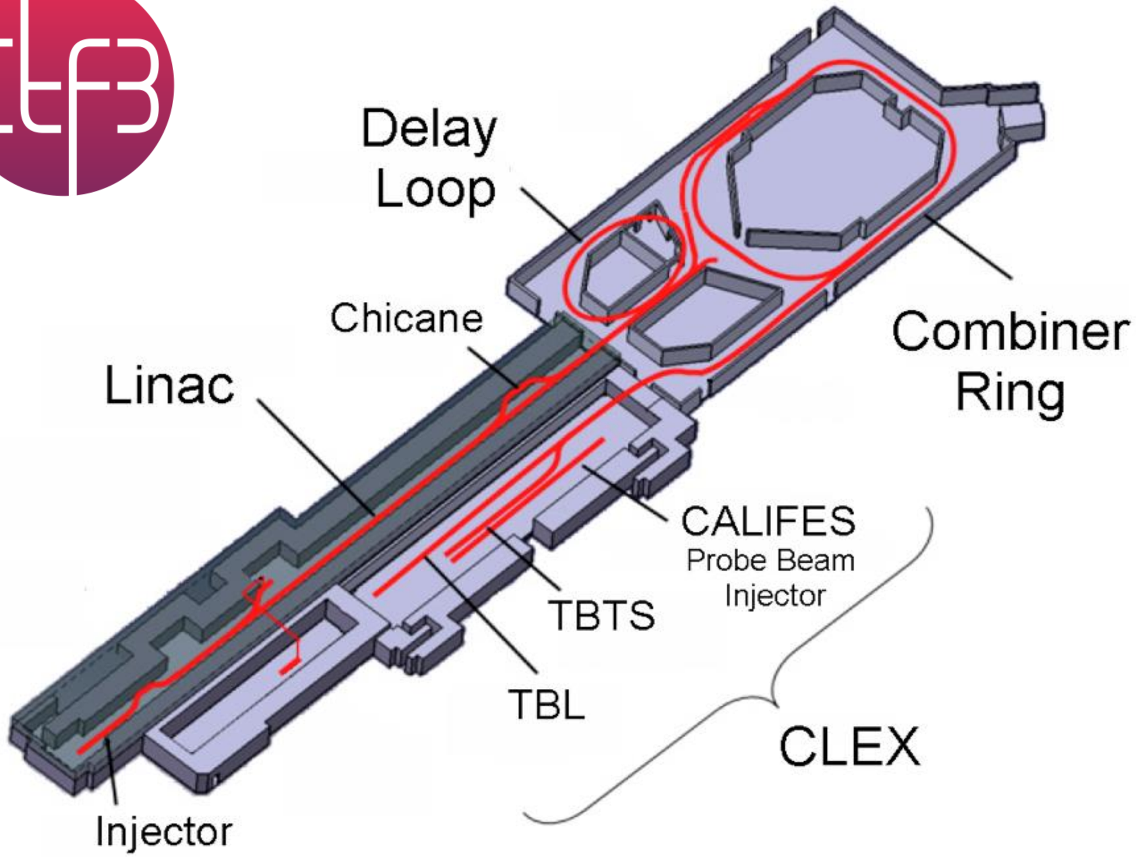

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First beam – June 2003

Last beam – December 2016

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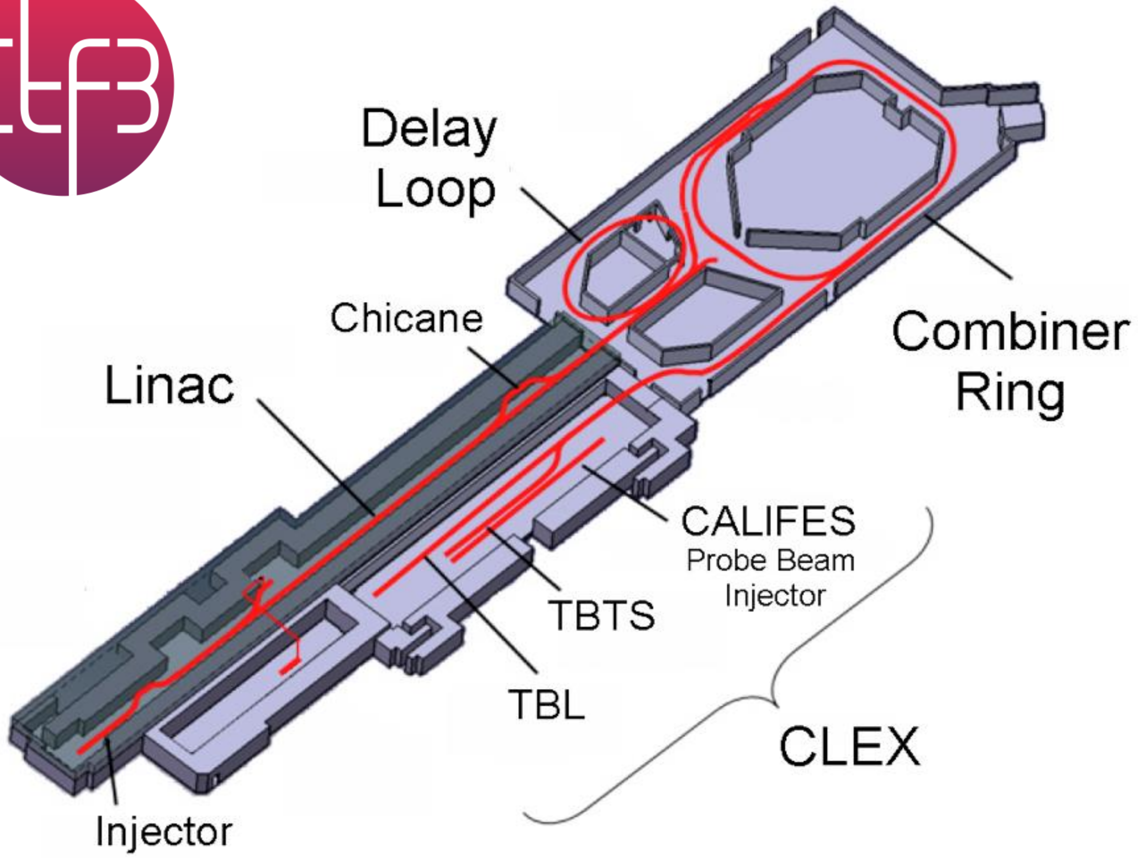

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R&D is NEEDED!

A new machine is needed (CLEAR) to maintain local testing capability at CERN for CLIC instrumentation and high-gradient structure testing with beam (alongside with other non-CLIC activities).

First beam – June 2003

Last beam – December 2016

CERN Linear Electron Accelerator for Research (CLEAR)

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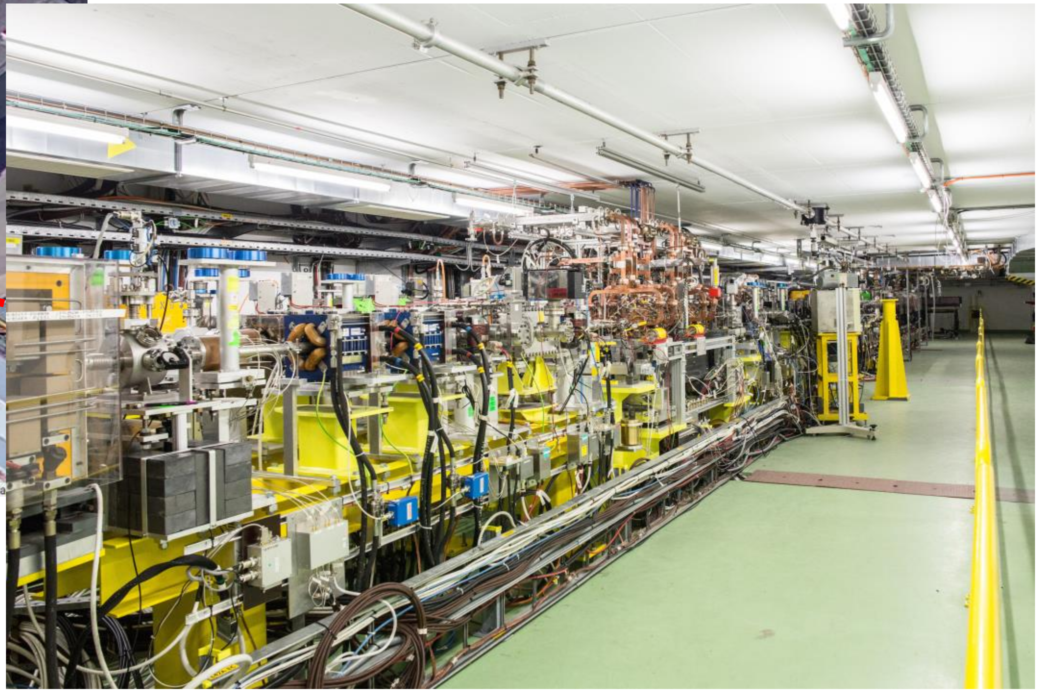
The CLEX experimental hall is 41 m long.

Web site →http://clear.web.cern.ch

https://clear.web.cern.ch/sites/clear.web.cern.ch/files/documents/CLEAR_proposal.pdf

Approved December 2016

CERN Linear Electron Accelerator for Research (CLEAR)



CLEAR is a user facility at CERN, running in parallel with the main CERN accelerator complex, with the primary goal of enhancing and complementing the existing accelerator R&D and testing capabilities at CERN.

The CLEX experimental hall is 41 m long.

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https://clear.web.cern.ch/sites/clear.web.cern.ch/files/documents/CLEAR_proposal.pdf

Approved December 2016

CLEAR program

Several experiments:

- ✓ CLIC structure wake-field measurements
- ✓ Wake-field monitors
- ✓ CLIC BPMs
- ✓ Nuclear irradiation tests
- ✓Cherenkov diffraction
- ✓ Plasma lens
- ✓ THz radiation
- ✓ Electro-Optical BPMs
- ✓ Impedance measurements
- ✓ X-Band ACS
- ✓ Bunch length studies

…Not exhaustive list…

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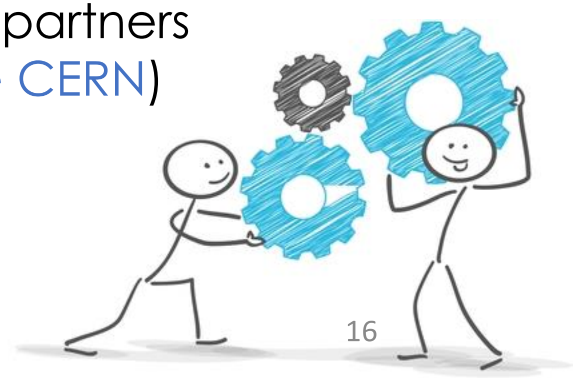
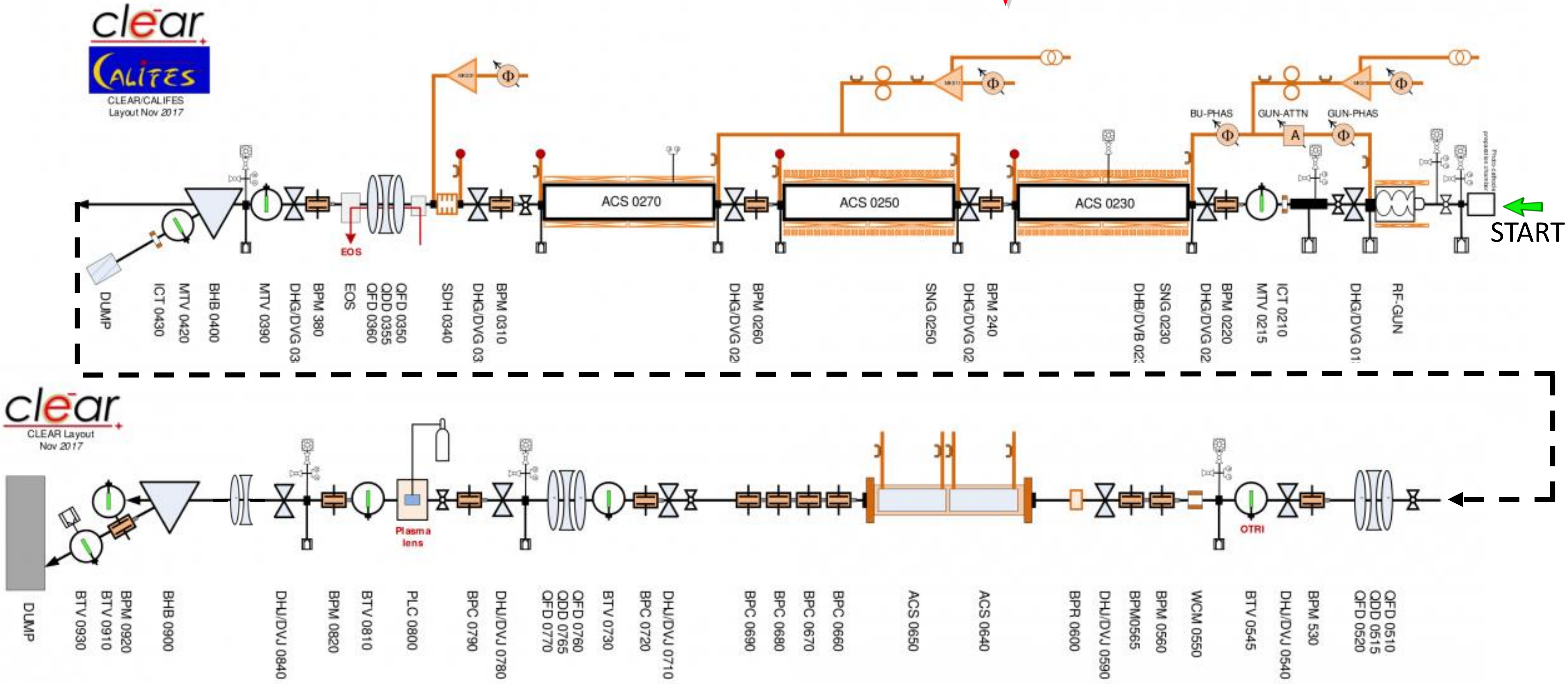
…Not exhaustive list…

Key point:
- Flexibility
- Easy and fast access
- Location

Beam parameters	Range
Energy	60 – 220 MeV
Energy Spread	< 1 MeV (FWHM)
Bunch Charge	10 pC –30 nC
Bunch Length	0.2 ps – 10 ps
Normalized emittances	3 mm to 30 mm
Micro-bunch spacing	1.5 GHz (Laser) 3.0 GHz (Dark current)

Find synergies with other potential partners (project/groups within and outside CERN)





CLEAR/CALIFES
Layout Nov 2017
BU-PHAS
GUN-ATTN
GUN-PHAS
ACS 0270
ACS 0250
ACS 0230
START
EOS
DUMP
ICT 0430
MTV 0420
BHB 0400
MTV 0390
DHG/DVG 03
BPM 380
EOS
QFD 0350
QDD 0355
QFD 0360
SDH 0340
DHG/DVG 03
BPM 0310
DHG/DVG 02
BPM 0260
SNG 0250
DHG/DVG 02
BPM 240
SNG 0230
DHG/DVG 02
BPM 0220
MTV 0215
ICT 0210
DHG/DVG 01
RF-GUN
CLEAR Layout
Nov 2017
Plasma lens
OTRI
DUMP
BTV 0930
BTV 0910
BPM 0920
BHB 0900
DHJ/DVJ 0840
BPM 0820
BTV 0810
PLC 0800
BPC 0790
DHJ/DVJ 0780
QFD 0760
QDD 0765
QFD 0770
BTV 0730
BPC 0720
DHJ/DVJ 0710
BPC 0690
BPC 0680
BPC 0670
BPC 0660
ACS 0650
ACS 0640
BPR 0600
DHJ/DVJ 0590
BPM0565
BPM 0560
WCM 0550
BTV 0545
DHJ/DVJ 0540
BPM 530
QFD 0510
QDD 0515
QFD 0520

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  - Electronic irradiation test
  - Medical irradiation test
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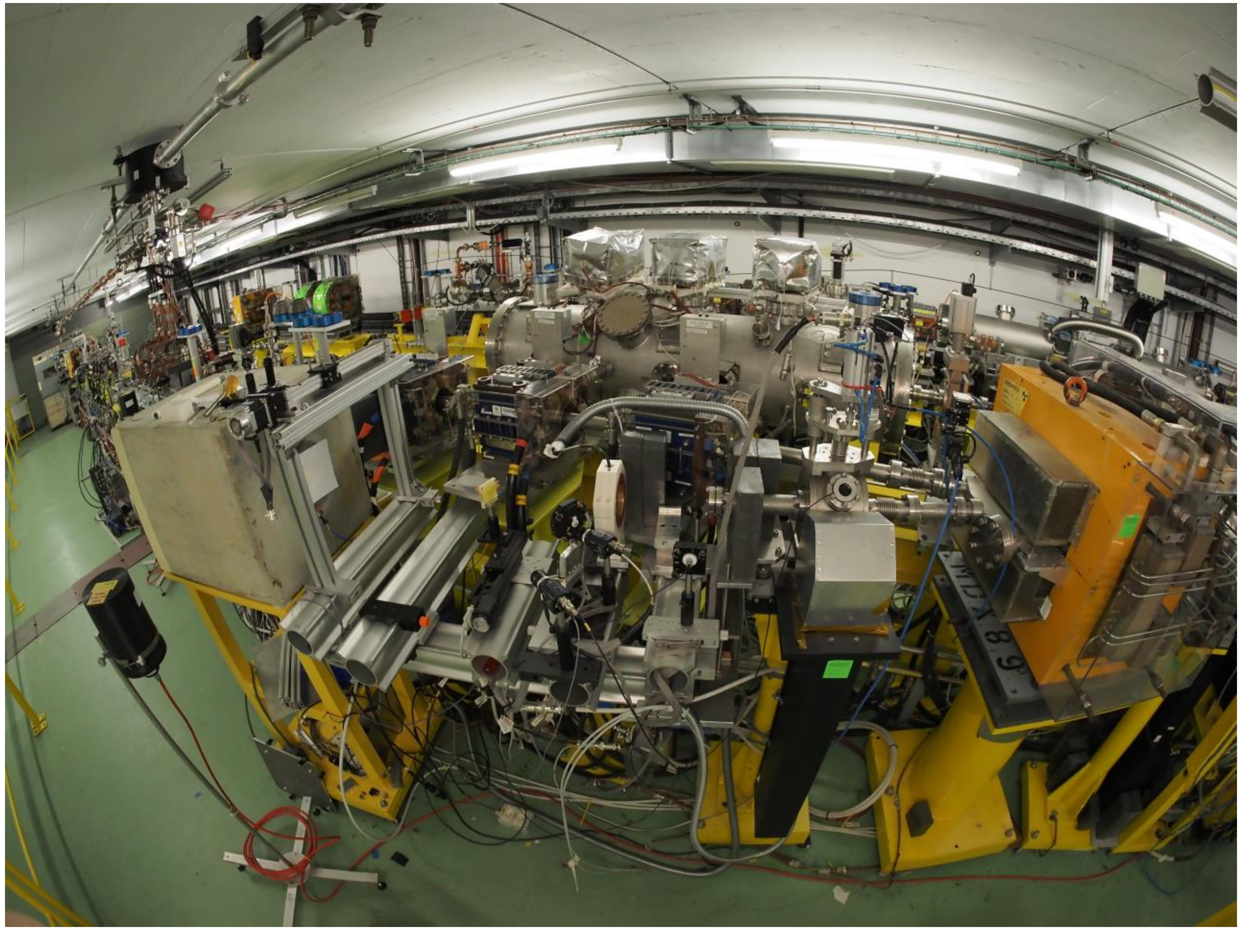
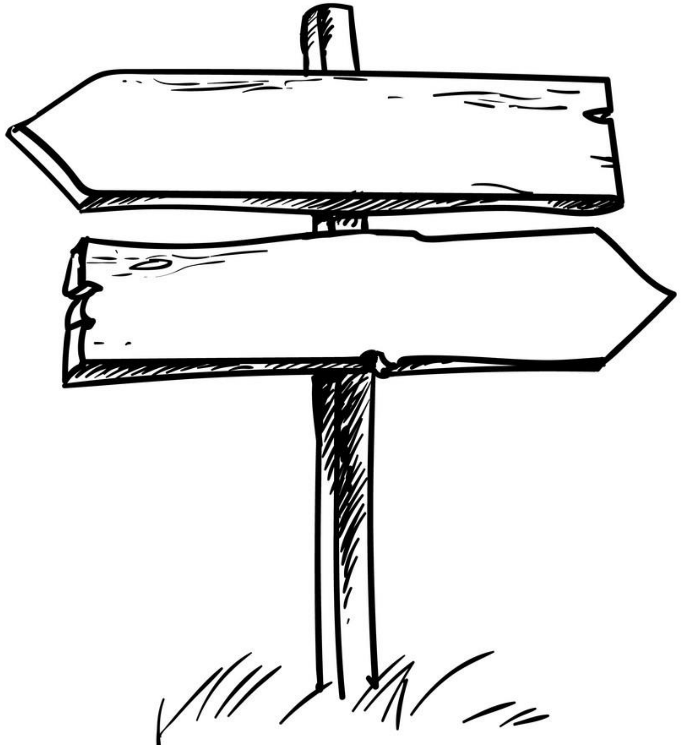
- Proposed activity



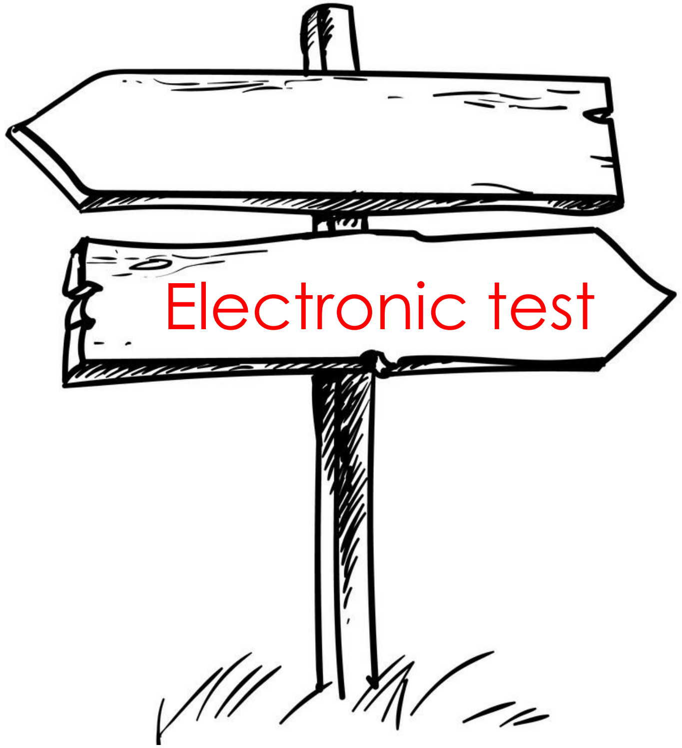
Nuclear irradiation

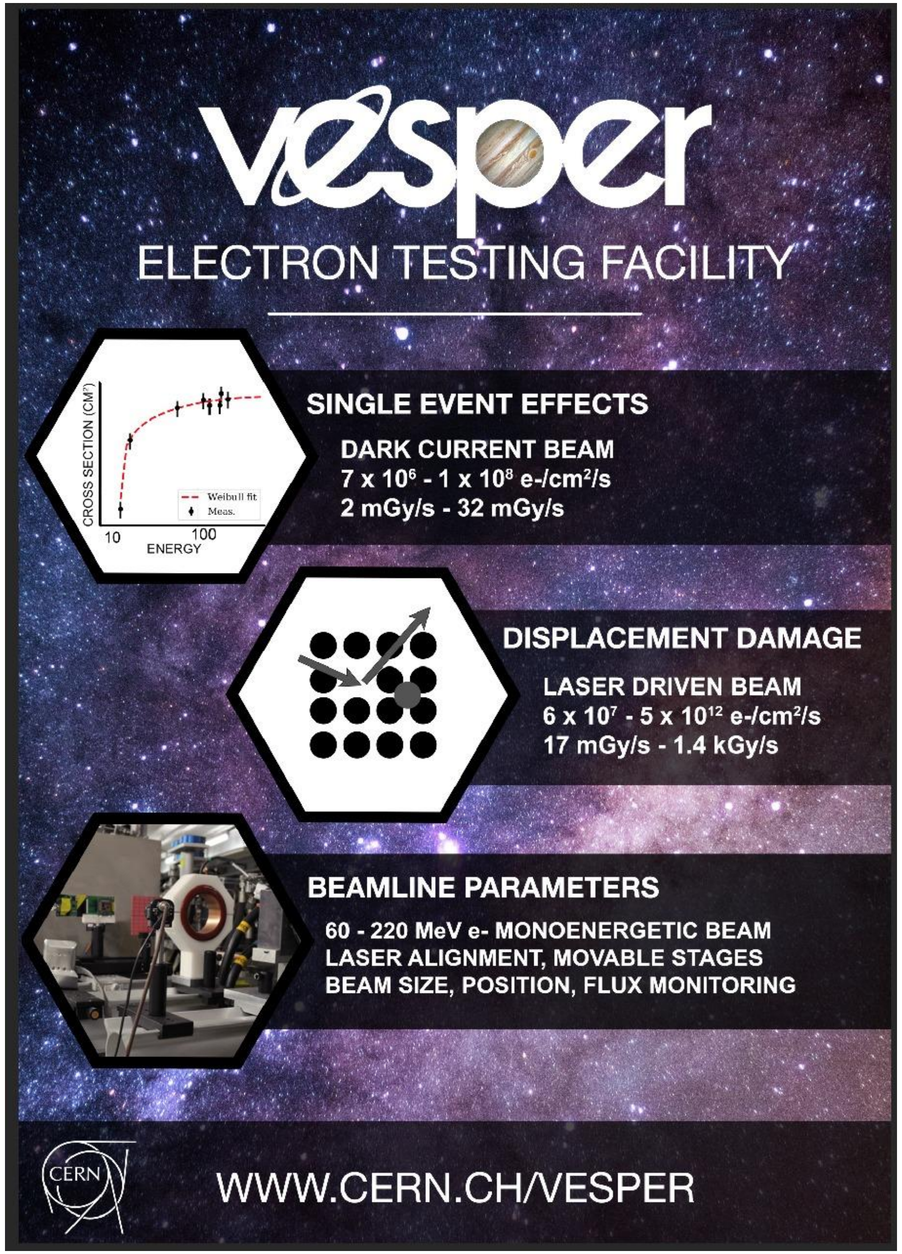


Two main branches:

Nuclear irradiation

Very energetic Electron facility for Space Planetary Exploration missions in Radiative environments



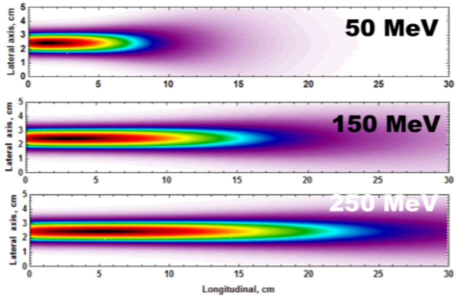


Two main branches:

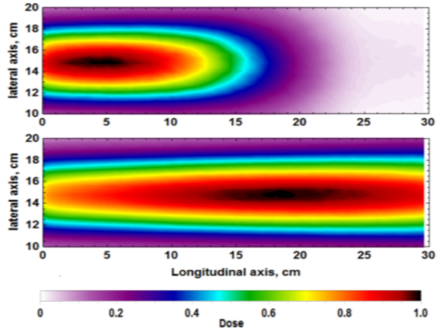
Nuclear irradiation

VHEE

Very High Energetic Electron for medical application

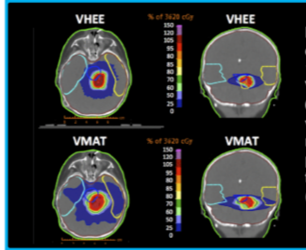


Dose maps of narrow () VHEE beams in water

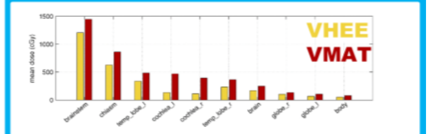


Dose maps of wide () VHEE beams in water

- **Clinical studies by M. Bazalova-Carter *et al.* (2015) have compared 100 MeV VHEE** with conventional **(and MV) VMAT** (Volumetric Modulated Arc Therapy) photon radiotherapy plans
- ***Pediatric brain tumour, lung*** and ***prostate cases***
- VHEE therapy plan showed a **decrease of dose** up to **70%** in surrounding organs-at-risk (**OARs**)
- ***VHEE plan was found to be more conformal than VMAT plan***



Brain tumour dose maps for 100 MeV VHEE and 6 MV volumetric modulated arc photon therapy (VMAT) .



Absorbed dose histograms for surrounding organs-at-risk.

M. Bazalova-Carter *et al*, «Treatment planning for radiotherapy with very high-energy electron beams and comparison of VHEE and VMAT plans», Medical Physics, vol. 42(5), **2015**.

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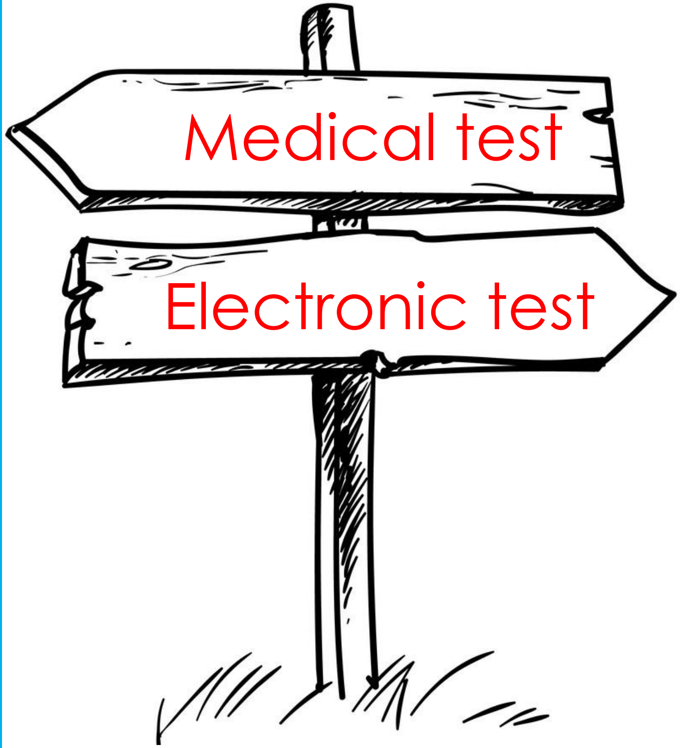
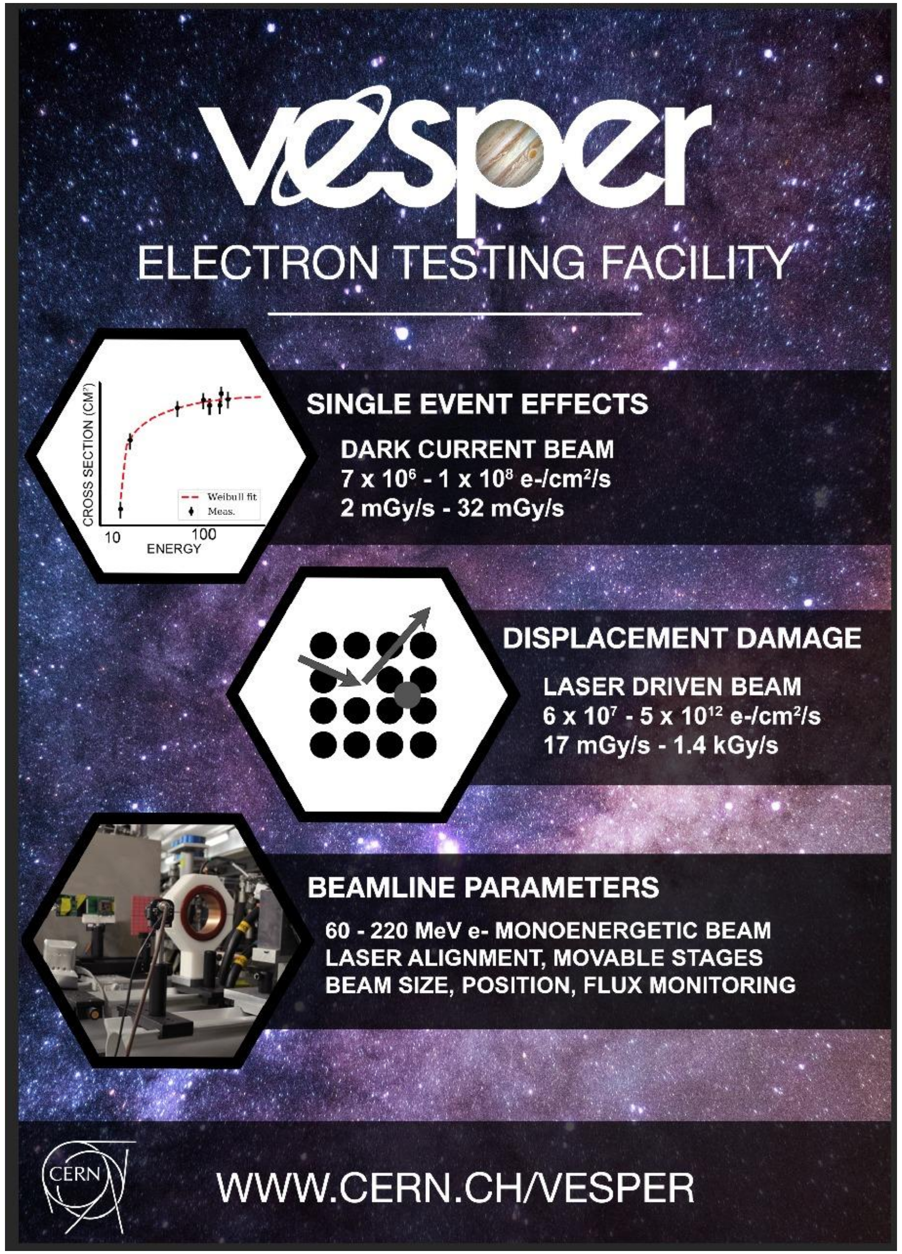


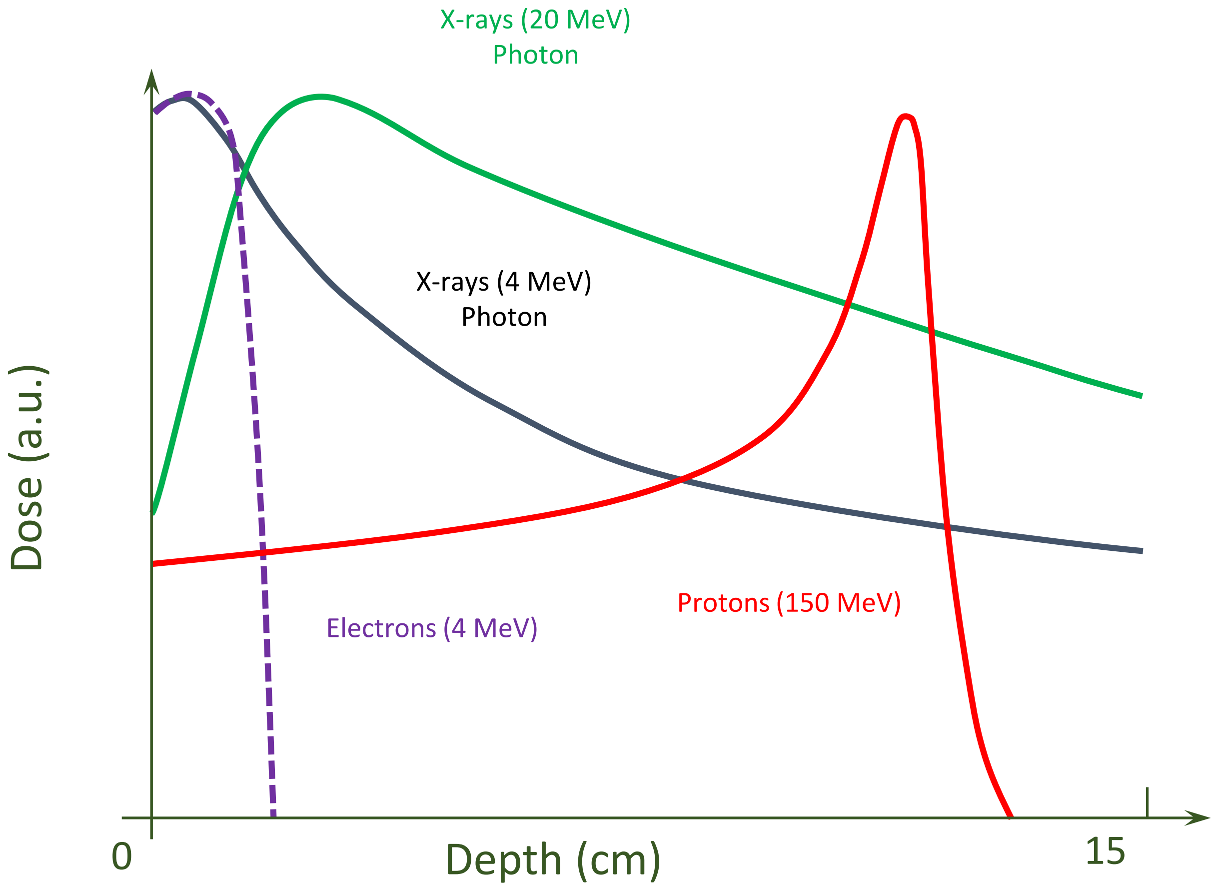


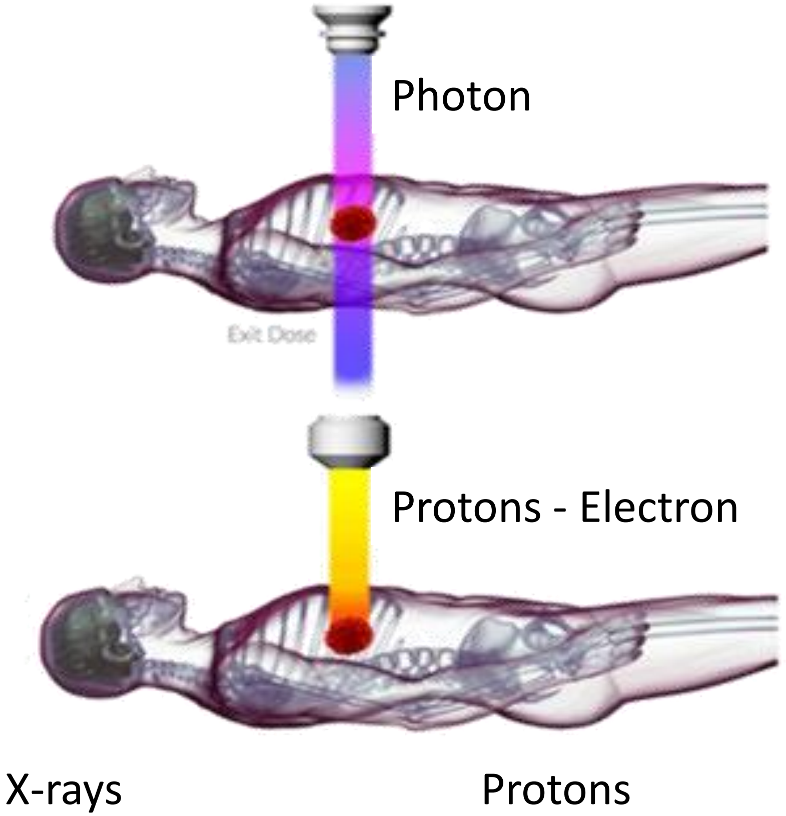
Two main branches:

Medical irradiation test

Basic idea

L. Bottura[1], E. Felcini[1,2] et al.
https://indico.cern.ch/event/754093/

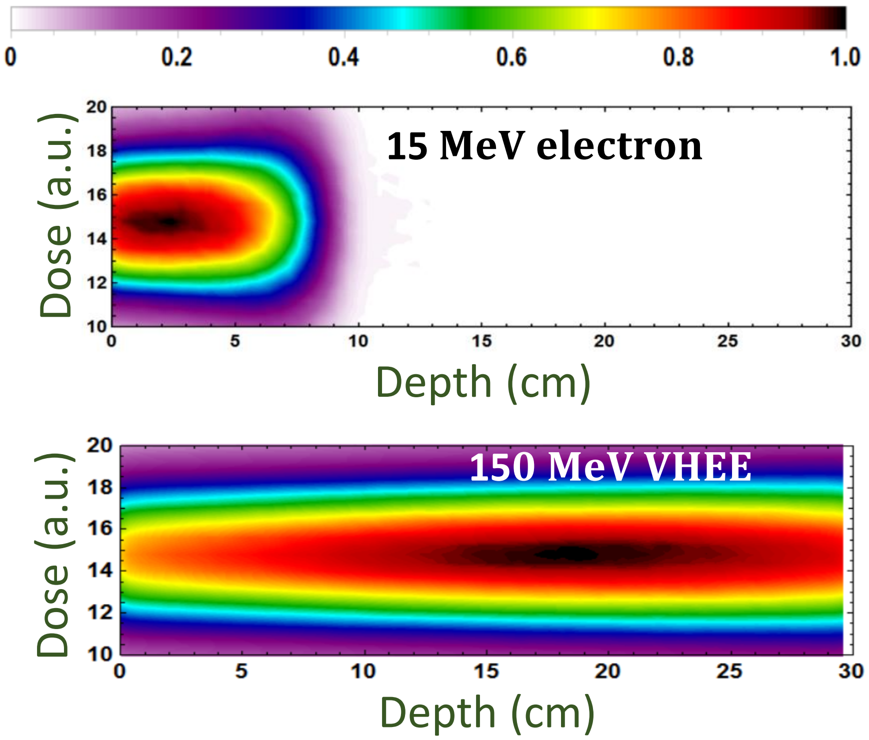




Medical irradiation test

The experimental campaign is done scanning:

- the beam energy
- the particle
- the longitudinal position



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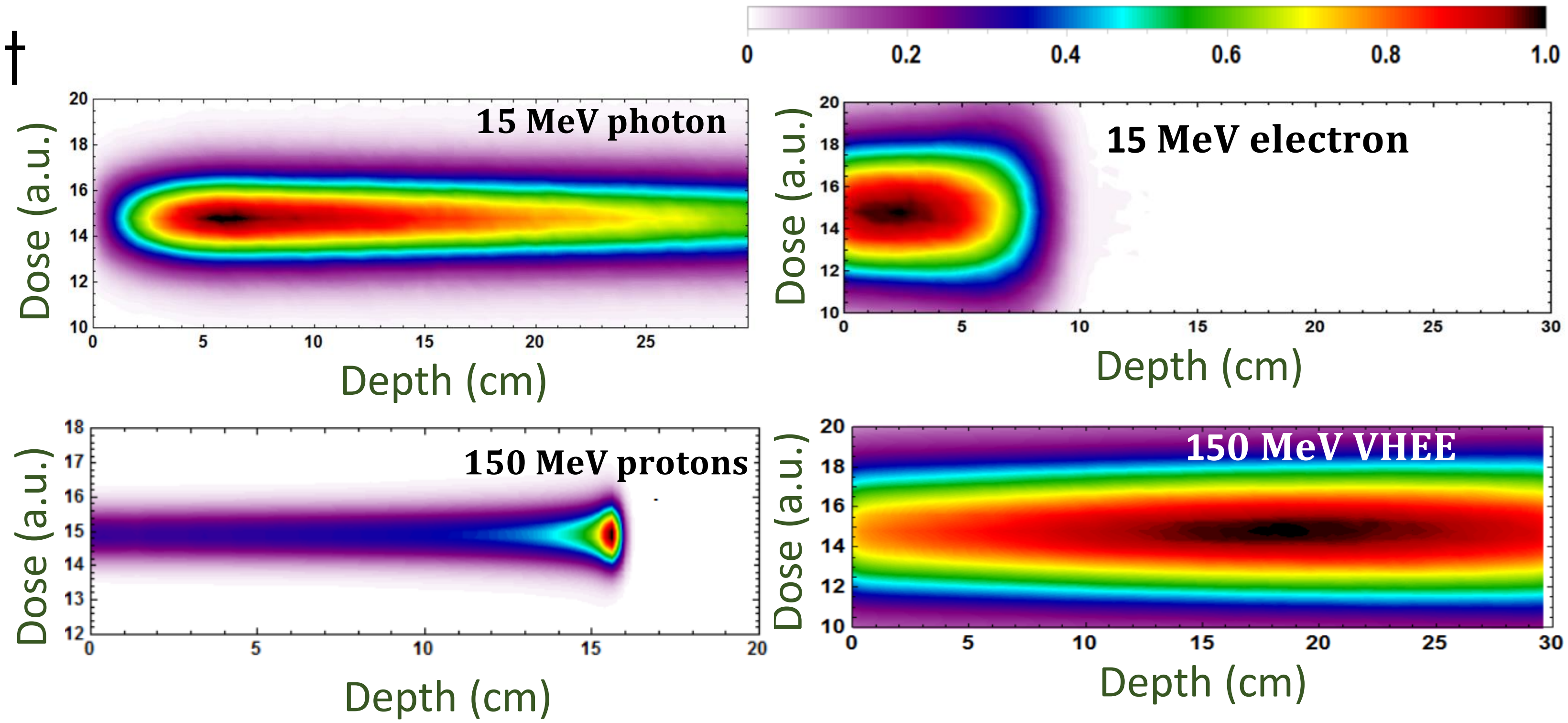

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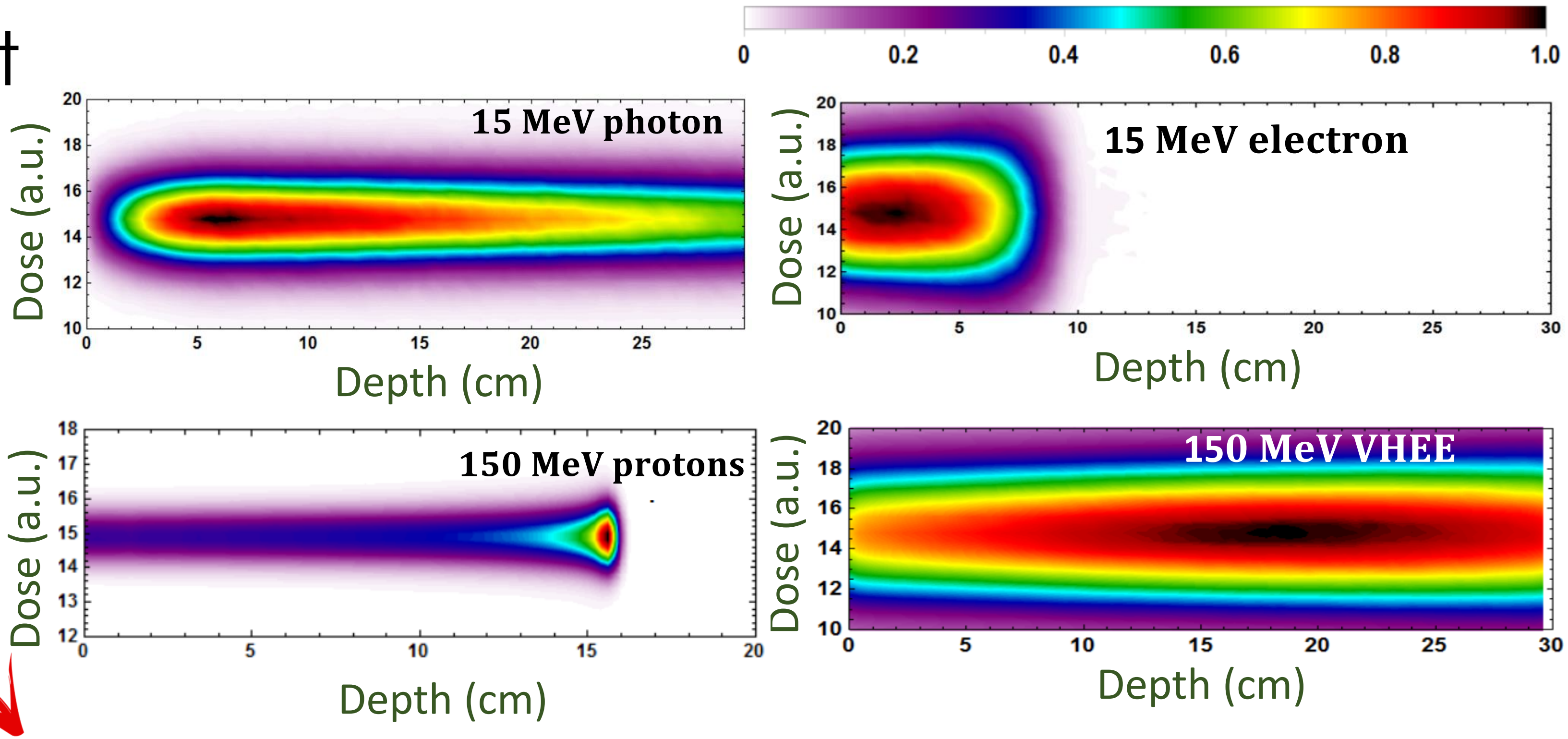

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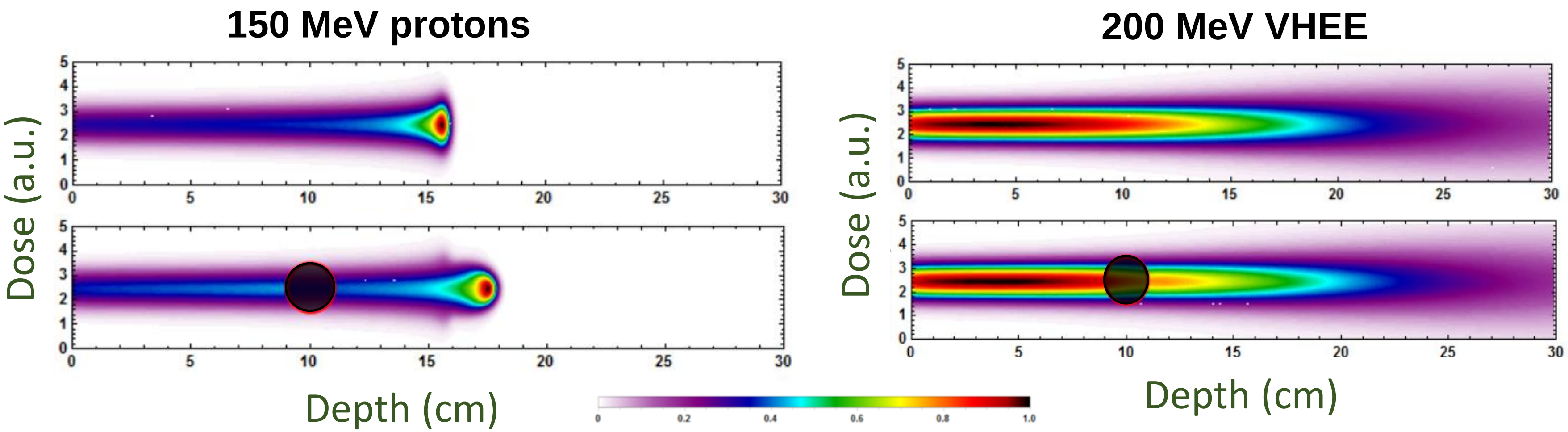

VHEE dose is quite insensitive to inhomogeneities

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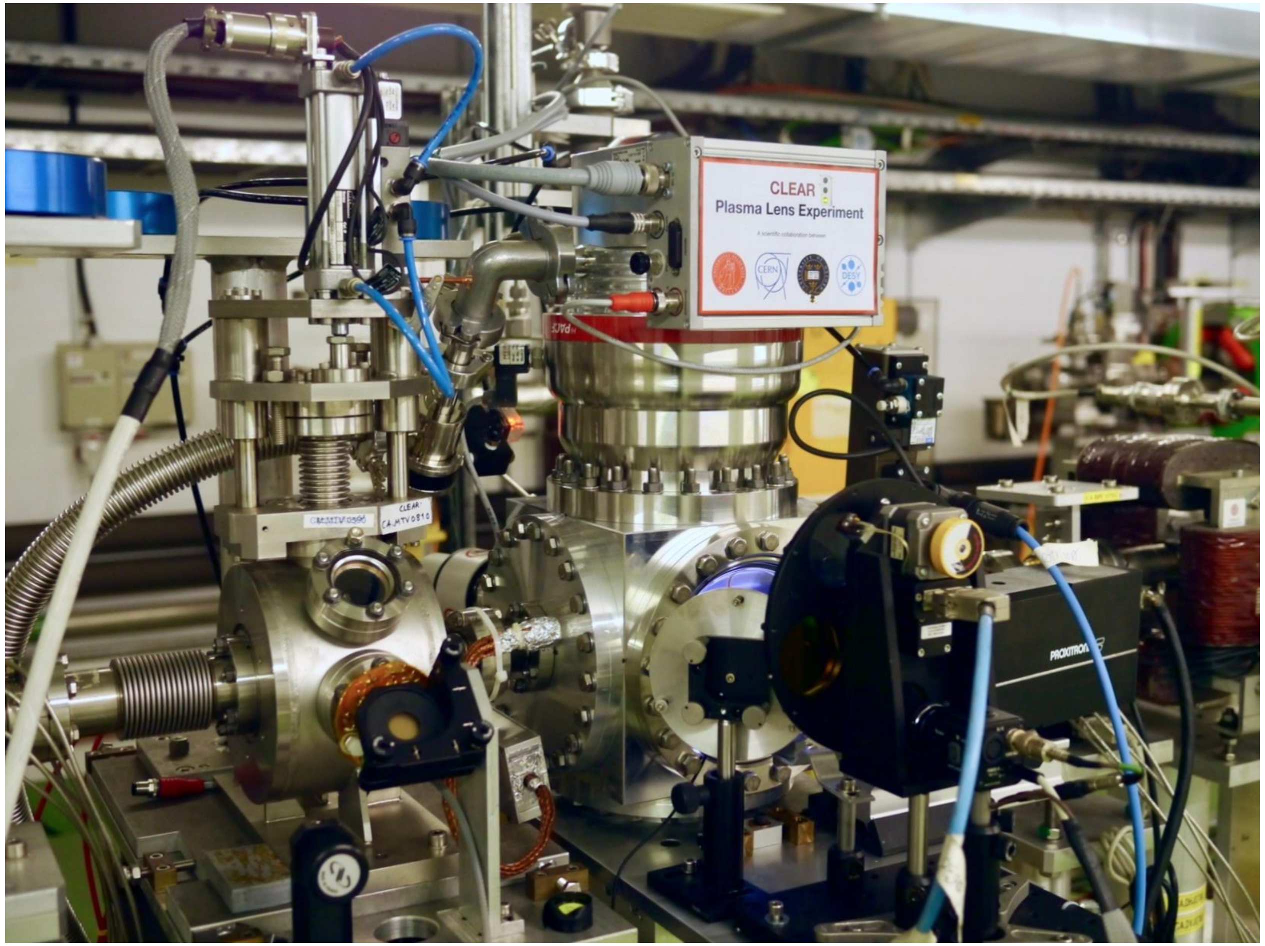
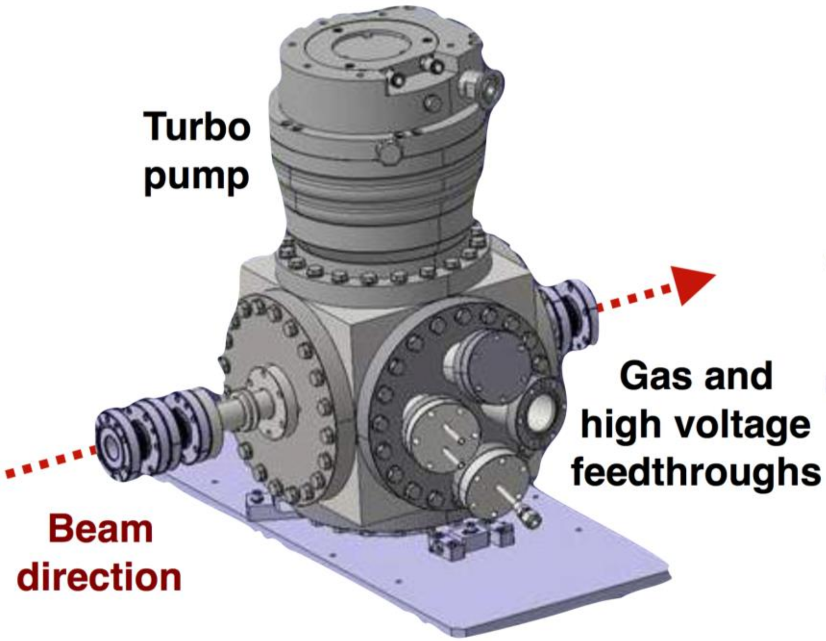
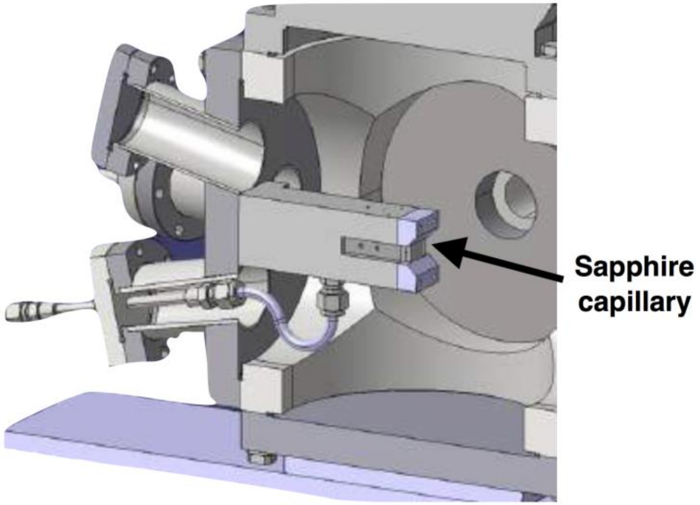


Plasma lens

Compact radial focusing device

- Passing the beam *inside* the conductor
- Observed gradients > 300 T/m (1000 T/m last run)





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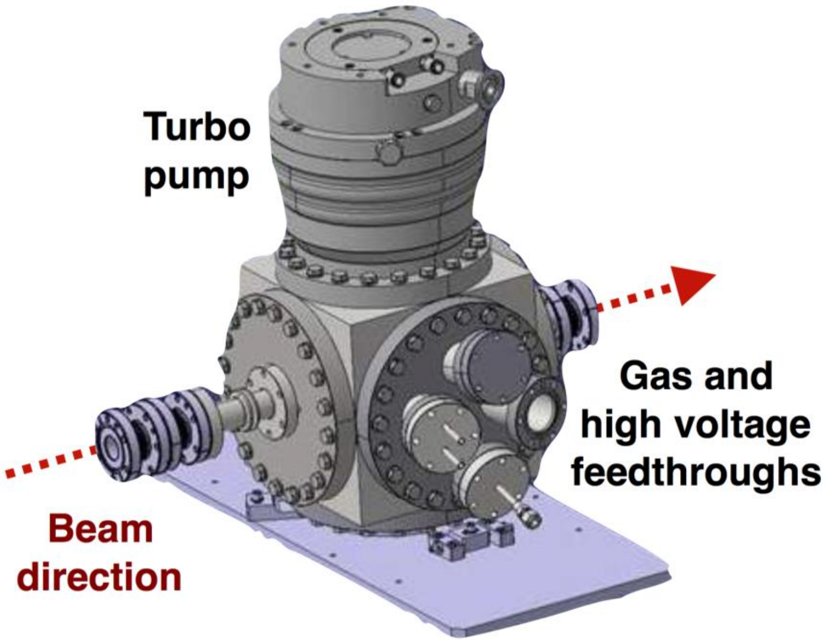
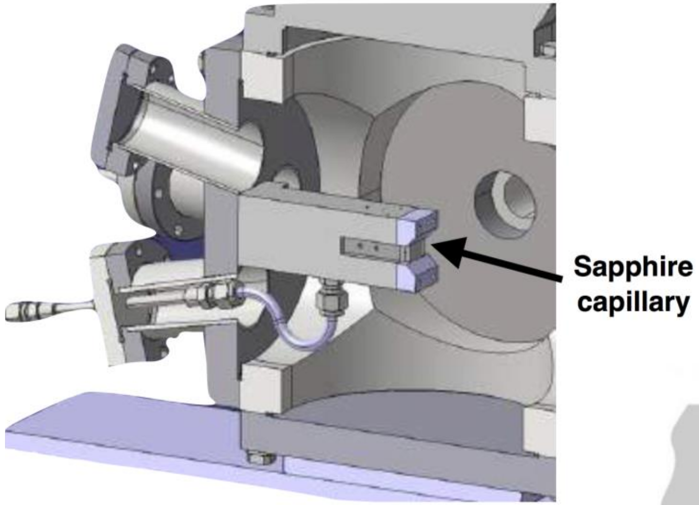
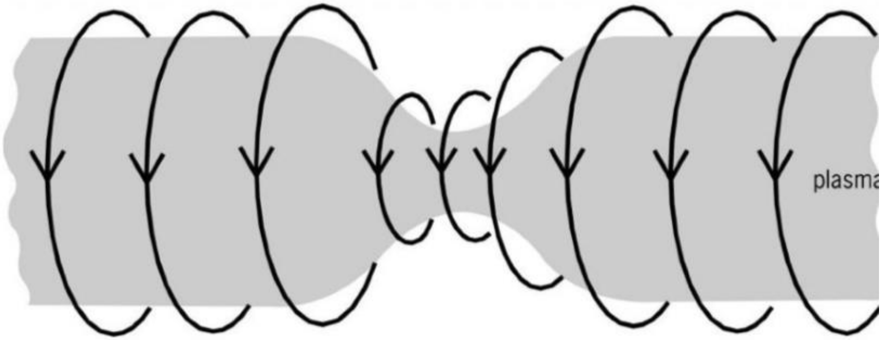


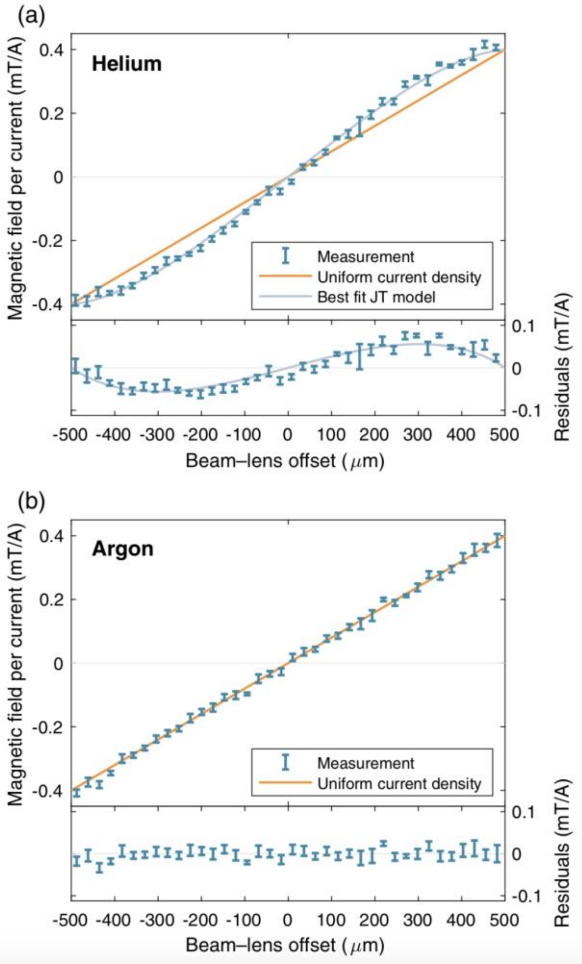


Goal: drive a current through a uniform plasma. The magnetic field leads to linear focusing. Plasma is created by a high-voltage discharge in the gas.



Plasma lens

Demonstrated linearity in terms of emittance, in active plasma lens and explained linear/nonlinear behavior linked to Gas species in plasma.



Results published in Phys. Rev. Letters
https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.121.194801

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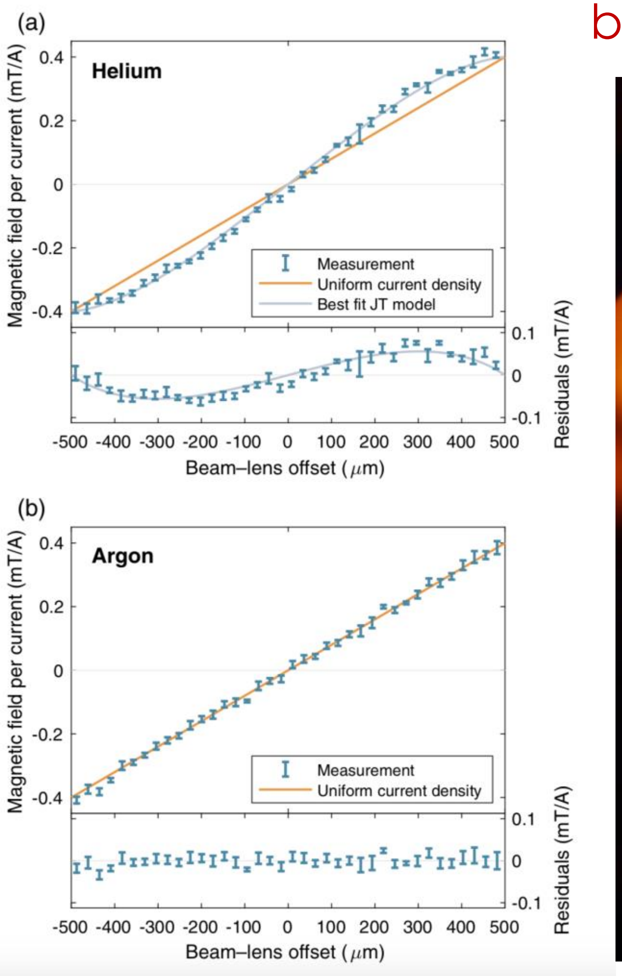

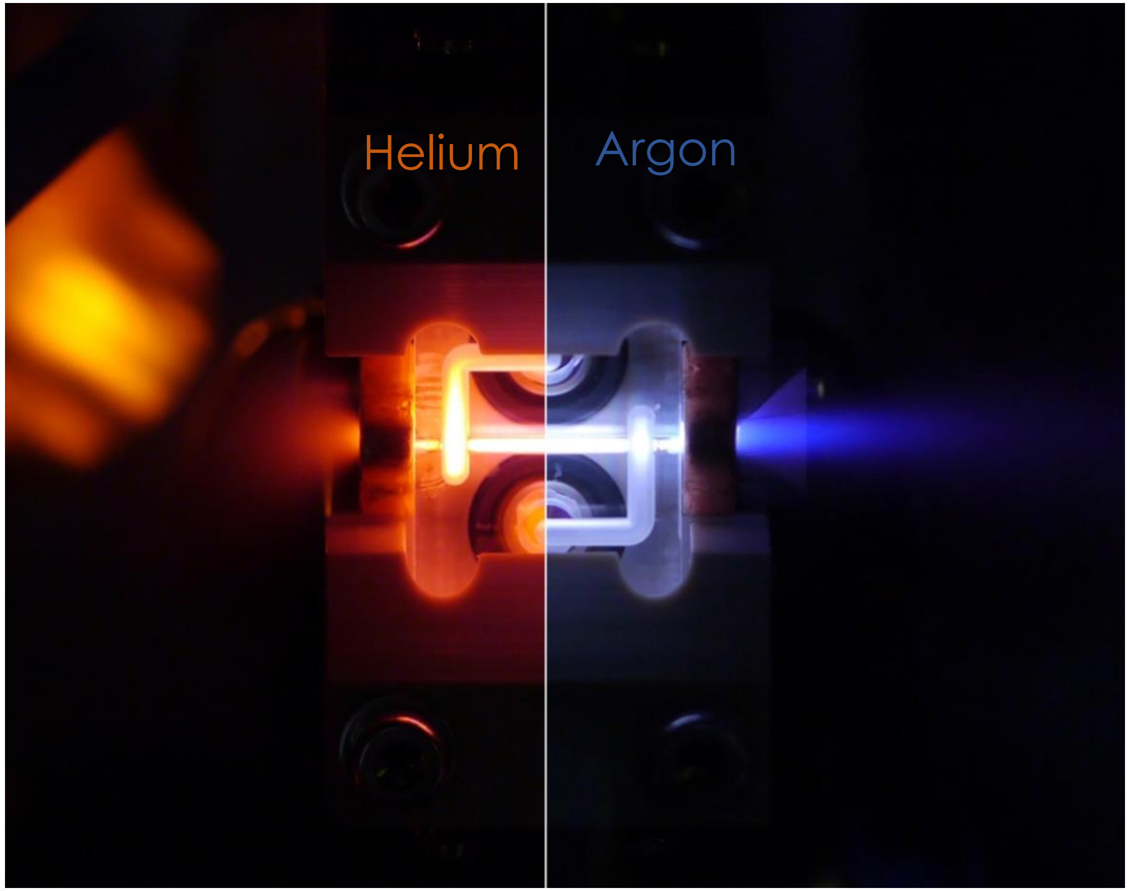

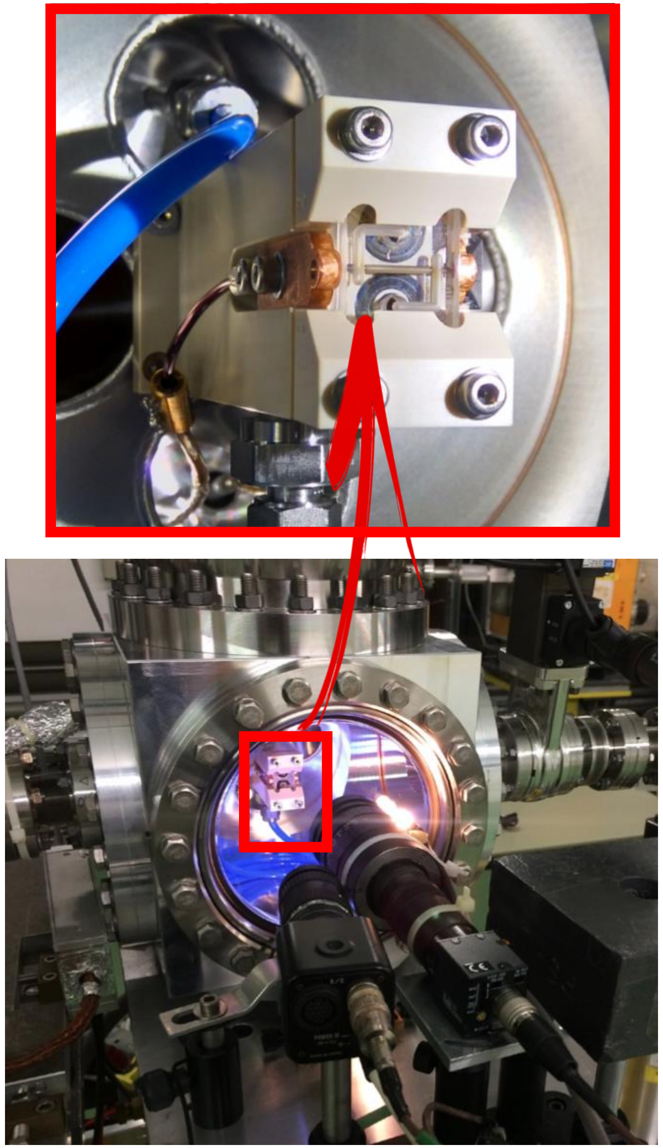

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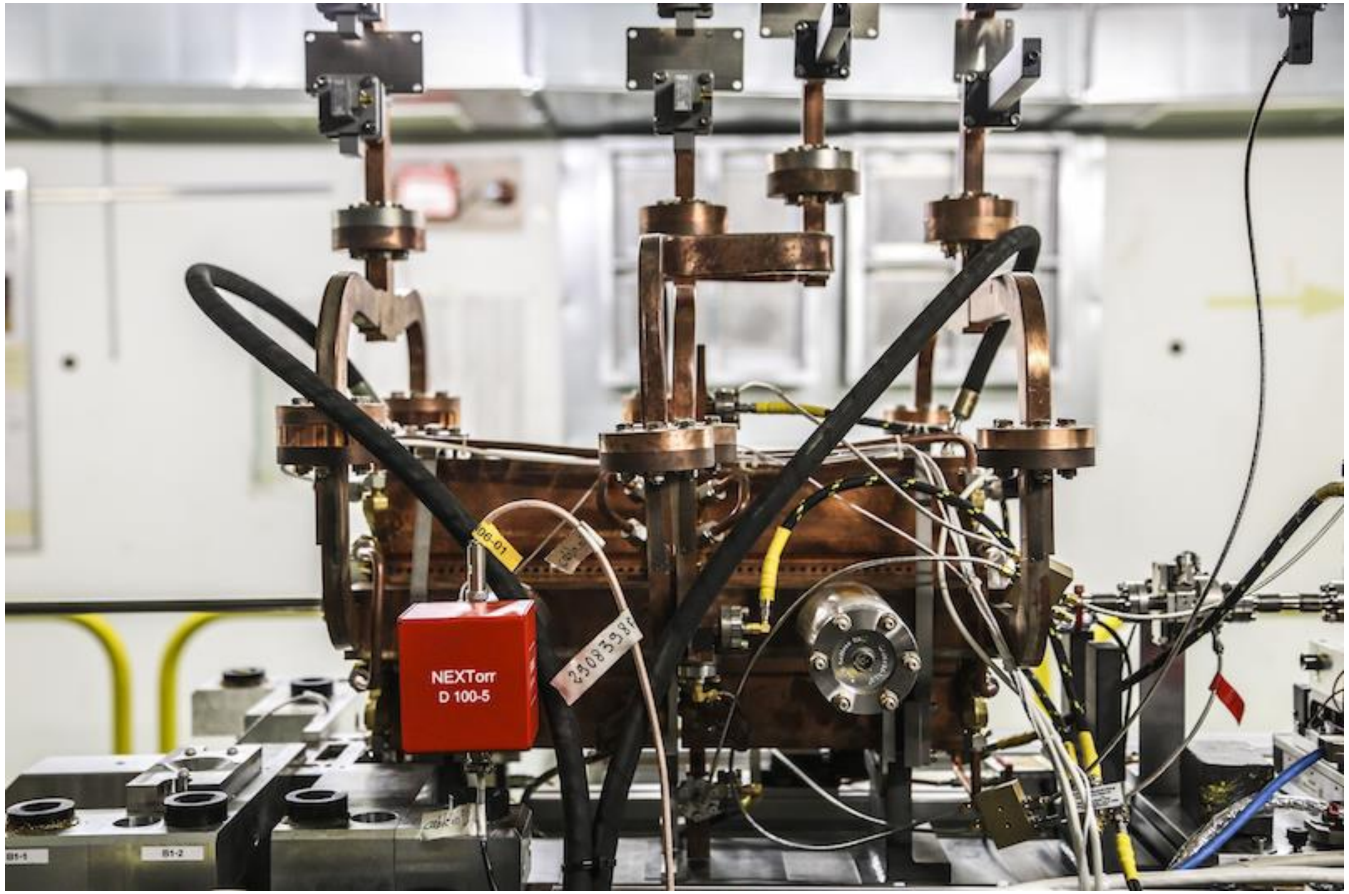
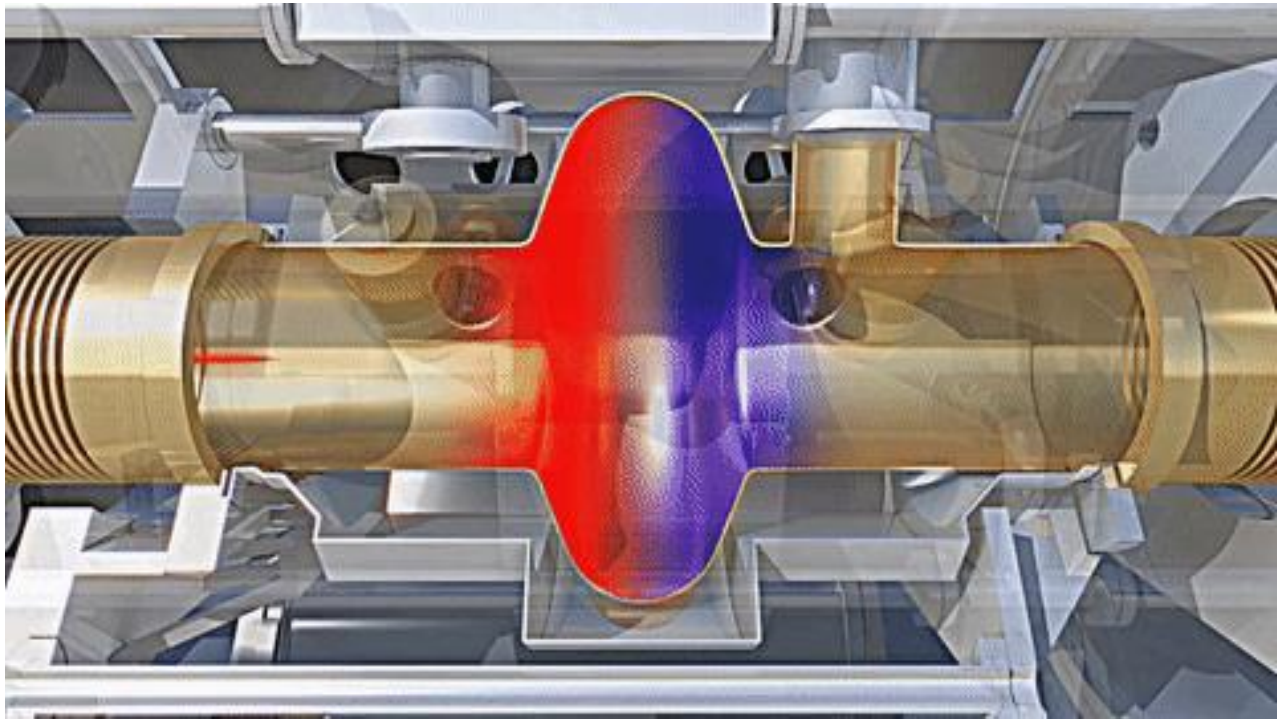


X-Band ACS

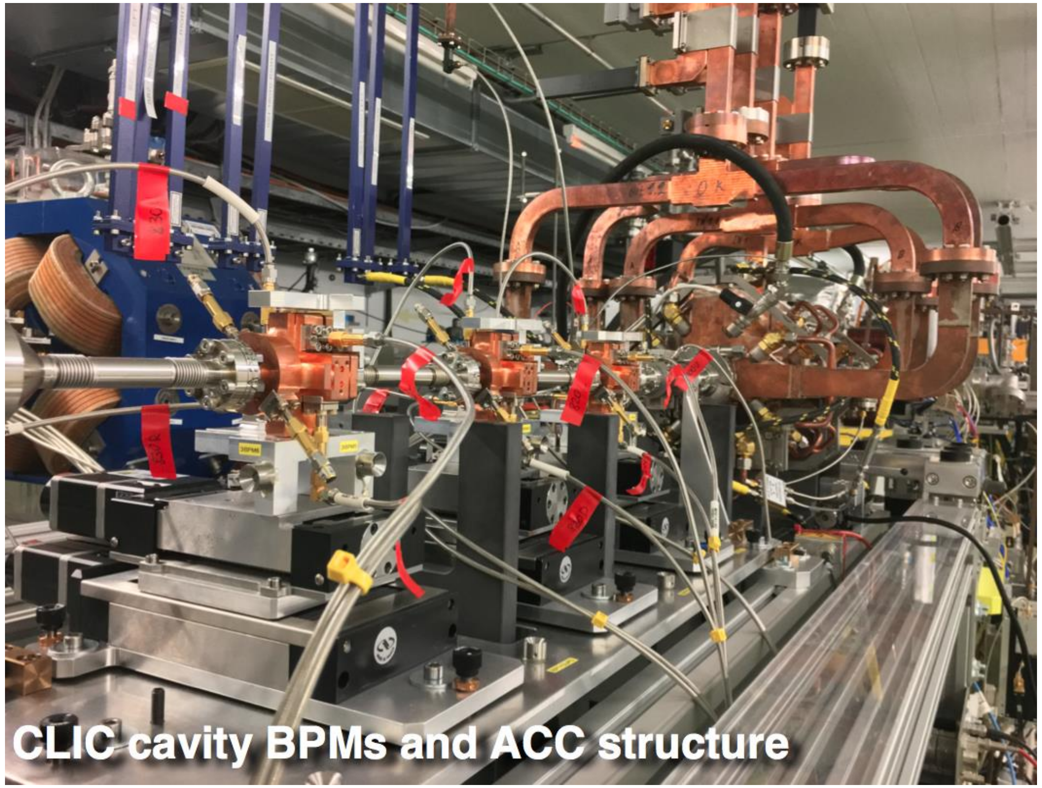
Ongoing experiments:

- Wake-Field monitors
- Wake-field kicks

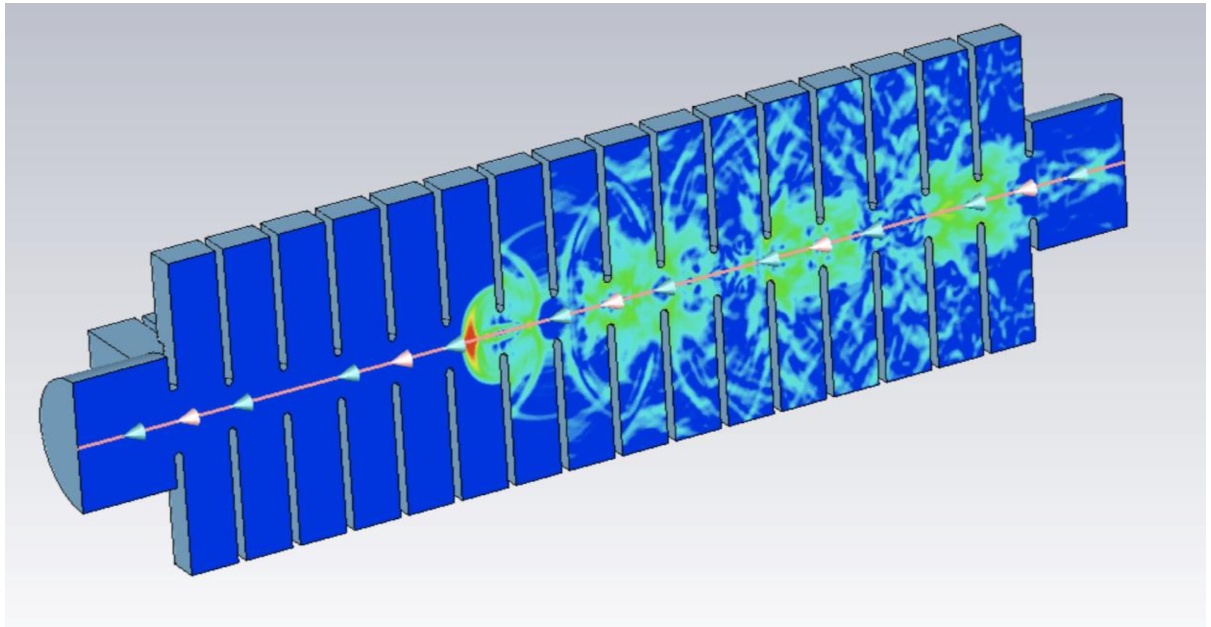
Principle:



Former CLIC Module

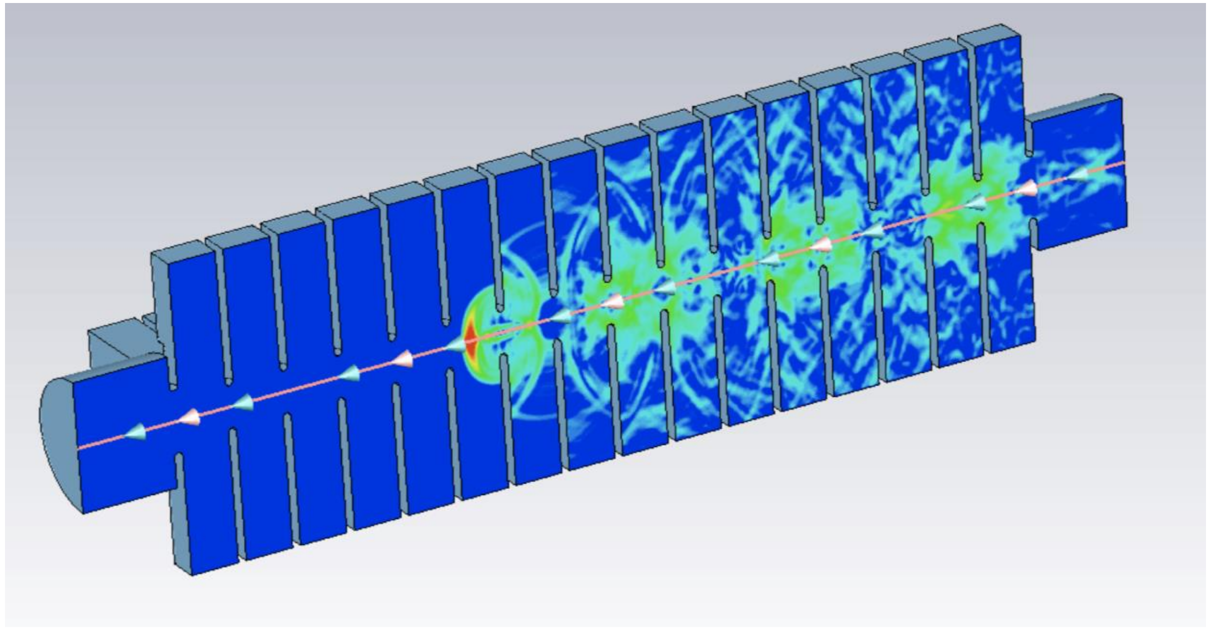


Introduction to the problem



Well known effect, the WAKEFIELD

Introduction to the problem



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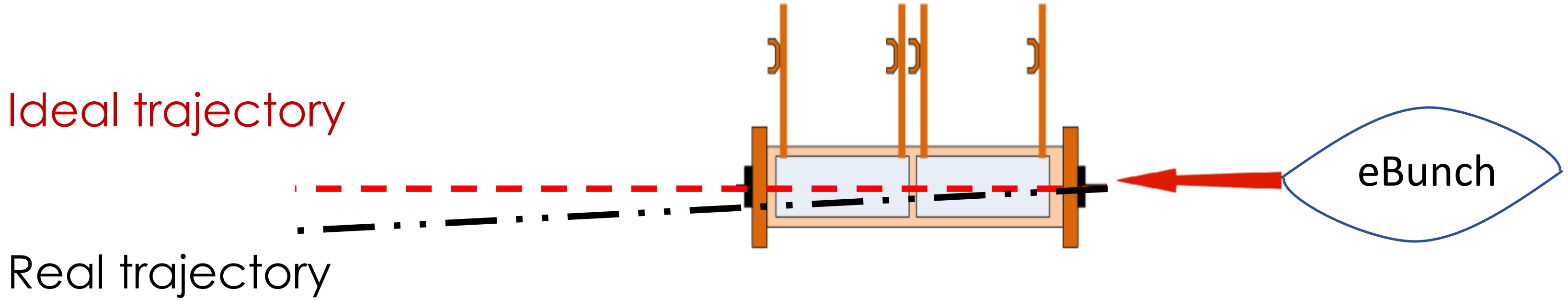

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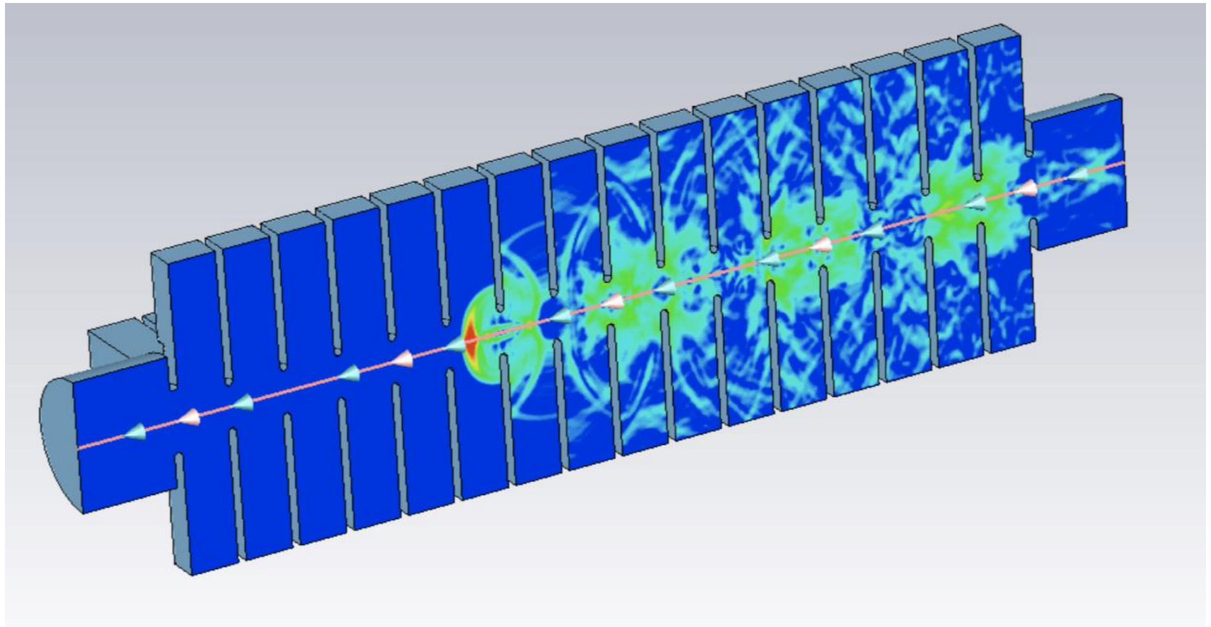
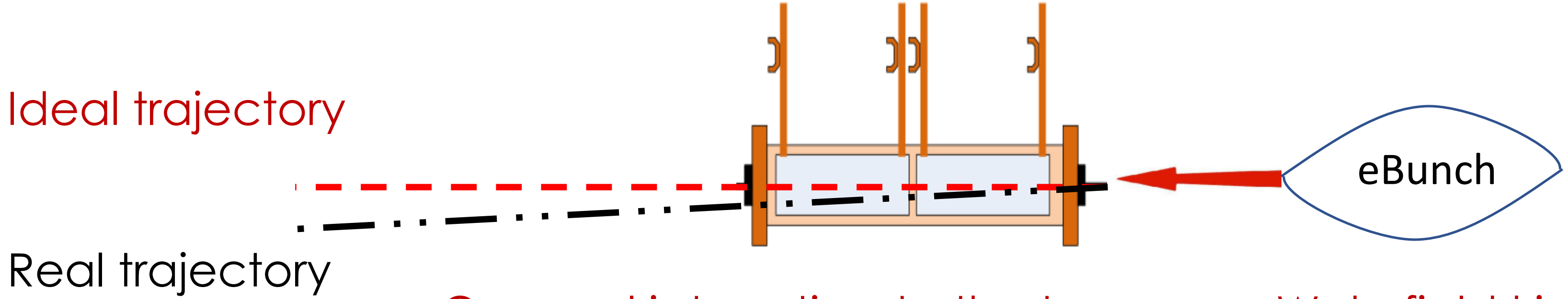


Well known effect, the WAKEFIELD

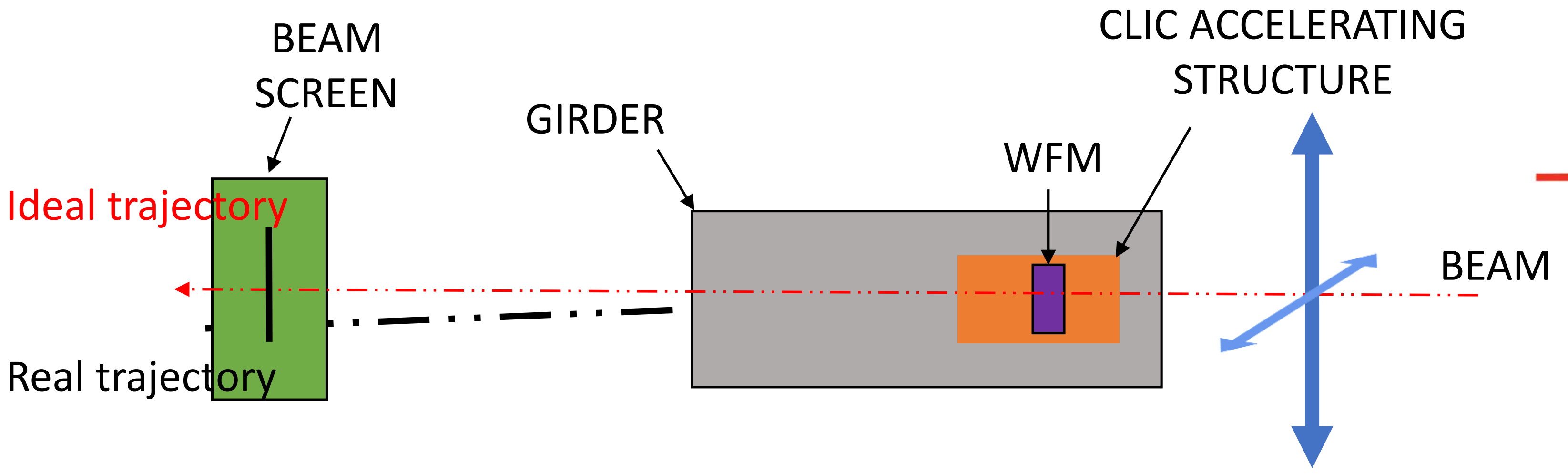
What make it worse:

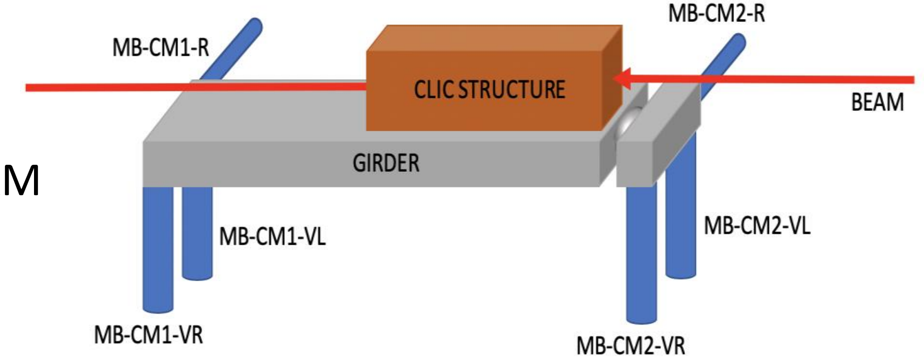
- Pipe aperture
- High charge
- Beam offset



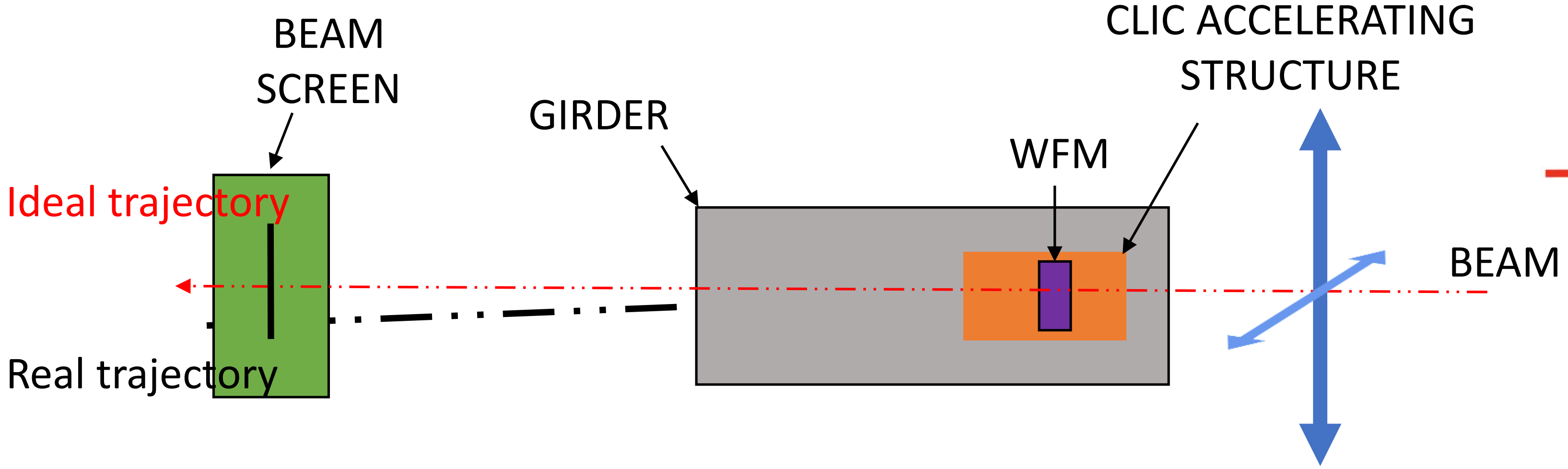
Our goal is to estimate the transverse Wakefield kick

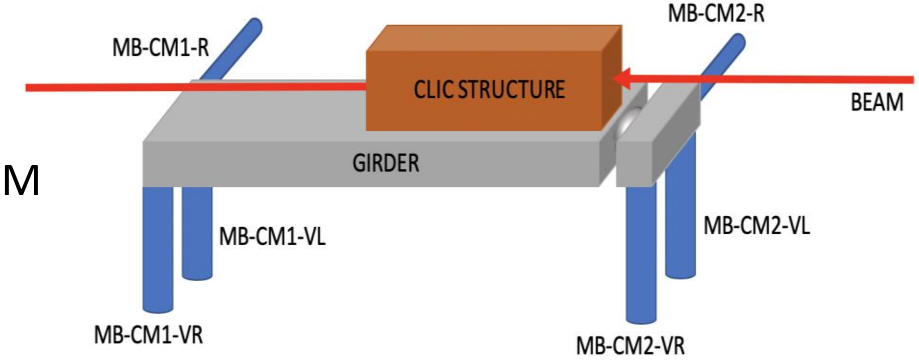
Experimental setup

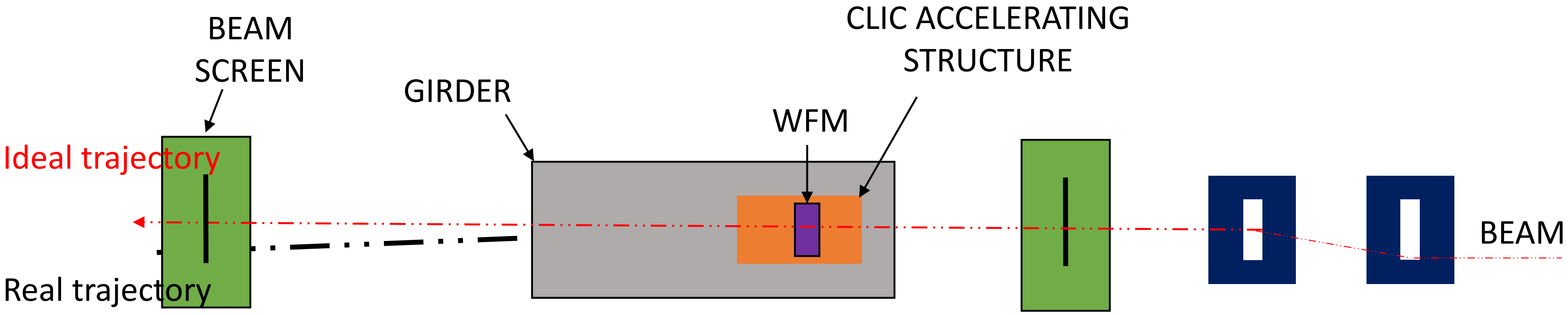




Experimental setup



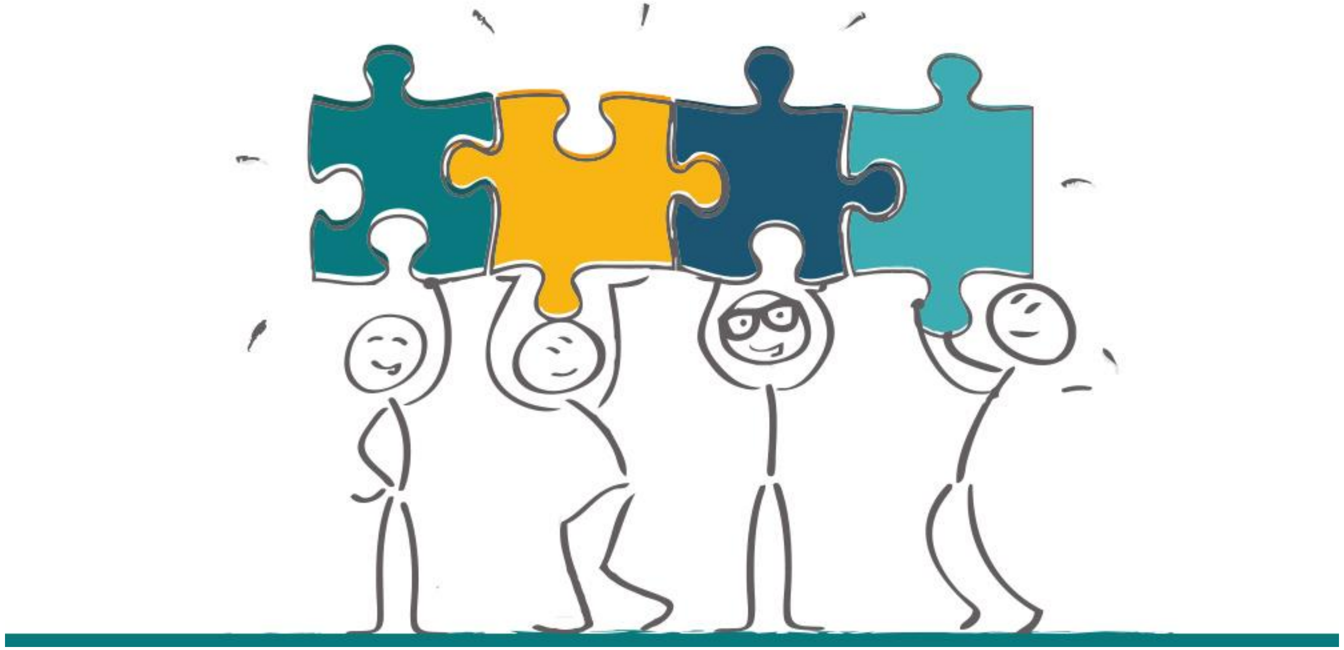




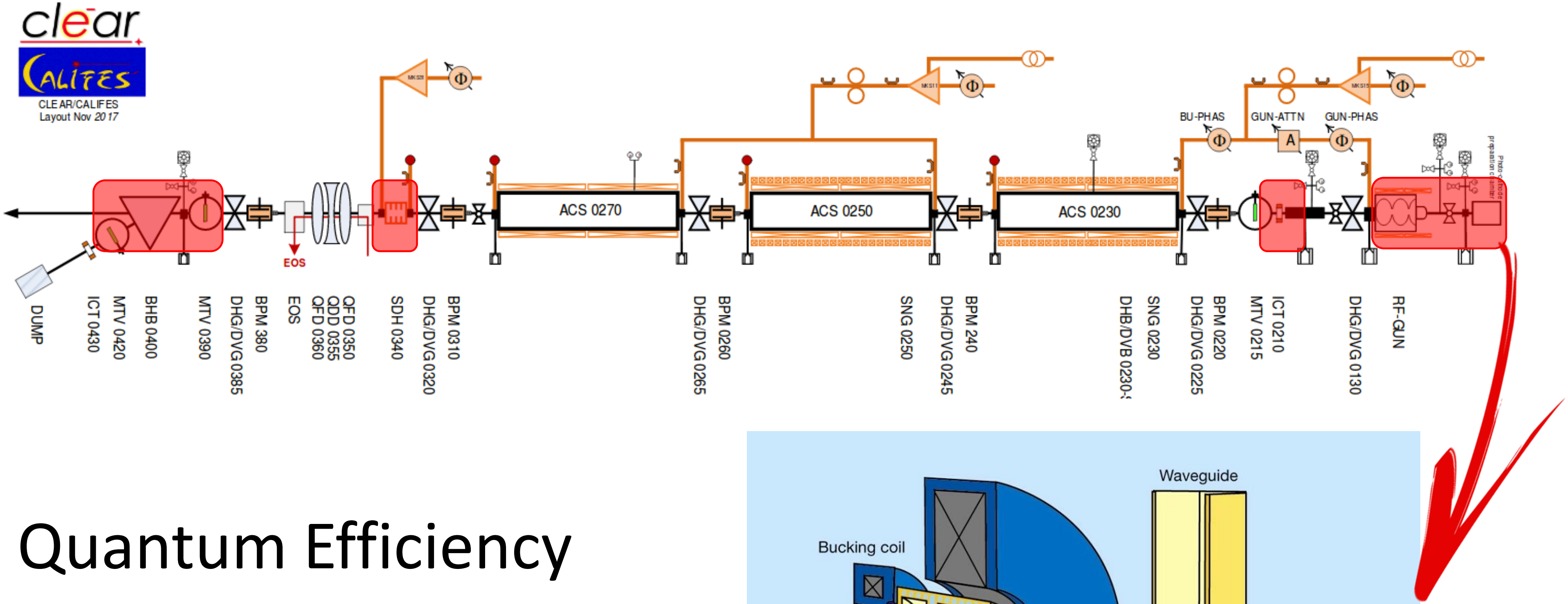
Proposed activity:

Proposed activity:

- CLEAR photocathode characterisation
  - Quantum Efficiency
  - Bunch length measure
  - Energy measuremer

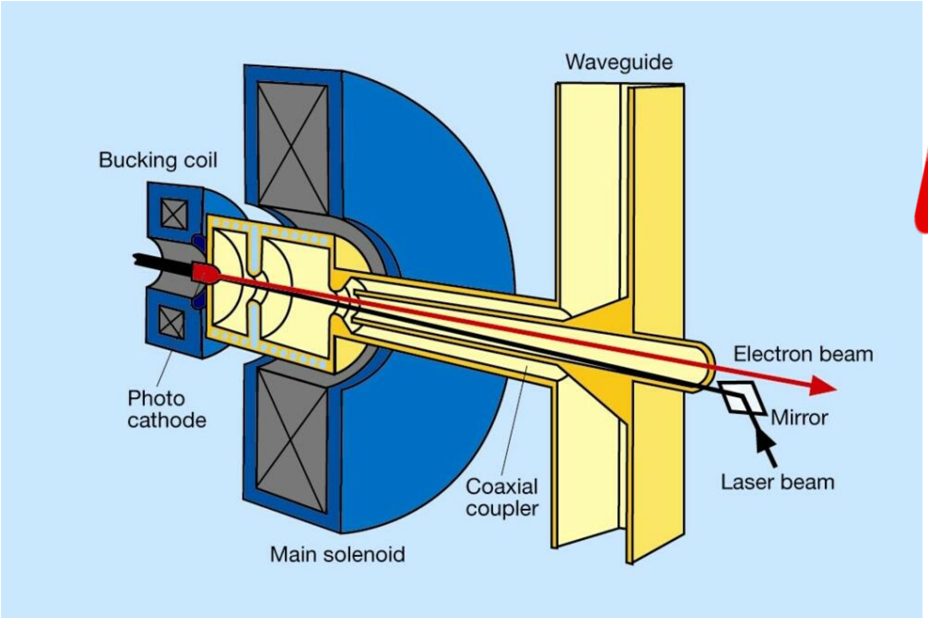


CLEAR photocathode characterisation

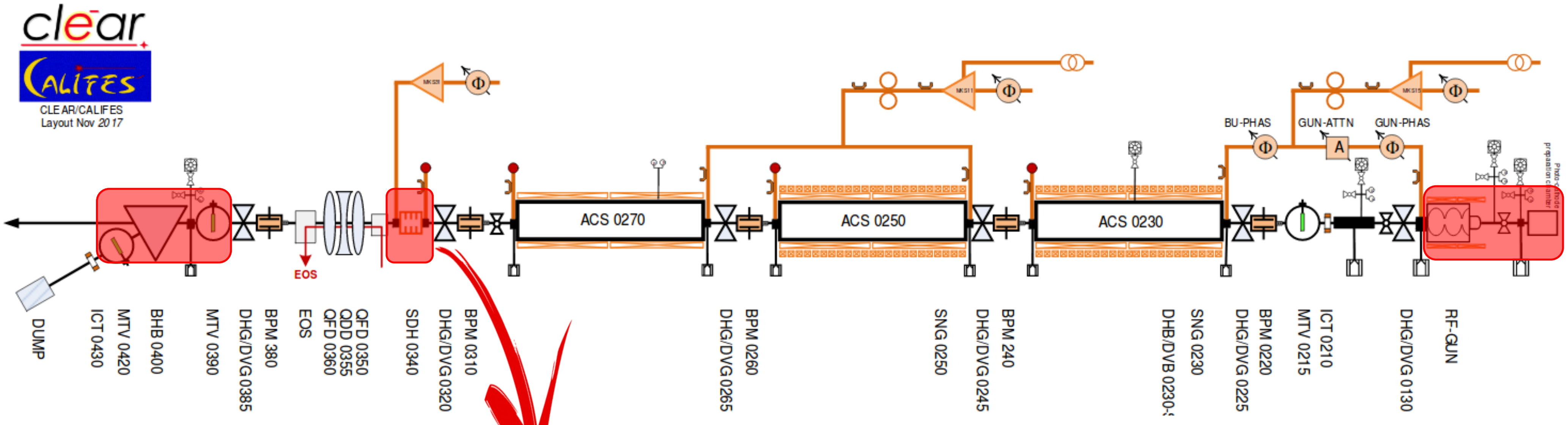


Quantum Efficiency

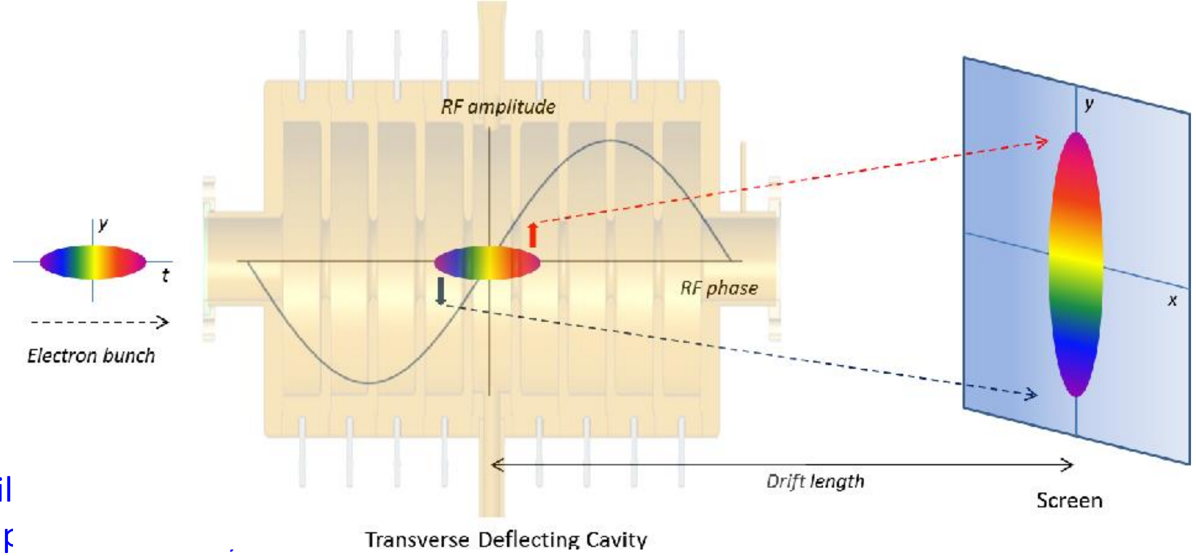
"it is the ratio between the number of charge carriers collected and the number of photons hitting the device's photoreactive surface"



CLEAR photocathode characterisation

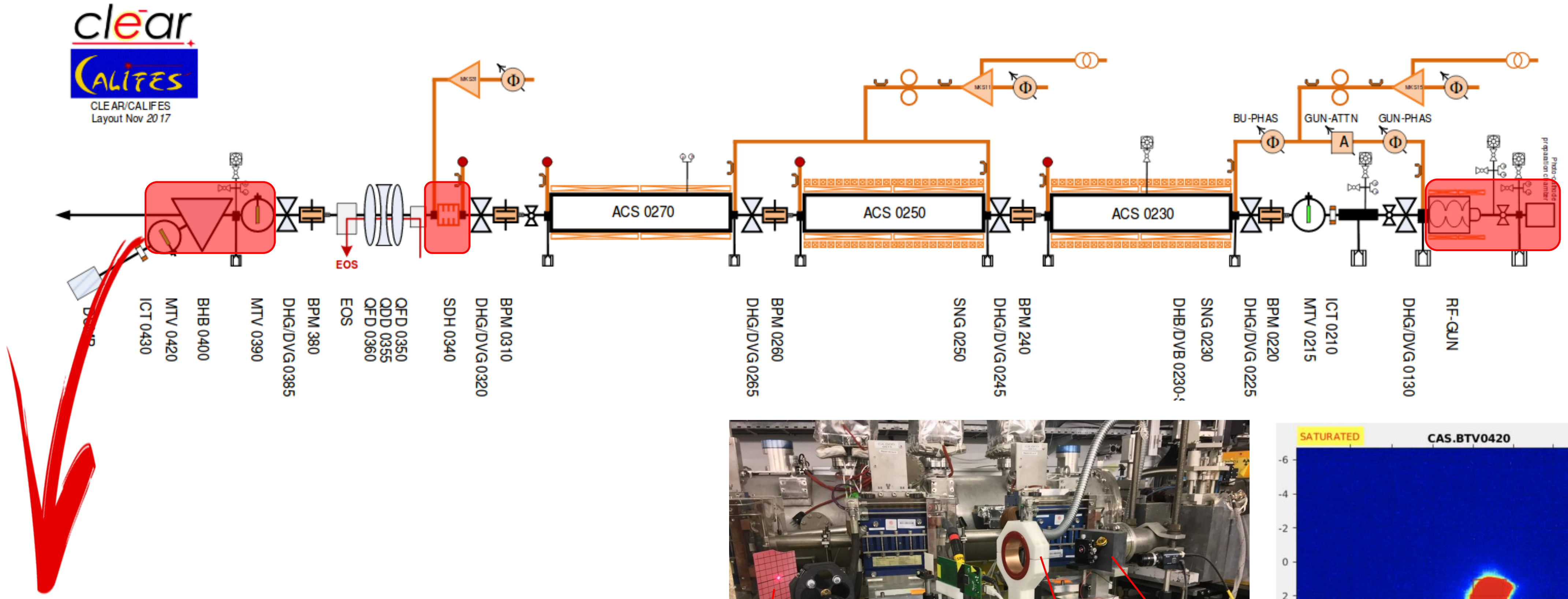


Bunch length measure

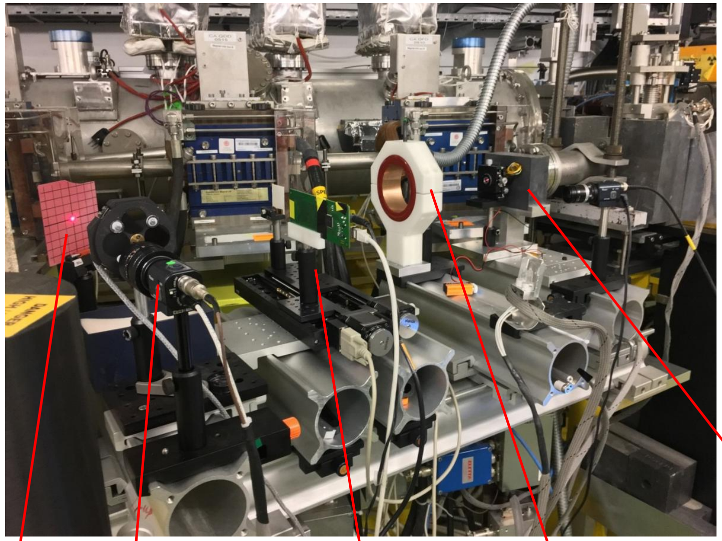


Operating principle:
- bunch pass at zero crossing in a deflecting cavity,
- bunch head experiences a transverse kick downward, bunch tail
- bunch transverse size is then downstream measured on a beam p
-Power phase shifter allows to vary the bunch length via the velocity bunching structure.

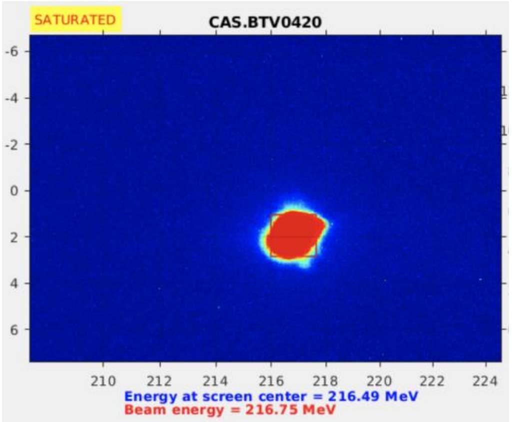
CLEAR photocathode characterisation



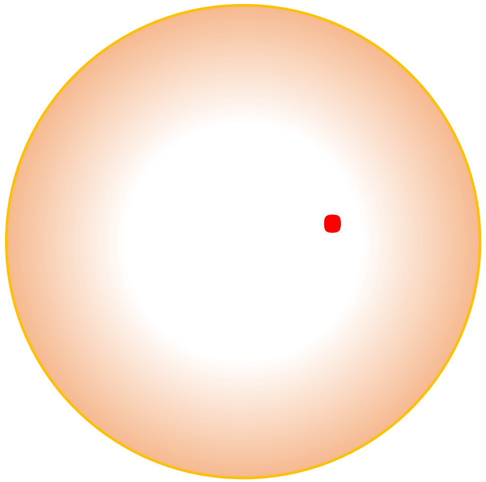
Energy measurements



Alignment screen
camera
Movable stage
Charge monitor
collimators



CLEAR photocathode characterisation

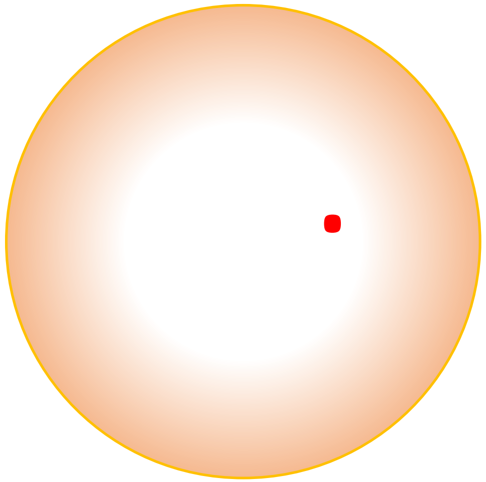


All this is for on point of the photocathode
(Even in a random position)

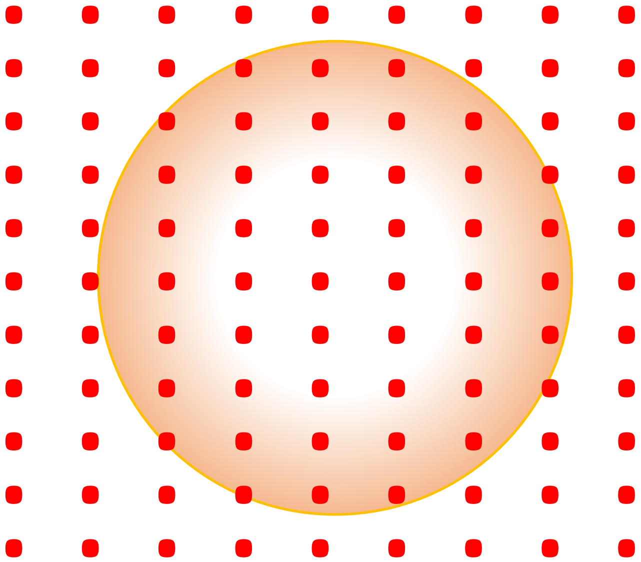
What we would like is to have something like:

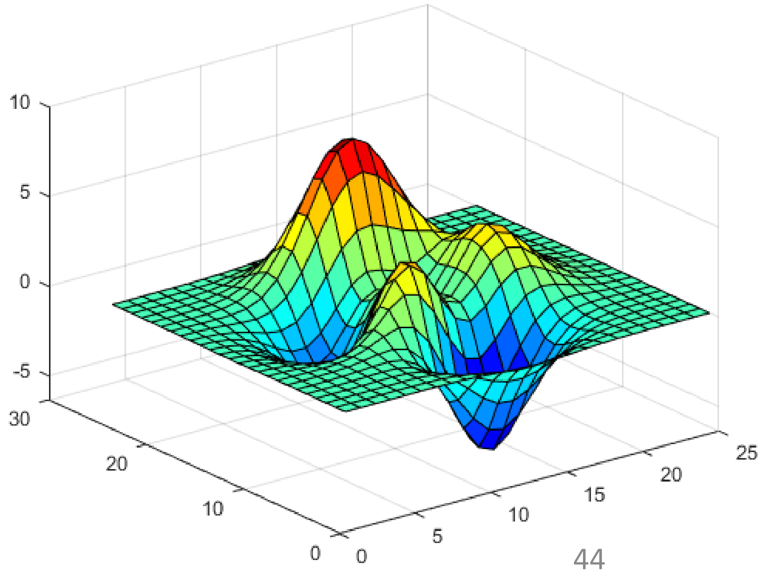
CLEAR photocathode characterisation

All this is for on point of the photocathode
(Even in a random position)



What we would like is to have something like:





CLEAR photocathode characterisation

All this is for on point of the photocathode
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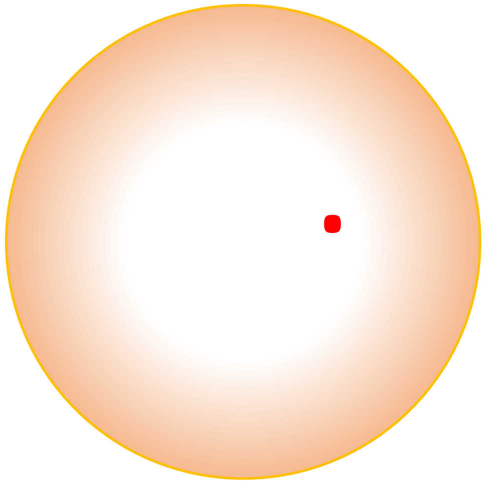
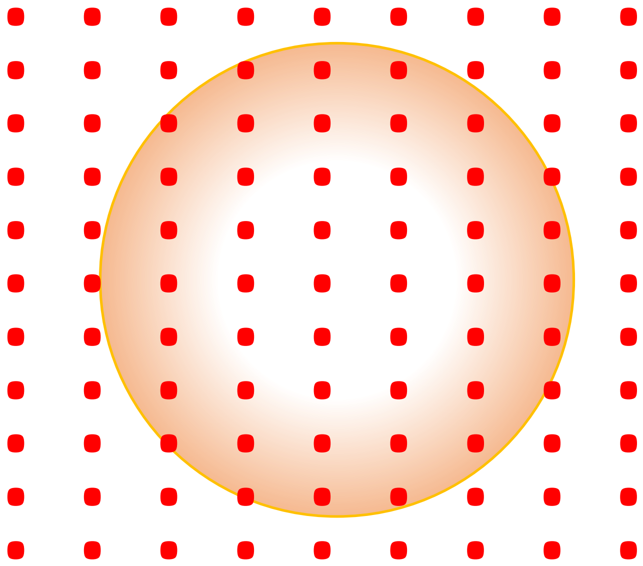
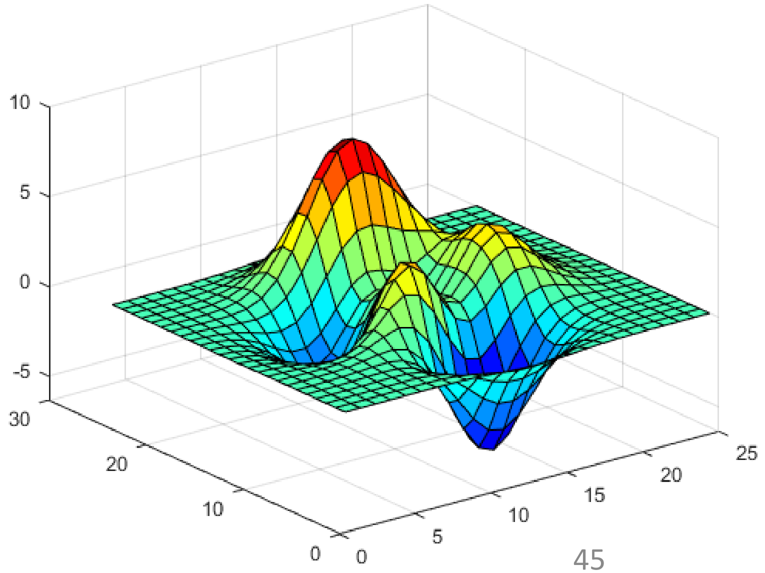


Many free parameters:

- Spot size
- Laser Energy
- Step size
- GUN setup
- ACS setup
- ….
- ….

What we would like is to have something like:



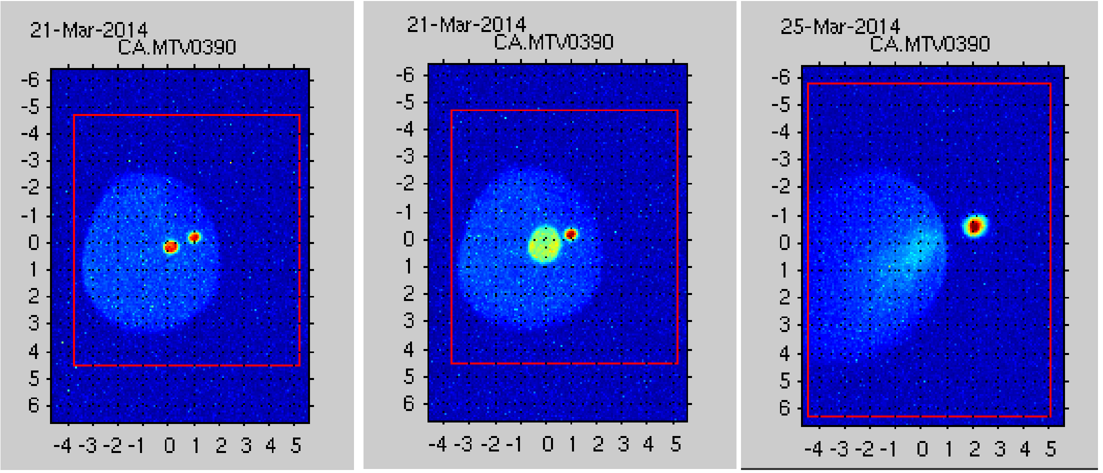


clear

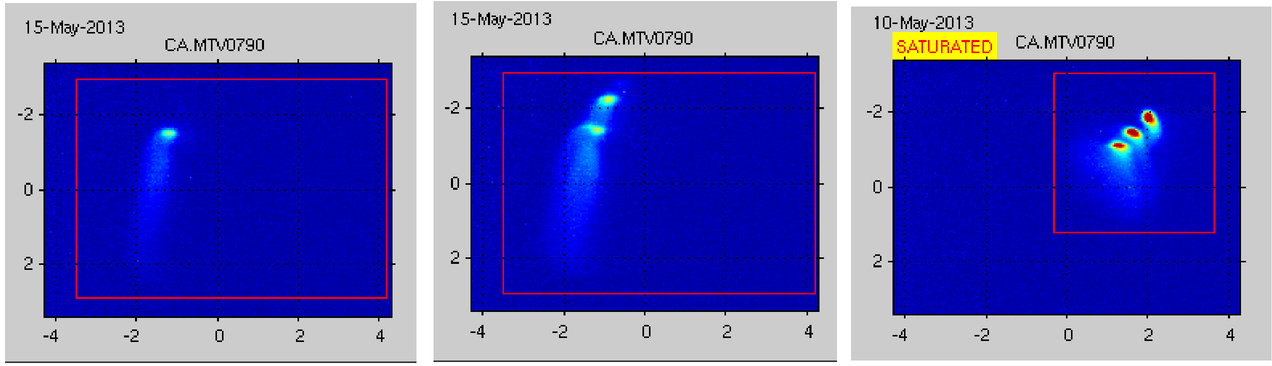
Thanks for your attention

Back up slides

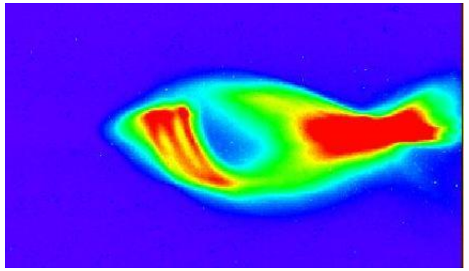
Contest (Strange beam contest)



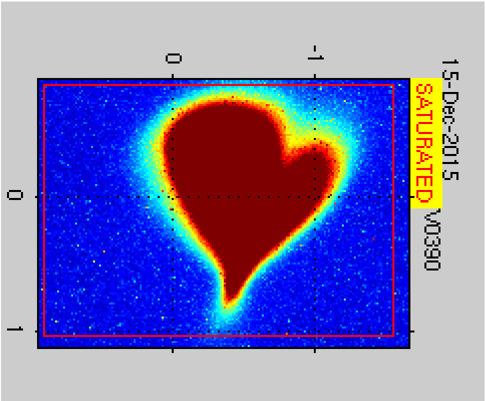
3 bunches of various charge and emittance



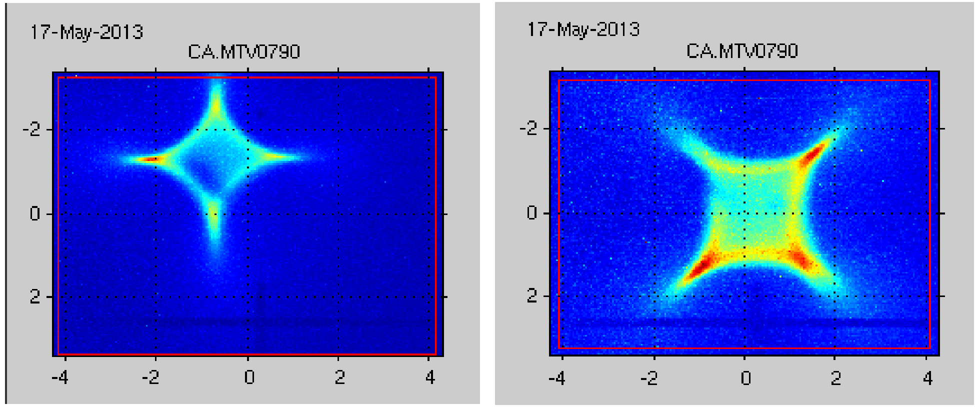
1, 2, 3… bunches with transverse space separation



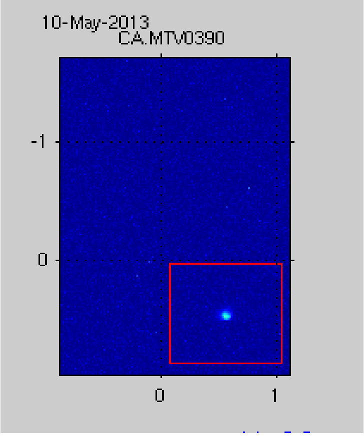
Fishy beam



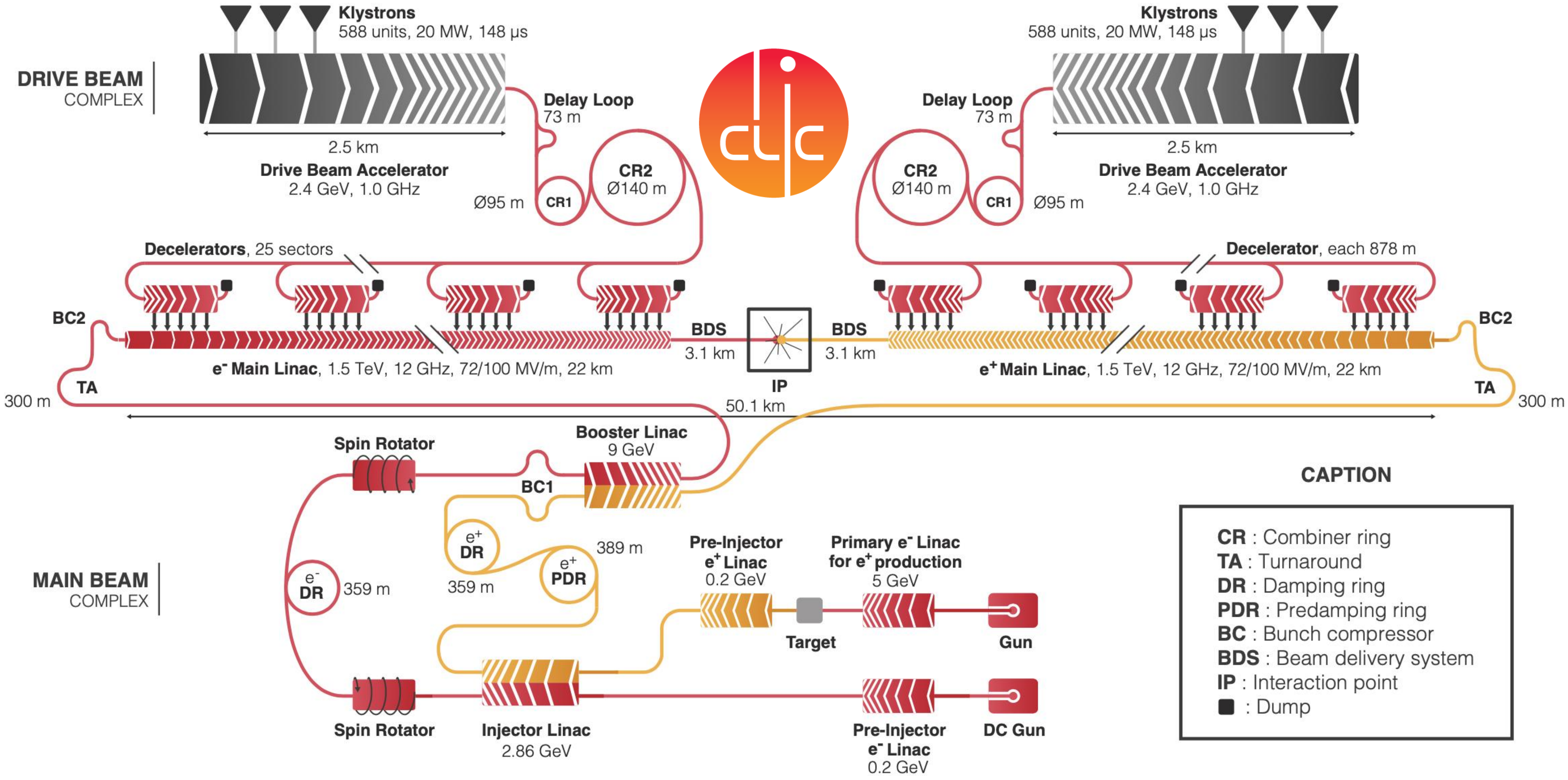
Valentine's day beam



Octupolar fields beam shape



Beam size 37 x 33 μm


DRIVE BEAM
COMPLEX
Klystrons
588 units, 20 MW, 148 μs
Klystrons
588 units, 20 MW, 148 μs
2.5 km
Drive Beam Accelerator
2.4 GeV, 1.0 GHz
Delay Loop
73 m
CR2
Ø140 m
CR1
Ø95 m
Delay Loop
73 m
CR2
Ø140 m
CR1
Ø95 m
2.5 km
Drive Beam Accelerator
2.4 GeV, 1.0 GHz
Decelerators, 25 sectors
Decelerator, each 878 m
BC2
BC2
BDS
3.1 km
BDS
3.1 km
IP
e⁻ Main Linac, 1.5 TeV, 12 GHz, 72/100 MV/m, 22 km
e⁺ Main Linac, 1.5 TeV, 12 GHz, 72/100 MV/m, 22 km
TA
300 m
TA
300 m
50.1 km
Spin Rotator
Booster Linac
9 GeV
BC1
e⁺
DR
389 m
e⁺
PDR
359 m
e⁻
DR
359 m
MAIN BEAM
COMPLEX
Pre-Injector
e⁺ Linac
0.2 GeV
Primary e⁻ Linac
for e⁺ production
5 GeV
Target
Gun
Spin Rotator
Injector Linac
2.86 GeV
Pre-Injector
e⁻ Linac
0.2 GeV
DC Gun
CAPTION
CR : Combiner ring
TA : Turnaround
DR : Damping ring
PDR : Predamping ring
BC : Bunch compressor
BDS : Beam delivery system
IP : Interaction point
: Dump

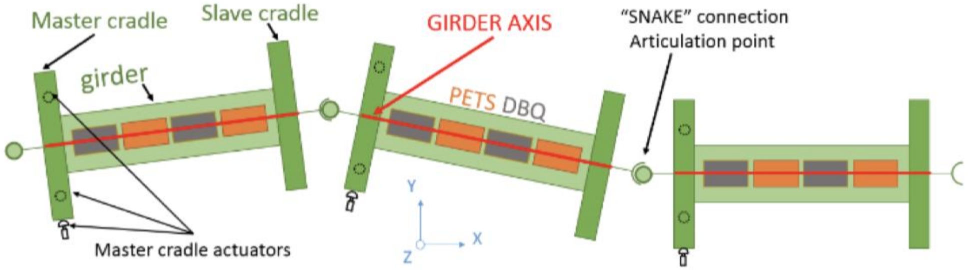
CLIC & high-gradient X-band

Present experiments:

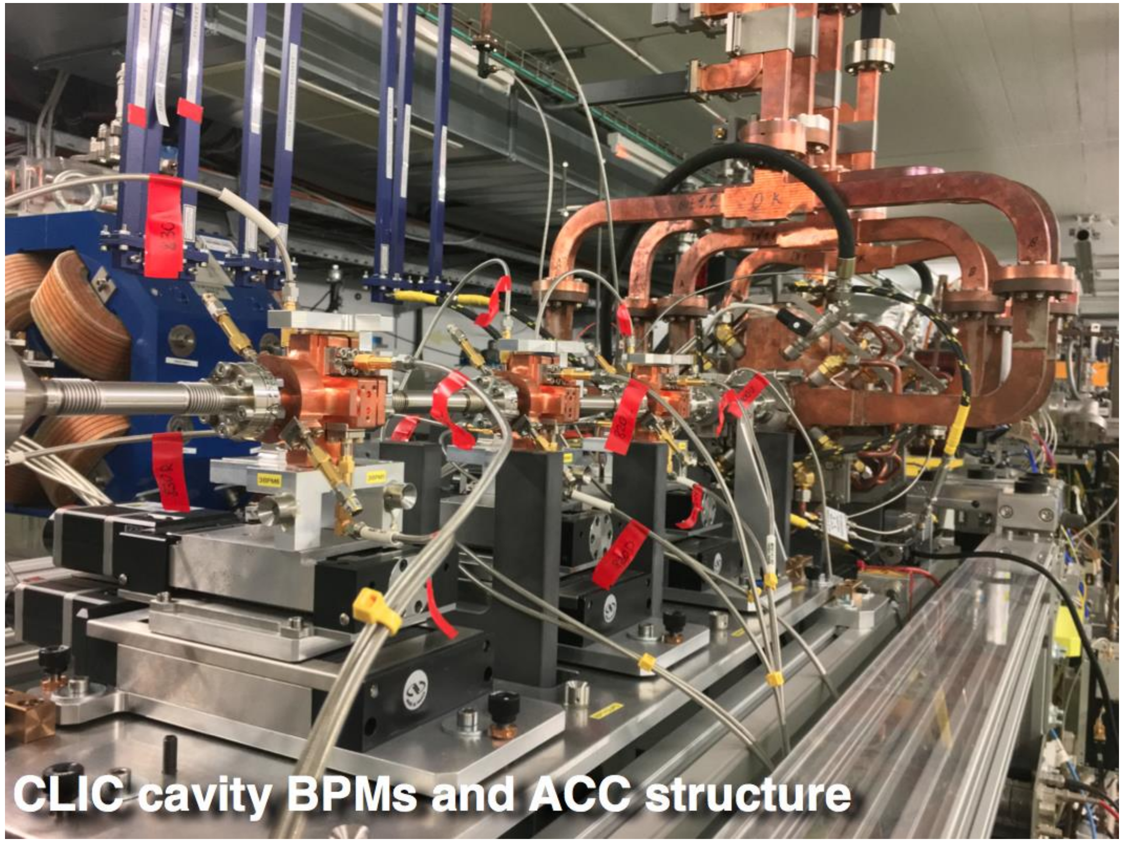
- Wake-Field monitors
- Wake-field kicks
- CLIC cavity BPMs

Possible tests:

- RF kicks
- Breakdown kicks
- RF effect on WFMs
- Stability & reliability runs



Former CLIC Module



R. Corsini

XBAND Power source will be connected

Beam Instrumentation R&D

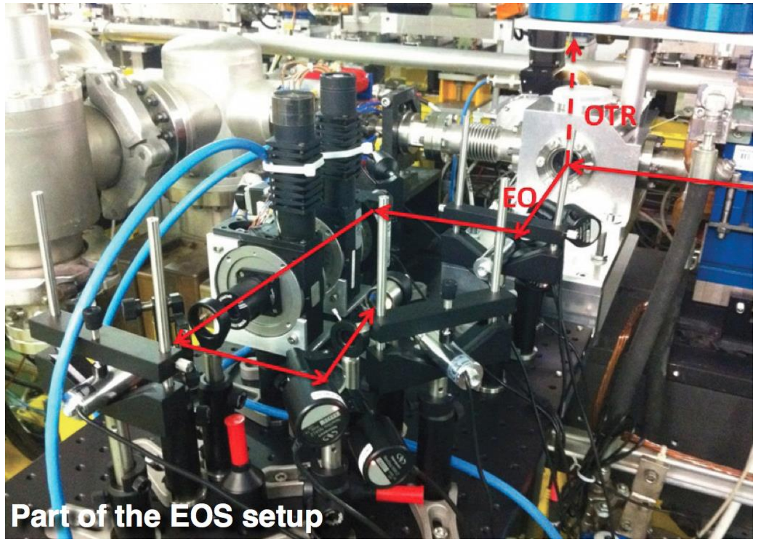
Many activities planned (most ongoing)

Two main goals:

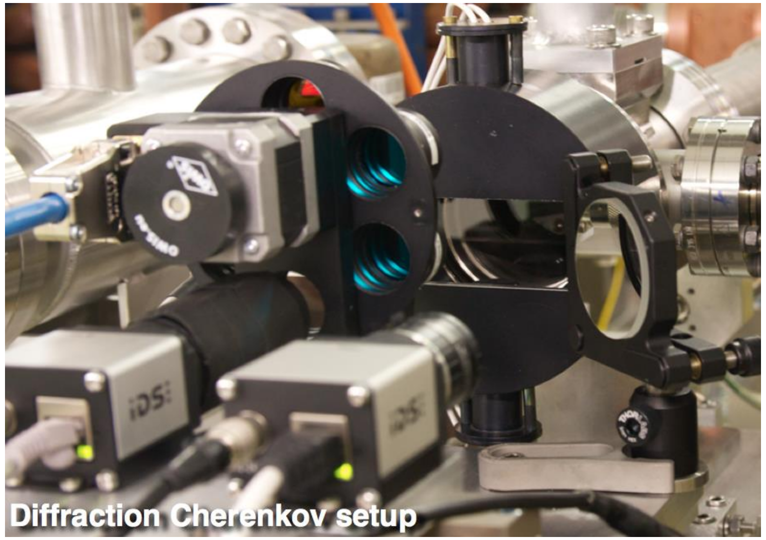
1) Consolidate and improve beam instrumentation for CLEAR

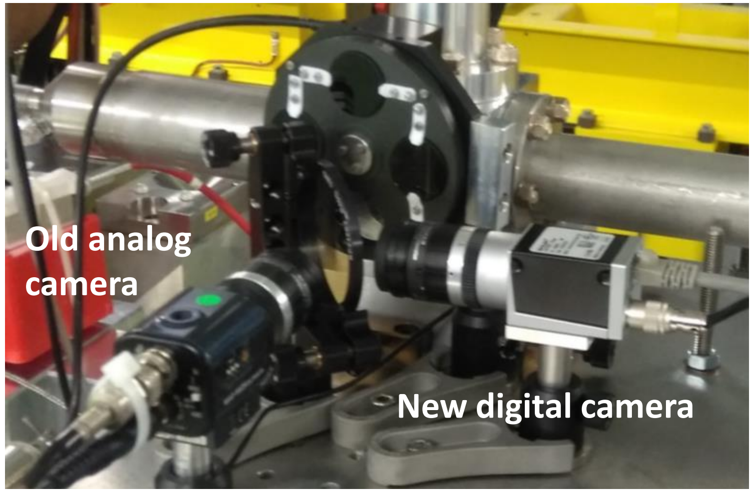
2) Diagnostics R&D

Direct applications to CERN accelerator complex & potential for future applications

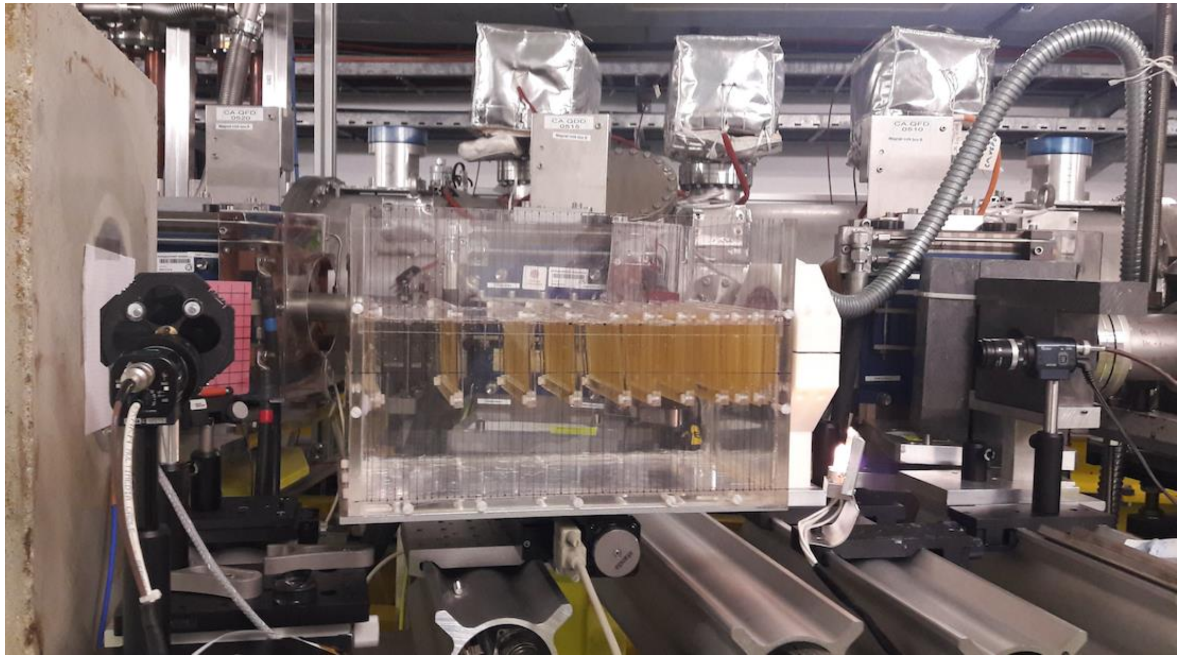


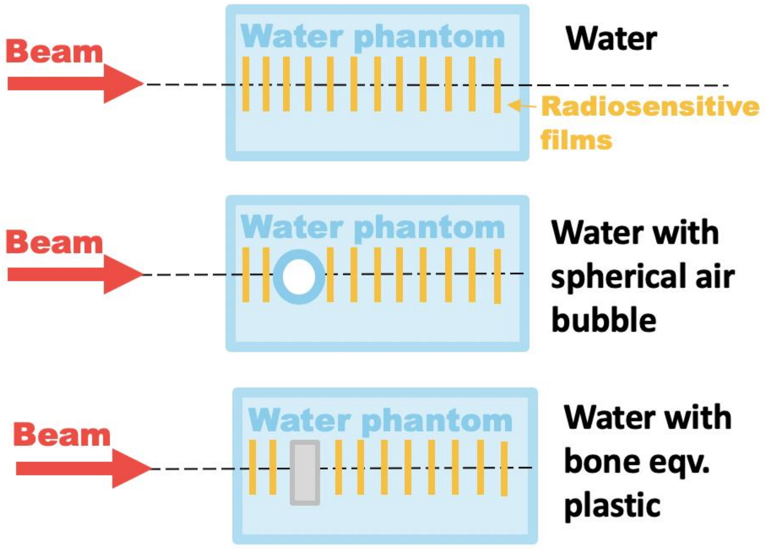
Electro-Optical monitors

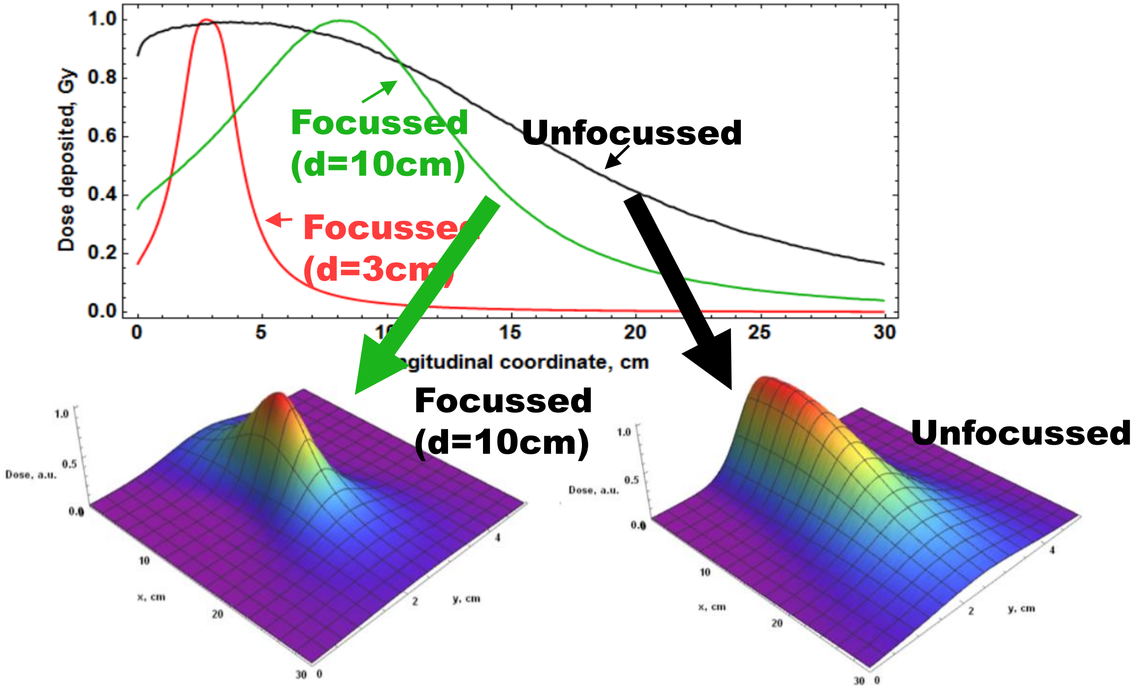


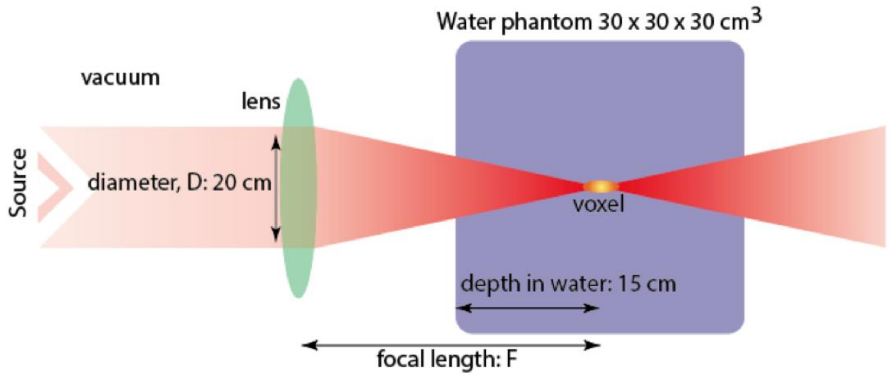


Medical irradiation test





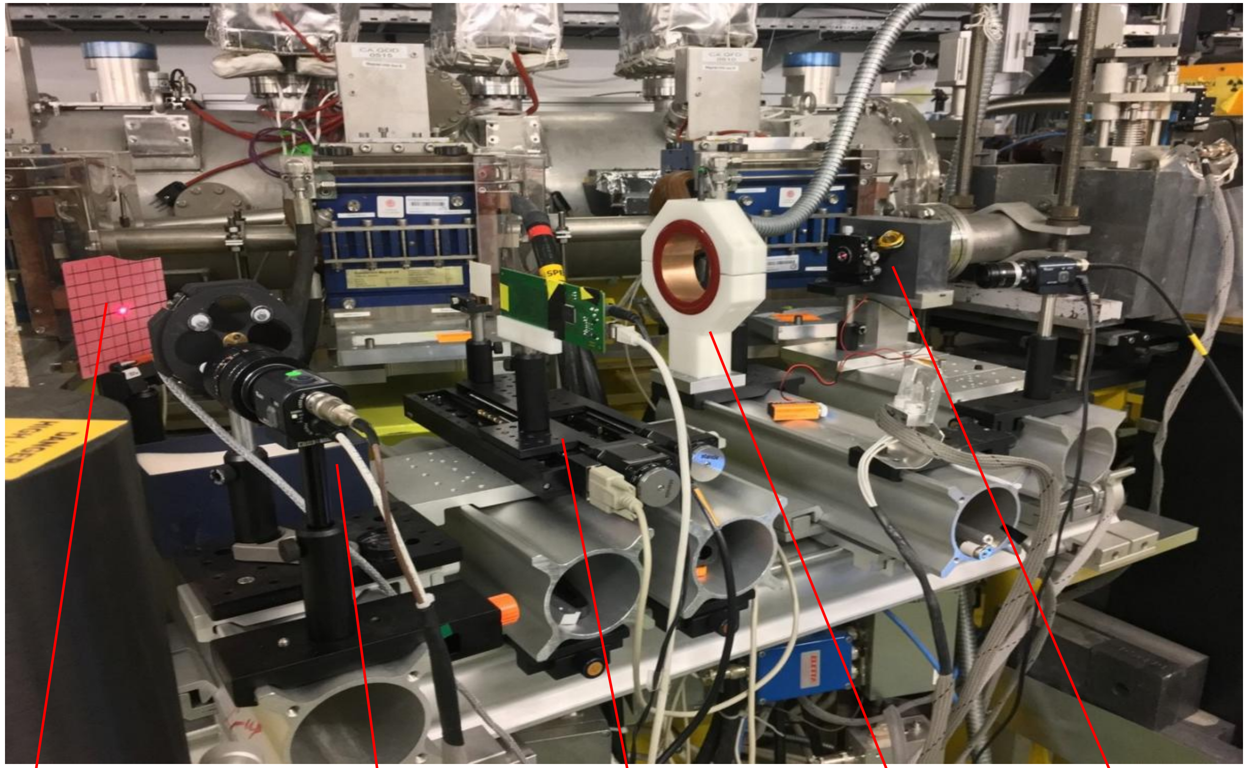


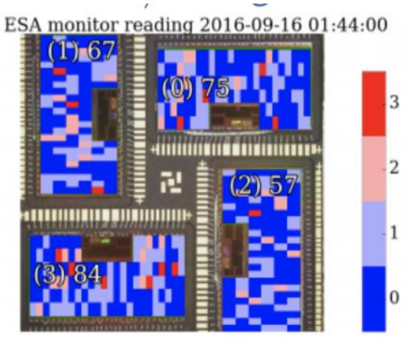


Electronic irradiation test

Main tests:

- **Only wiht dark current**
- **With laser beam**





Radiation hardness of electronic components for space missions

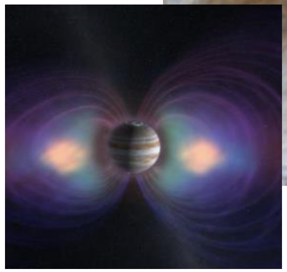
Scientific program

- Radiation hardness test on different commercial device
- ESA collaboration, SEU studies at high e- energy for JUICE mission
- Contact with NASA

Jet Propulsion Laboratory
California Institute of Technology

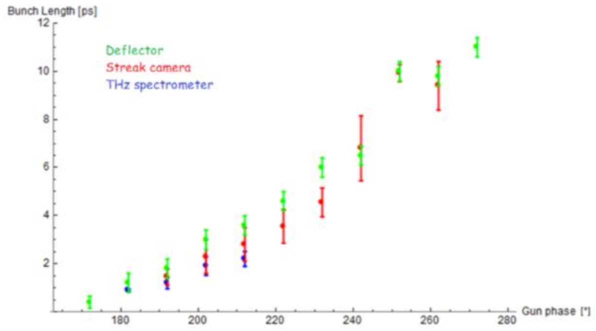
esa JUICE mission (ESA)

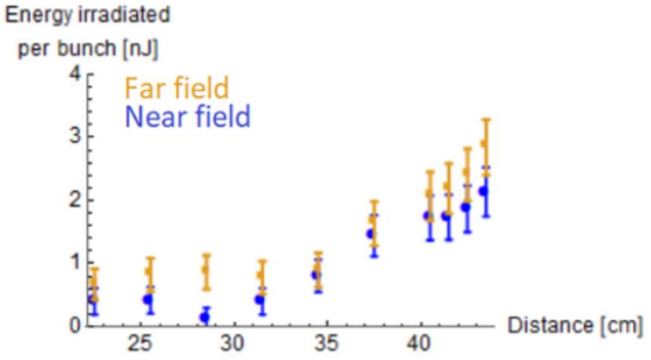
juice

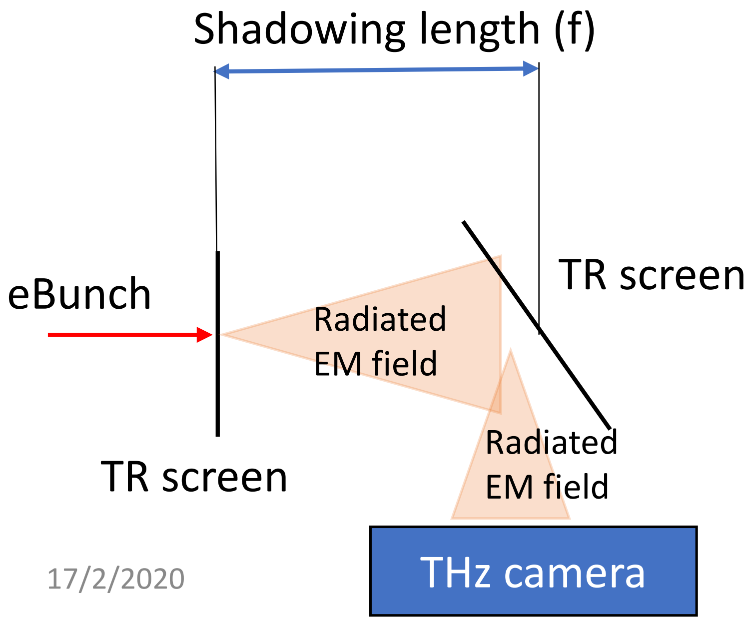


THz studies

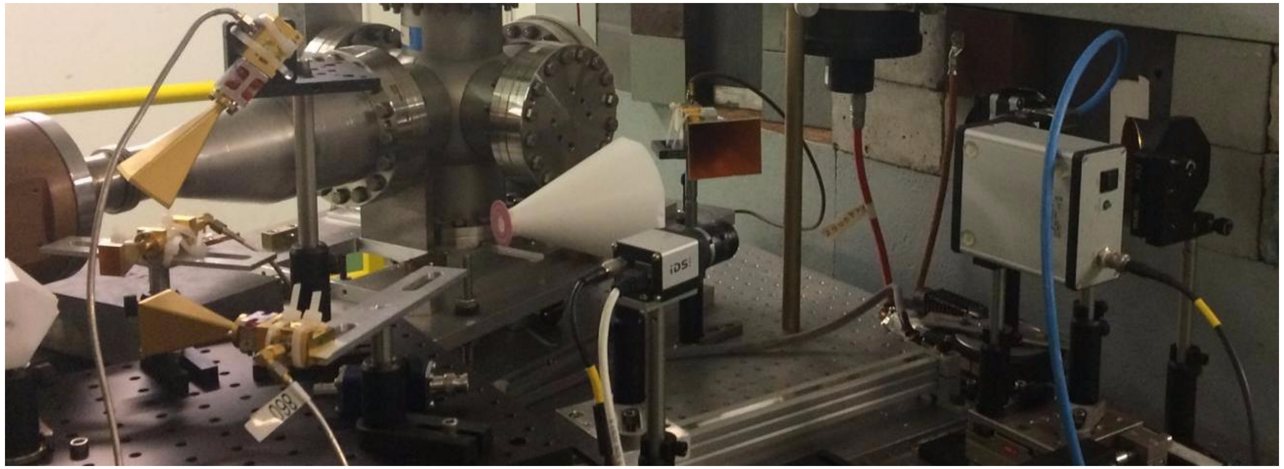
- First tests in sub-THz region, demonstrated use as bunch length diagnostics
- Characterization of beam-produced THz radiation from transition radiation (TR) screen + shadowing studies, using THz camera
- Bunch length diagnostics for CLEAR
  - Close to be operational - Teflon conical Cherenkov diffraction radiator, 4 frequency detection bands.
- High power THz from different sources
  - Tested so far: diamond, TR screens, Teflon, gratings, metamaterials







Actual Shadowing setup



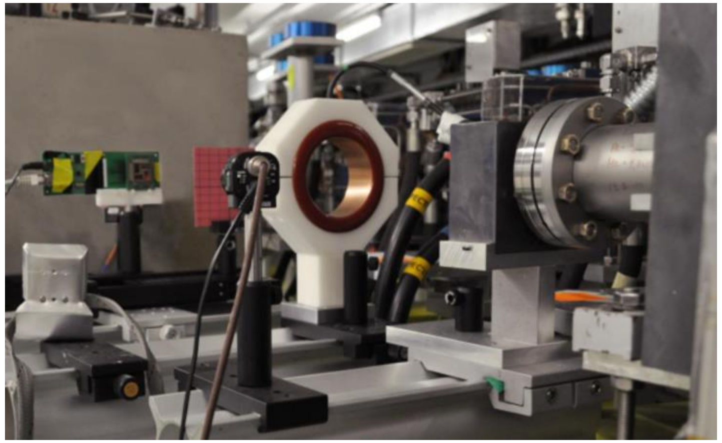
Very energetic Electron facility for Space Planetary Exploration missions in harsh Radiative environments

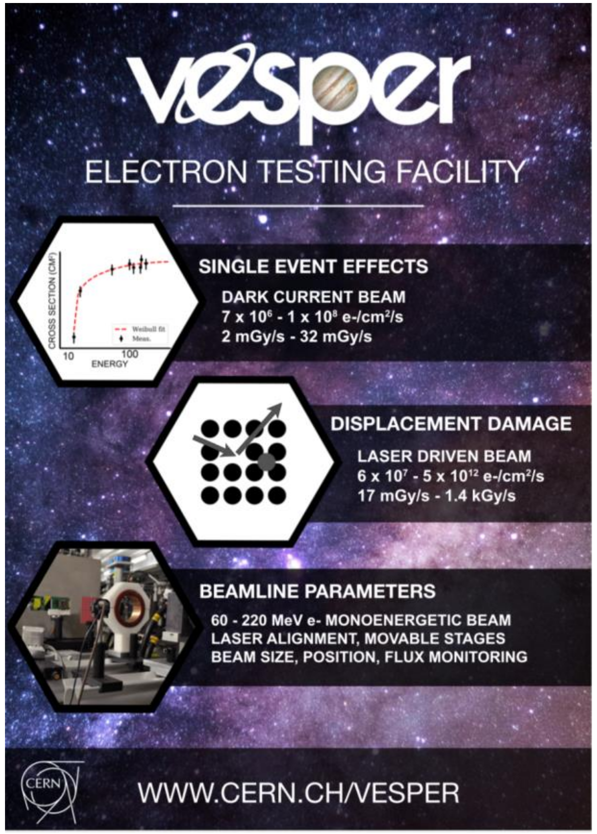
Beam line already developed and tested in CALIFES

- Improved diagnostics, stability and energy range (60 - 220 MeV)

Scientific program

- ESA collaboration
- Used also for test of AWAKE spectrometer screen
- Interest for detector electronics (Uppsala/ATLAS - wireless communication)
- Several medical applications as VHEE
- Contact with NASA (pencil beams)

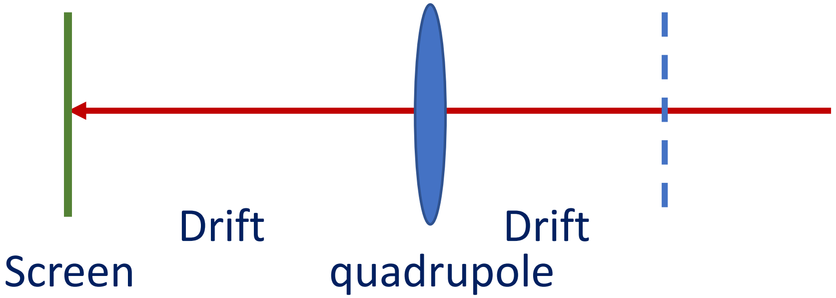


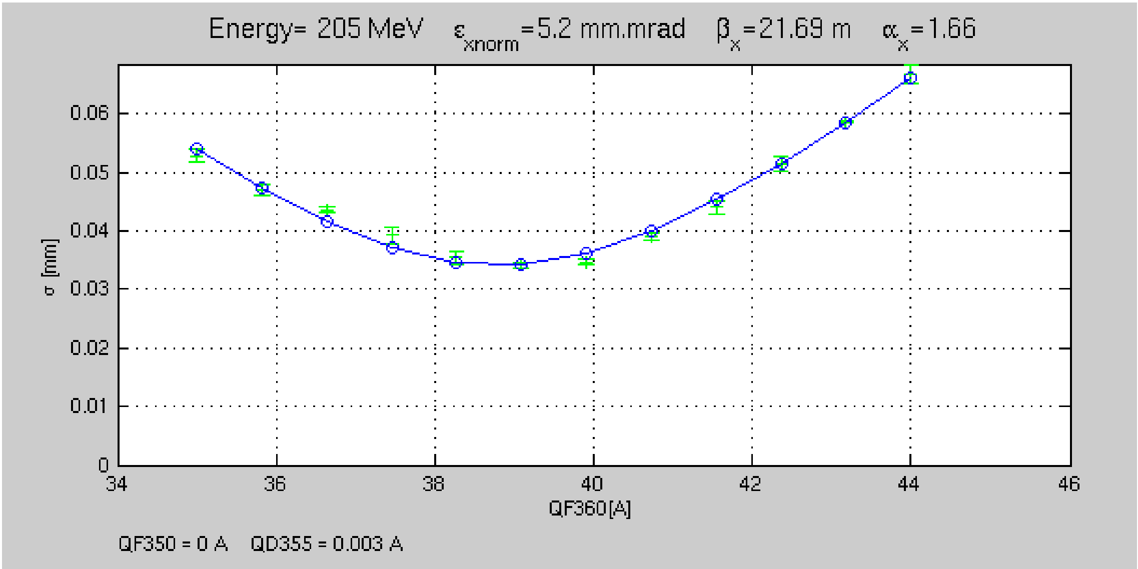


Twiss parameter measure

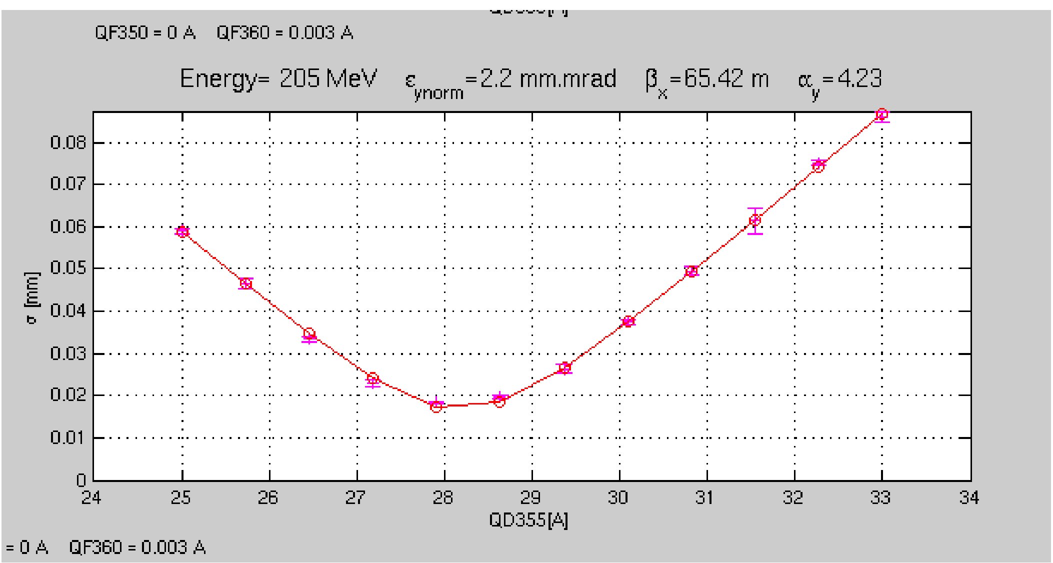
$$\begin{pmatrix} \beta_s & -\alpha_s \\ -\alpha_s & \gamma_s \end{pmatrix} = \begin{pmatrix} A_{0S} & B_{0S} \\ C_{0S} & D_{0S} \end{pmatrix} \begin{pmatrix} \beta_0 & -\alpha_0 \\ -\alpha_0 & \gamma_0 \end{pmatrix} \begin{pmatrix} A_{0S} & C_{0S} \\ B_{0S} & D_{0S} \end{pmatrix}$$

$$\begin{pmatrix} \beta_{s,1} \\ \beta_{s,2} \\ \vdots \\ \beta_{s,n} \end{pmatrix} \epsilon = \begin{pmatrix} A_1^2 & -2A_1B_1 & B_1^2 \\ A_2^2 & -2A_2B_1 & B_2^2 \\ \vdots & \vdots & \vdots \\ A_n^2 & -2A_nB_n & B_n^2 \end{pmatrix} \begin{pmatrix} \beta_0 \\ \alpha_0 \\ \gamma_0 \end{pmatrix} \epsilon$$



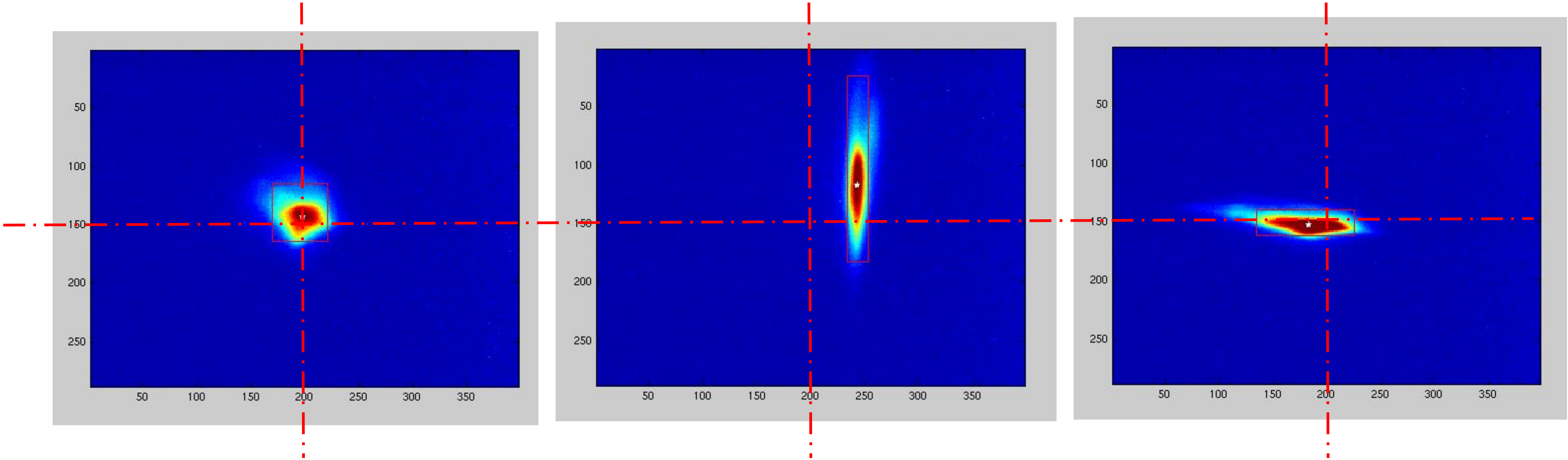


Horizontal beam size as function of quadrupole current



Vertical beam size as function of quadrupole current

Alignment of the beam inside quadrupoles



Quads Off

Horizontal focusing quad on
Beam offset in both axis

Vertical focusing quad on
Horizontal beam offset