CLEAR Facility Status and 2023 Experimental Program

CLEAR Scientific Board Meeting 16 Feb 2024, CERN

Avni Aksoy on behalf of the CLEAR team:

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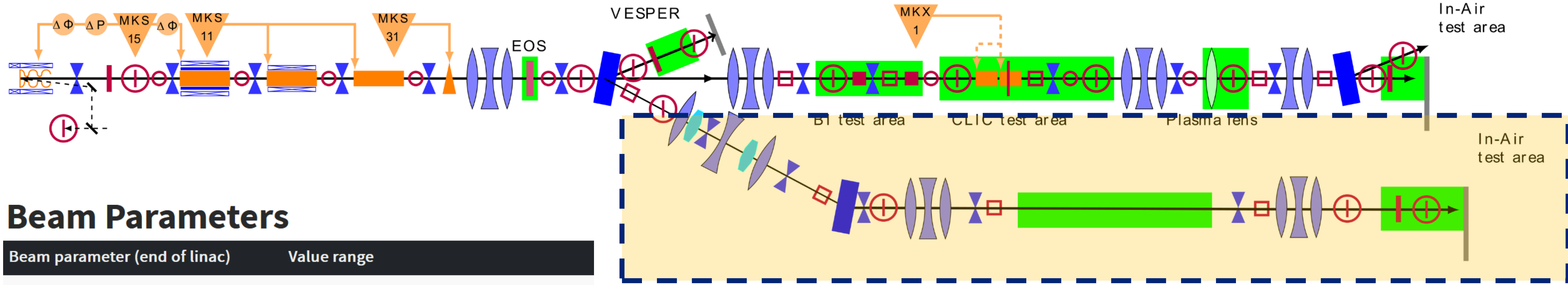
E. Granados – M. Calderon (Laser)

S. Doebert - S. Curt – A. Chauchet (RF)

Introduction



Beam Parameters

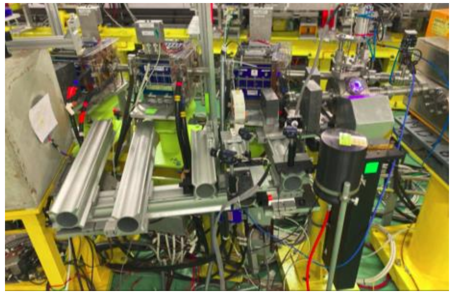
Beam parameter (end of linac)	Value range
Energy	60 - 220 MeV
Bunch charge	0.01 - 1.5 nC
Normalized emittances	3 um for 0.05 nC per bunch 20 um for 0.4 nC per bunch (in both planes)
Bunch length	~100 um - 1.2 mm
Relative energy spread	< 0.2 % rms (< 1 MeV FWHM)
Repetition rate	0.8 - 10 Hz
Number of micro-bunches in train	1 - 150
Micro-bunch spacing	1.5 or 3.0 GHz

- **Unique electron beam test facility at CERN** with high availability, easy access and high-quality. Part of Euro-Labs, transnational access program
  - R&D on accelerator components: **beam instrumentation**, high gradient RF technology.
  - **Irradiation facility** with Very High Energy Electrons (VHEE) and Ultra-High dose rate, for technical and medical applications
  - Maintaining CERN and European expertise for **electron LINACs linked to future collider studies**.
  - Using CLEAR as a **training infrastructure** for the next generation of accelerator scientists and engineers.

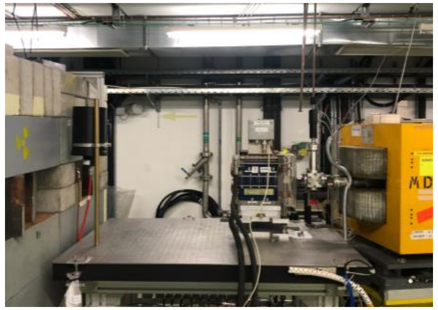
CLEAR Infrastructure 2023

Credit: P. Korysko

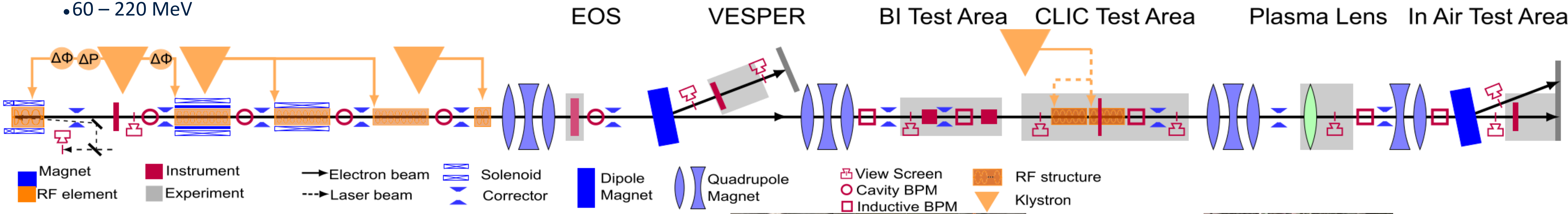
CLEAR Injector/Linac
- 60 – 220 MeV

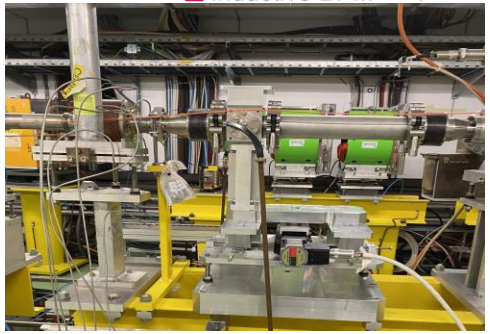


vesper
- Irradiation facility
  - Space probes
  - Electronics
  - **VHEE**

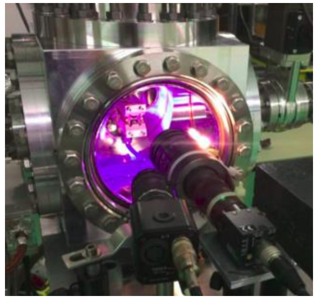


In-Air Test Stand
- Diagnostics studies
- Irradiation
  - Electronics
  - **VHEE**





BI Test Stand



Plasma Lens
- Novel plasma based focusing

Summary of operation weeks

Credit: W. Farabolini

Week	Type of experiment	Institute	Install (h)	Acces nb.	Beam time (h)
11	MD	ABP	6	1	6
	Neutron monitors	CERN- RP	2	7	22
12	Optic fiber dosimetry	Oxford U.	5	8	20
	Film dosimetry	Oslo U.	5	2	19
13	LUXE BPM	INFN Bol./Pad.	16	5	46
14	Scatterers	Oxford U.	8	5	24
	Real time dosimetry	Oxford U.	2	0	6
	Uniform beam generation	Cern-ABP	0	0	6
15	Wall current transformer	Bergoz	2	2	12
	MD Cavity BPMs	ABP			
16	MD Dispersion free steering	ABP			
	Optic fiber dosimetry	Oxford U.			
	Film dosimetry	Oslo U.			
	MD Flat Beam space charge	ABP			
17	Plasmid irradiations	Manchester			
	Film dosimetry	Oxford U.			
18	Medical irradiation Ch. ZFE Cells	CHUV			
	Optic fiber dosimetry	Oxford U.			
19	Ch DR	CERN-BI			
20	VHEE UHDR	Victoria U.			
	ZFE irrad. And phantom dosimetry	CHUV			
	MD	ABP			
21	Scintillator dosimetry	Victoria U.			
	VHEE UHDR larve irrad.	EPFL			
	Spatially fractionated irrad.	Victoria U.			
	MD	ABP			
22	Ch DR BPMs for Awake	Oxford U.	2	2	20
23	EOS	CERN-BI	4	9	25
	LUXE BPM	INFN Bol./Pad.	0	0	4
24	MD	ABP	1	0	50
25	Quarz fiber Cherenkov	Bologna U.	10	5	32
	LUXE BPM	INFN Bol./Pad.	1	0	3
26	MD	ABP	8	7	36
27	Ch DR EOS	CERN_B	4	4	35
28	MD BBA	ABP	0	0	8
	CHUV preparation	CHUV	3	3	12

Week	Type of experiment	Institute	Install (h)	Acces nb.	Beam time (h)
29	Bunch Length Monitor EOS for FCC	KIT	8	3	25
	LUXE BPM	INFN Bol./Pad.	2	1	5
30	Real time dosimetry	Oxford U.	6	7	25
	ZFE irrad	CHUV	1	4	6
	MD uniform beam	ABP	0	0	12
31-33	Summer shut-down PL installation		30	1	
34	Plasma Lens	Oslo U.	6	5	25
35	Dual Scatterers for flat beam	Oxford U.	6	9	30
36	Ch DR BPMs for Awake	Oxford U.	4	6	15
			0.5	2	6
		thclyde U.	1	6	17
			0.5	1	4
		N-BI	1	1	18
		L	16	1	0
		L	16	1	25
		rpool U. / Cockcroft	2	8	36
			0	0	3
		TI-BMI HSE	5	5	50
			0	0	5
			12	7	18
		rd U. and JAI	8	7	15
		N-BI	3	2	4
			0	4	32
			5	5	50
			0	2	5
			4	3	30
46	microBPMs	CERN-EP-DT	3	7	12
	Detectors	Kansas U.	3	6	20
47	VHEE irradiation of cells	CHUV	2	5	20
48	optic fiber BPM	Oxford U.	8	2	15
	Dual Scatterers for flat beam	Oxford U.	2	1	15
	YAG/film comparison	Oslo U.	1	1	2
	MD dosimetry prediction code	ABP	0	0	5
49	MD BBA	ABP	0	0	50
	Flat beam generation	ABP	0	0	10
total			279	230	1209

- 37 weeks of beam
- 279 hours of set-up installation
- 230 accesses with the radioprotection
- 1209 hours of beam
- 40 hours of fatal failure
- 1.9 experiments per week in average

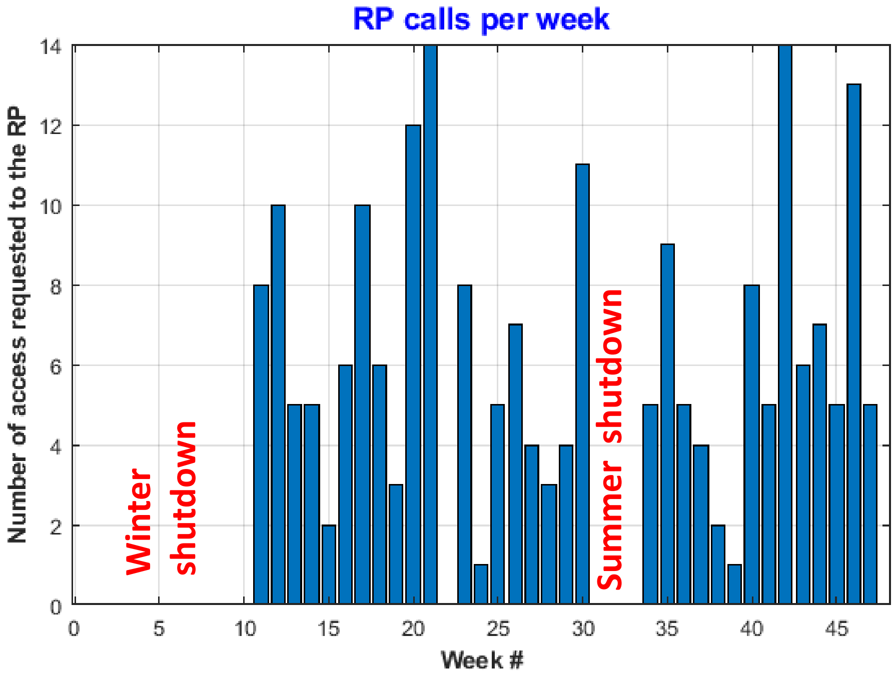
Beam availability

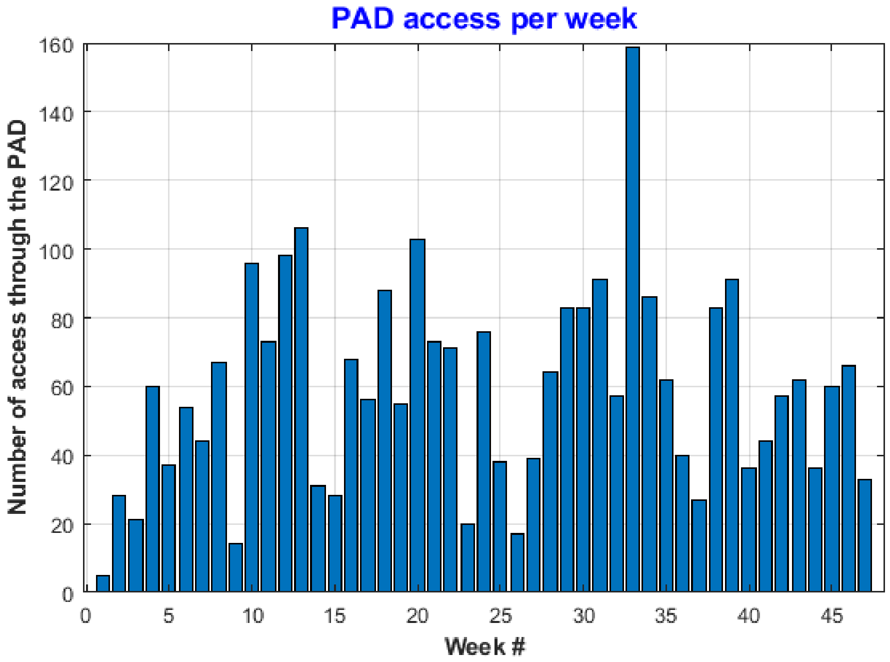
- Fatal failure time: 40 hours affecting 6 weeks (96.7 % beam availability)
  - Laser: chiller cartridge, attenuator controller, amplifier water leak, (continuous run during weeks
  - Klystrons: some periods of recurrent trips
  - Turbo-pump (controller inside CLEAR)
  - Access control
  - Power cuts
- Consolidation program
  - New laser oscillator bought
  - Many amplifier spares from PHIN injector
  - New modulator station being prepared for klystron active spares
  - Turbo-pump controller being installed in the klystron gallery

Access Numbers

A very large number of accesses for experiment installation and user's interventions on their set-up.

- RP calls: **213** from 01/01/23 to 30/11/23 (minimum delay 30 min, require klystron stop, limited to working hours)
- PAD accesses: **2802** D. Chapuis:





In average:
- **9 per day**
- **59 per week**
- **253 per month**

Mutualizing accesses with two experimental beam lines will increase the overall running time and allow more experiments per week. Complex set-up could stay installed for longer time.

Origins of experiments

Credit: W. Farabolini

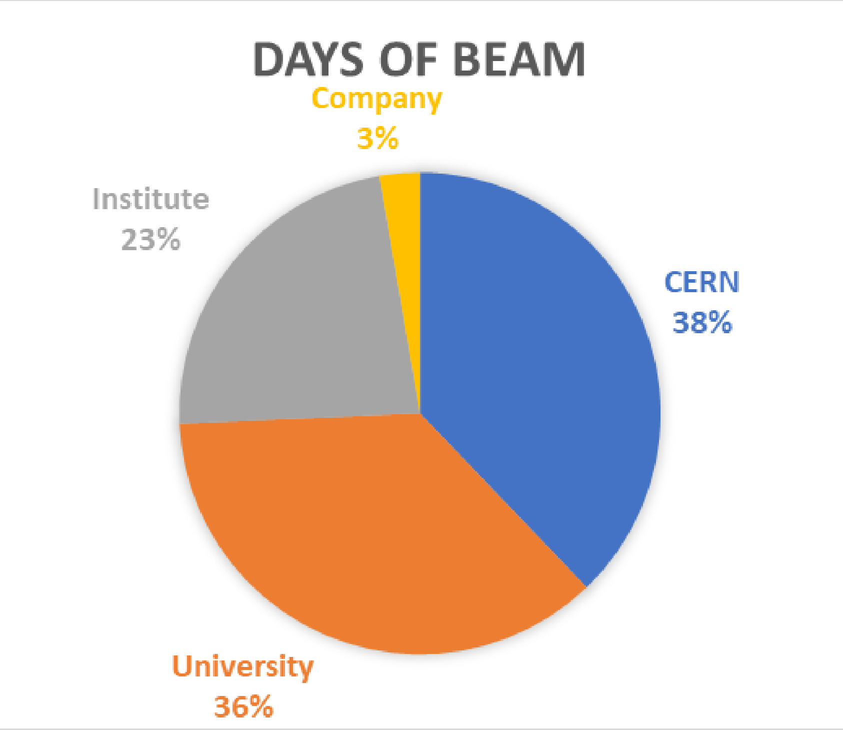
- 27 Experiments
- About 18 User Groups internal/external
- More than 13 external collaborating institutes

- CERN – ABP
- CERN – BI
- CERN – RP
- CERN – EP
- CERN – TE
- CERN – SY

- BERGOZ
- DAES

- Manchester Univ.
- Oxford Univ.
- RHUL
- Liverpool Univ.
- Strathclyde Univ.
- Queen's Univ.
- Oslo Univ.
- Bern Univ.
- Victoria Univ.
- Kansas Univ.

- PSI
- CHUV
- EPFL
- INFN Bologna
- INFN Padova
- KIT
- PTB
- RAL – ENEA
- Cockcroft Inst.
- JAI

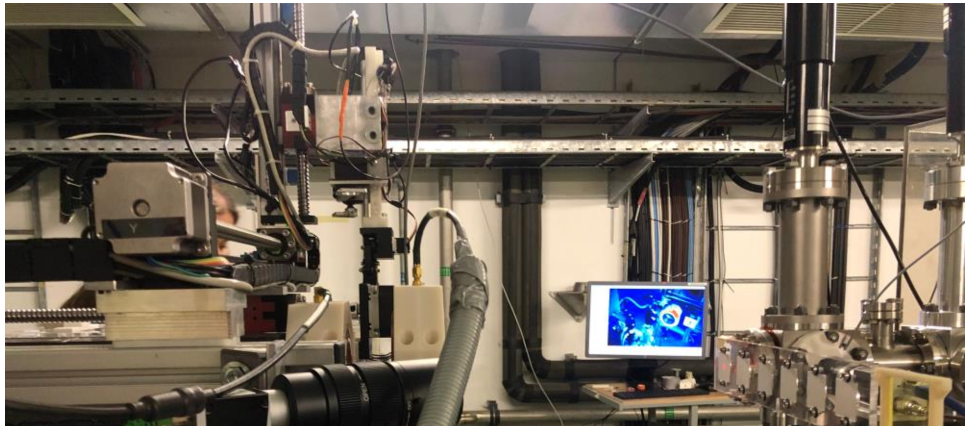


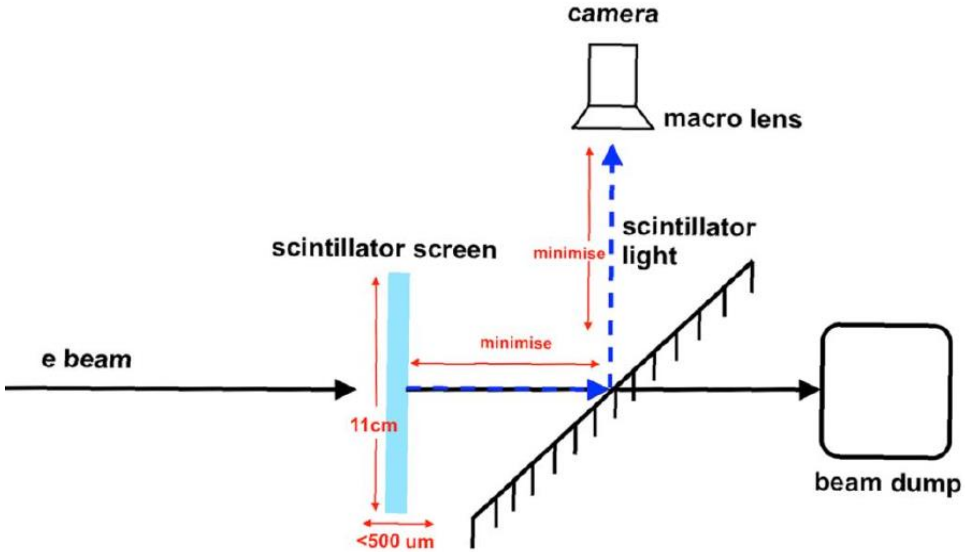
Some experiments that are not related to medical studies

AWAKE sintilation screen (University College London)

Understanding the resolution of the plastic scintillator screen , as well as test other samples to improving the limiting resolution of the spectrometer at AWAKE.

- Different type of screens were attached on linear state.
- Experiments performed with different angles of observer
- We could achieve < 50 um beam size in air for about 100 pC bunch charge.

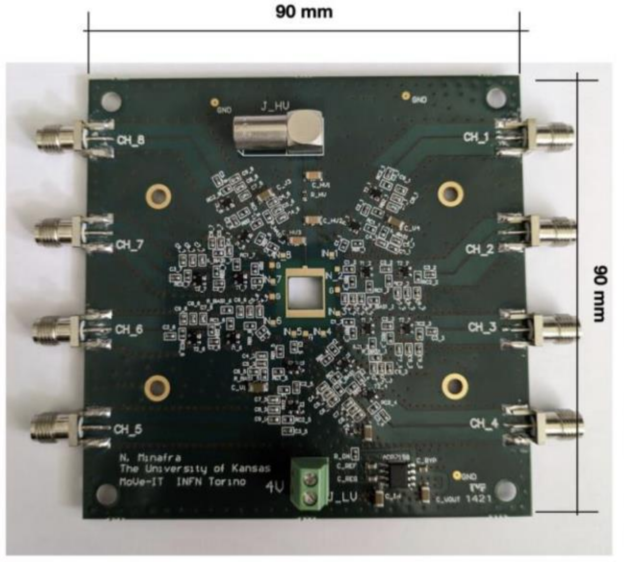


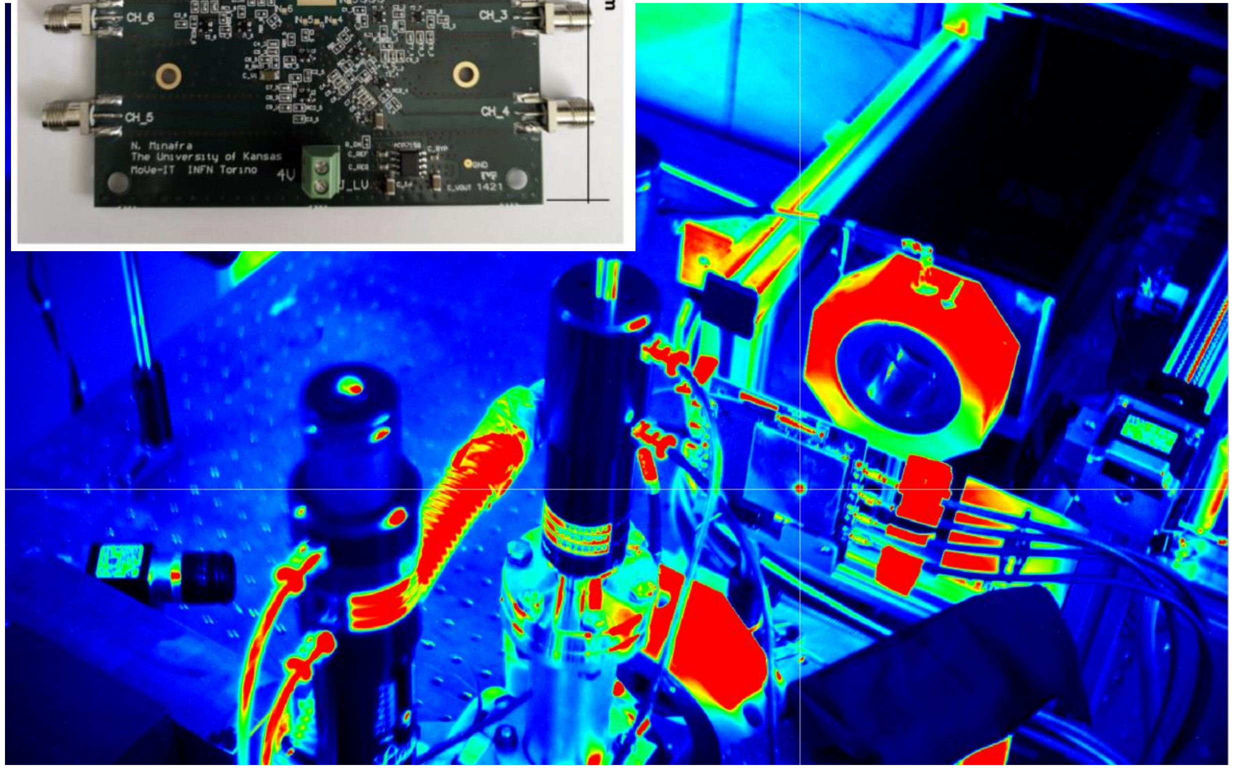


Test of 3D Diamonds Detectors (The University of Kansas)

- The time resolved detector designed to monitor beam polarization
  - Accuracy: ~1%
  - Time resolution : ~10ns
  - Spacial resolution: 1mm

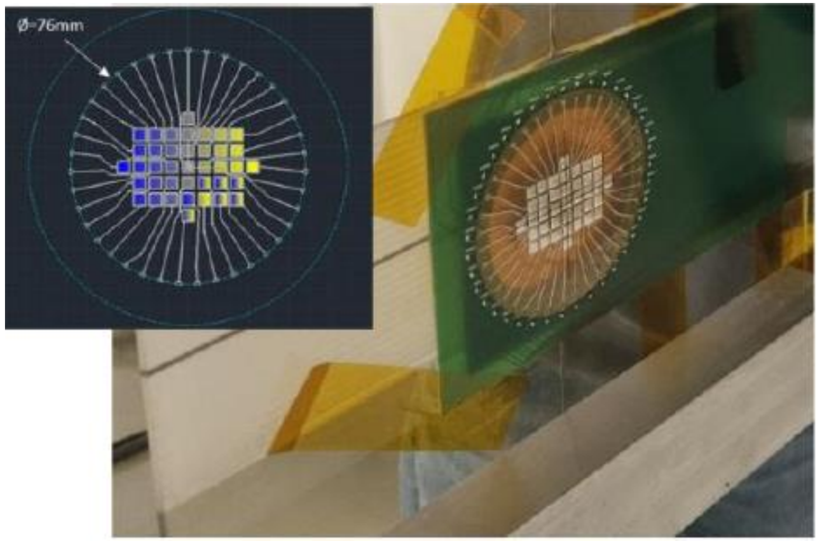
- Experiment was performed for different diamond crystals attached on board
  - scCVD, pCVD, Si LGADs

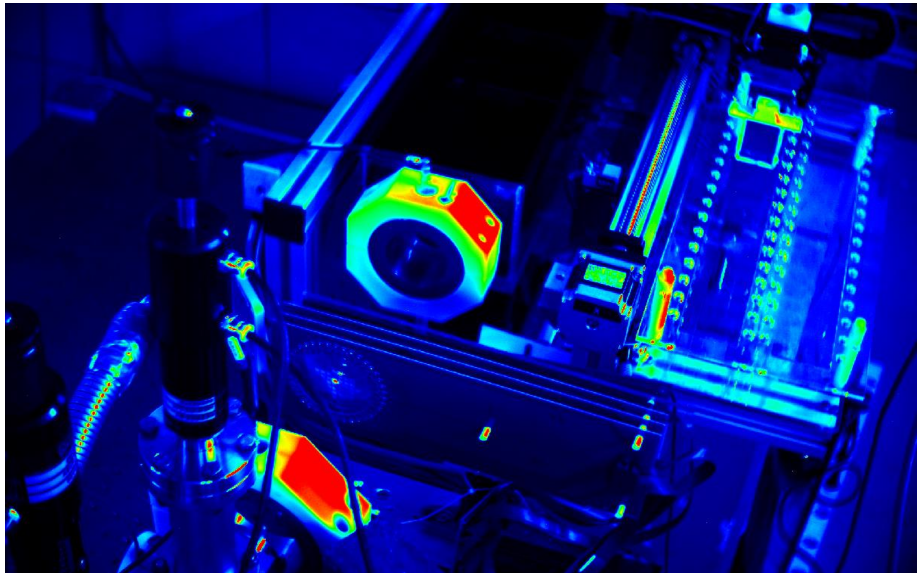




MicroBPM (CERN)

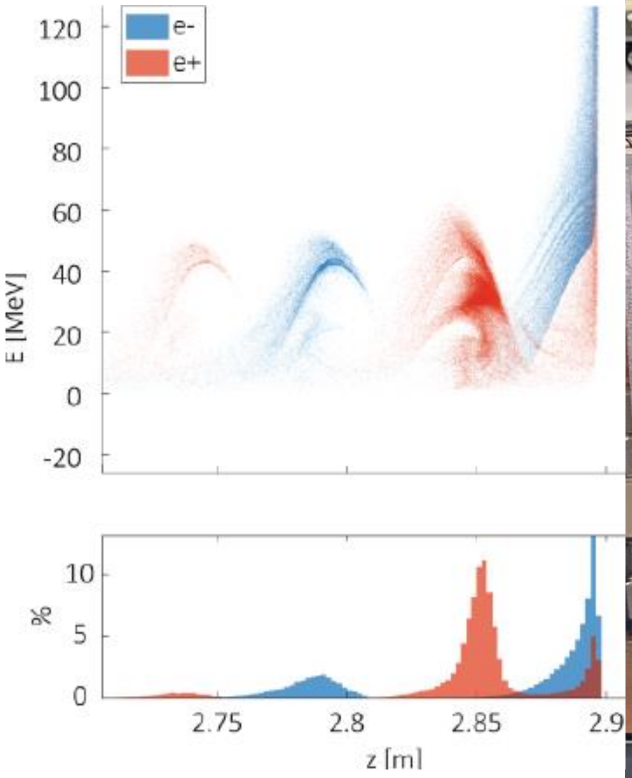
- Secondary Electron Emission (SEE) Beam Profile Monitors (BPMs) designed to be used at IRRAD facility at CERN
- High energy and intensity proton beam environment requires beam position that sits in the beam
- We tested different microBPMs that are manufactured with different microfabrication techniques
- The reduction in metal thickness minimizes the beam interaction and opens the possibility to monitor also lower energy charged particles,

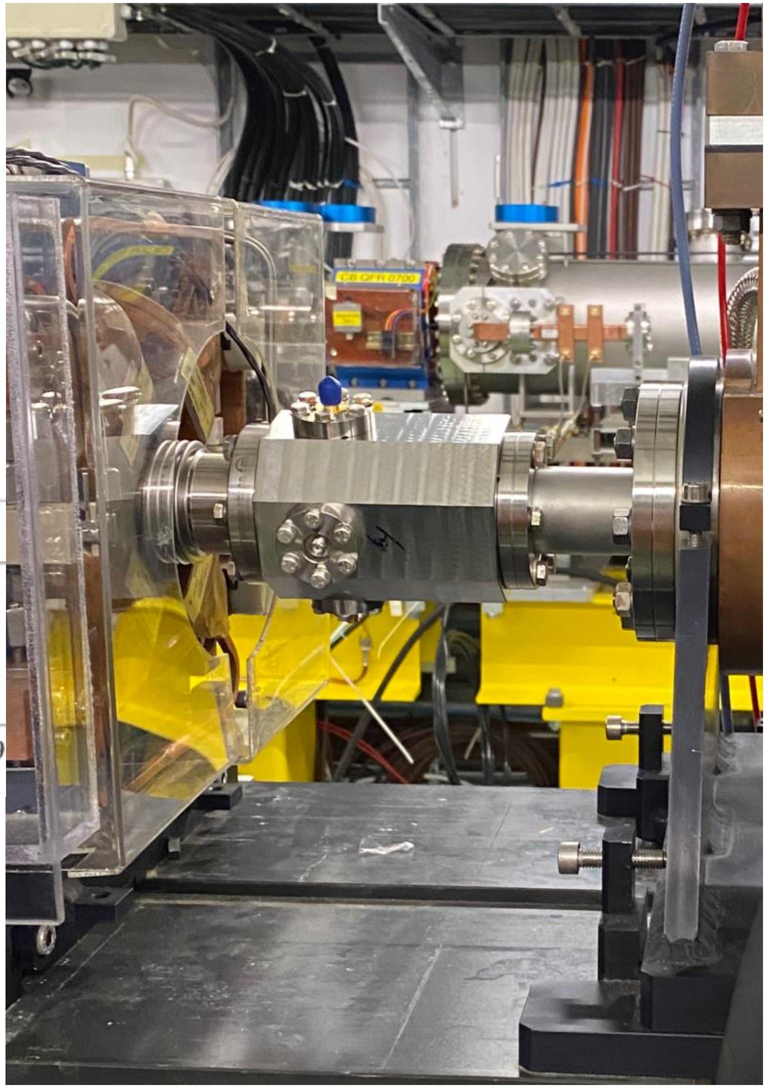




Broad Band pickups (PSI)

Pickups that are designed to measure length of e- / e+ bunches simultaneously for a novel positron source for FCC-ee.

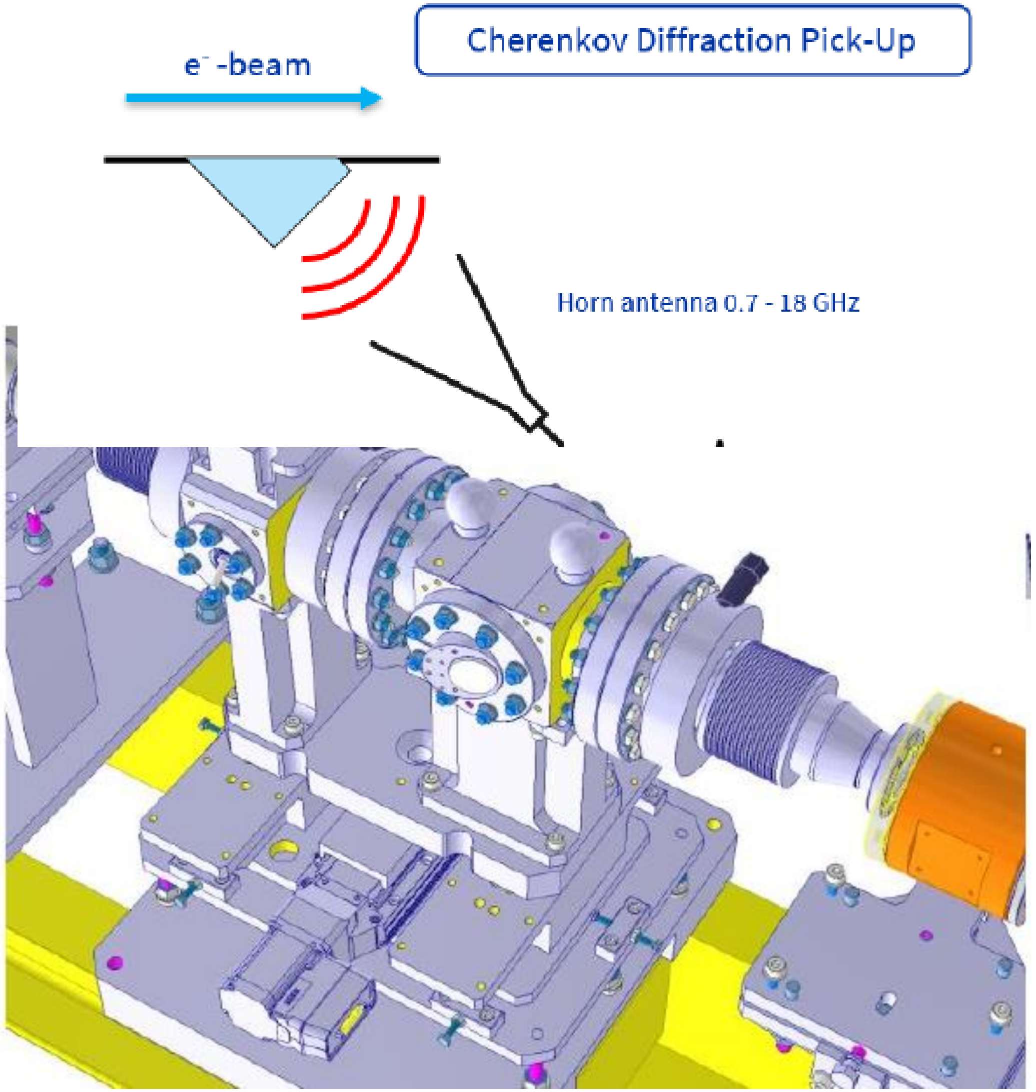




The BBPs consist of an arrangement of four pick-ups with large broadband response in order to measure the time structure of consecutive, non-gaussian electron and positron bunches;
The bunches are expected roughly 33 ps length and around 167 ps apart from each other.

FCC bunch length monitor (CERN)

Coherent Cherenkov diffraction radiation (CchDR) monitor consists of dielectric buttons for bunch length measurements for FCC.

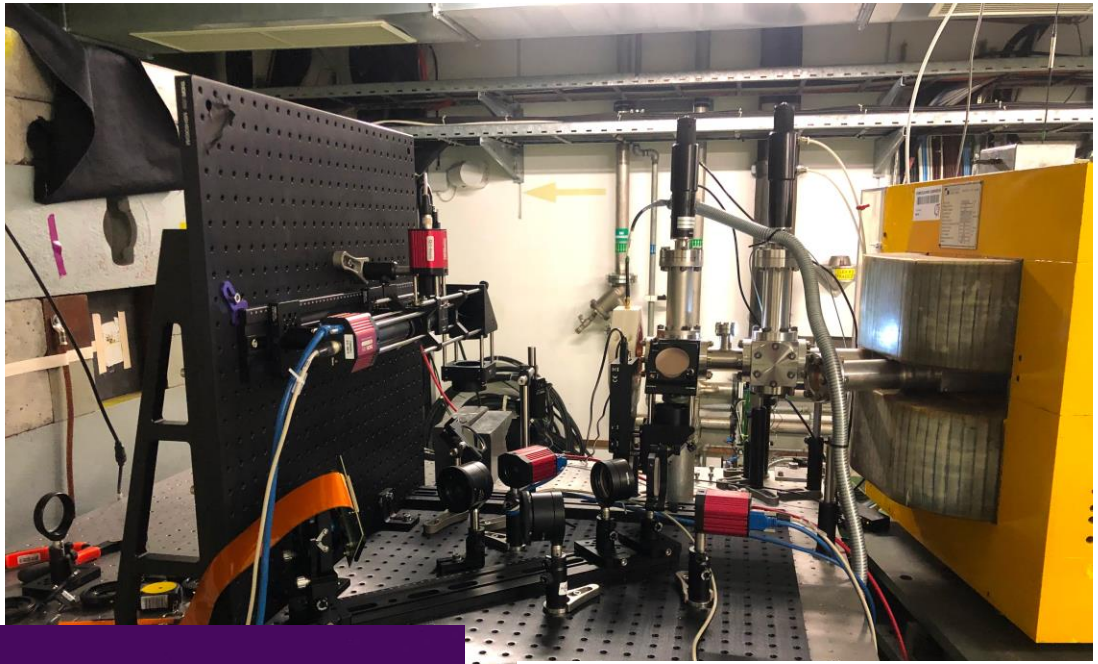


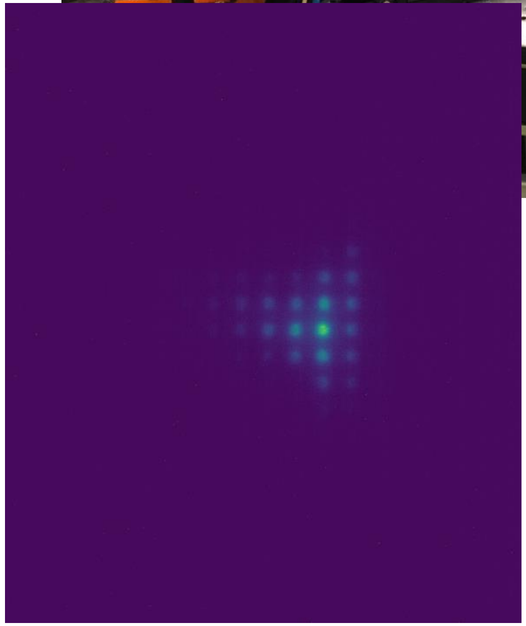
- CchDR was measured with very short bunches (<0.5 ps).
- A frequency bandwidth of 40 GHz was demonstrated,
- The shortest signals of CchDR in time domain were measured successfully.
- The stability (several hours) and the sensitivity (down to 10 pC) of the acquisition system was better than anticipated.

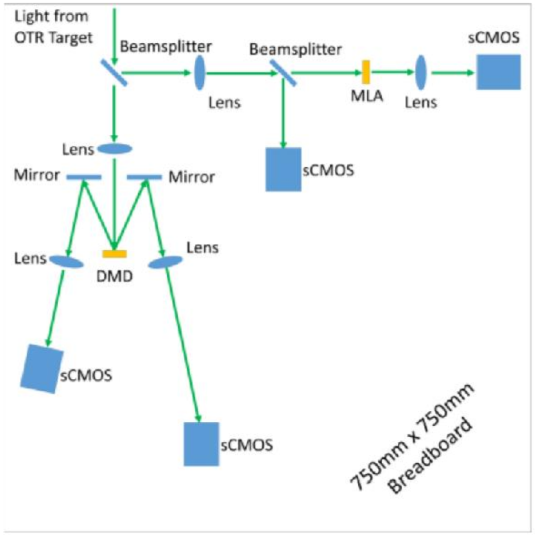
Novel Emittance Measurement (University of Liverpool)

The technique relies on phase space mapping of optical radiation (OTR) produced by an electron beam

This method be an optical equivalent of existing beam-based pinhole/slit/pepper-pot measurements but without slit..





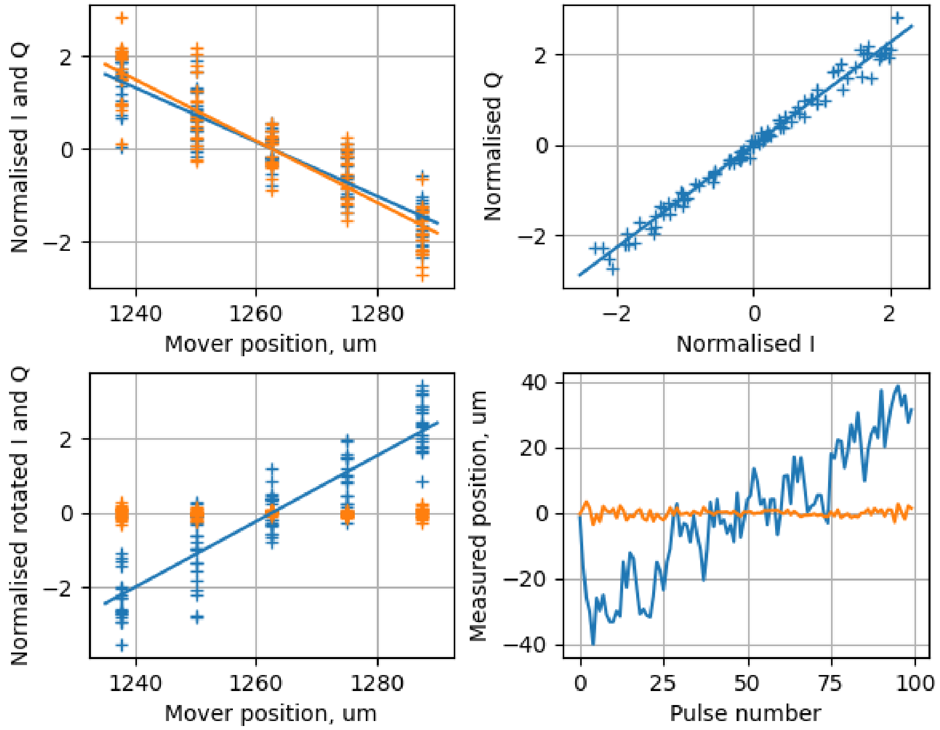


- In one week of experiment we have tested system for various beam parameters
  - Single bunch multi bunch low charge high charge..
- The results were benchmarked existing quadrupole scan setup during the week
  - Very good agreement for spacial resolution but chanllenges with angle resoluton

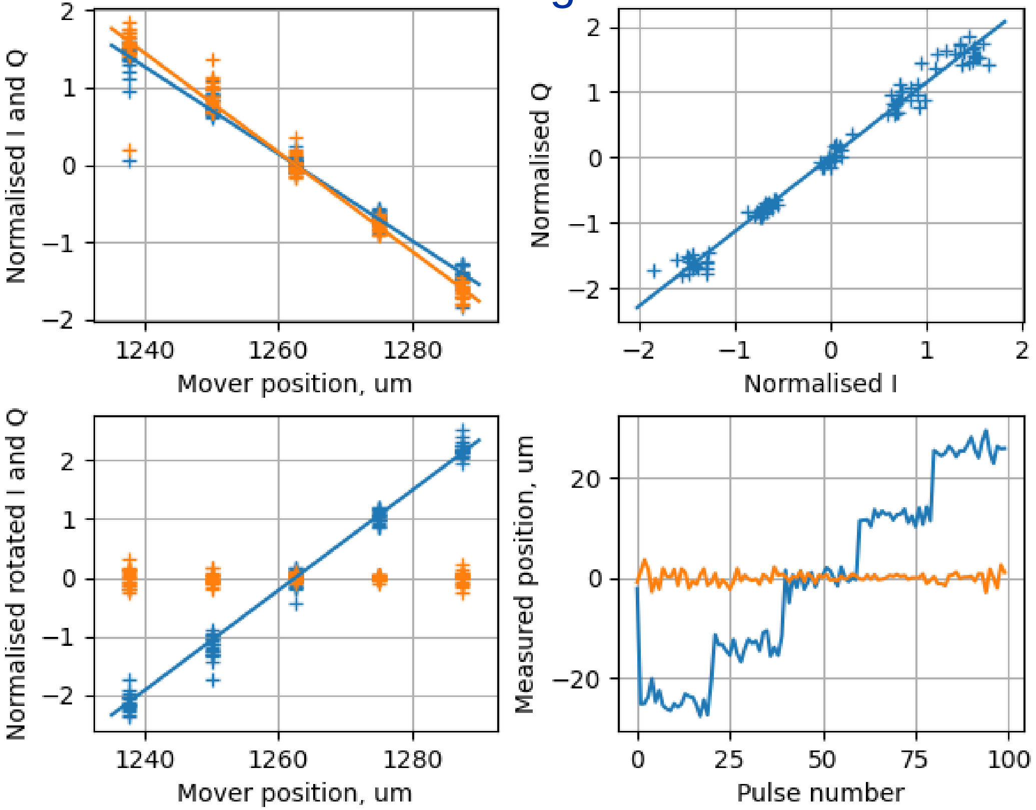
CLIC Cavity Beam Position Monitors (Royal Holloway, University of London)

Cavity BPMs operating at 15 GHz, I/Q demodulated to 375 MHz

- Complex setup with 3 BPMs very small beam pipe aperture (~3mm) attached about 1m length transversely movable system..
- BPM is translated by 50 um in 5 steps.
- By removing correlation in data 3 um resolution achieved.

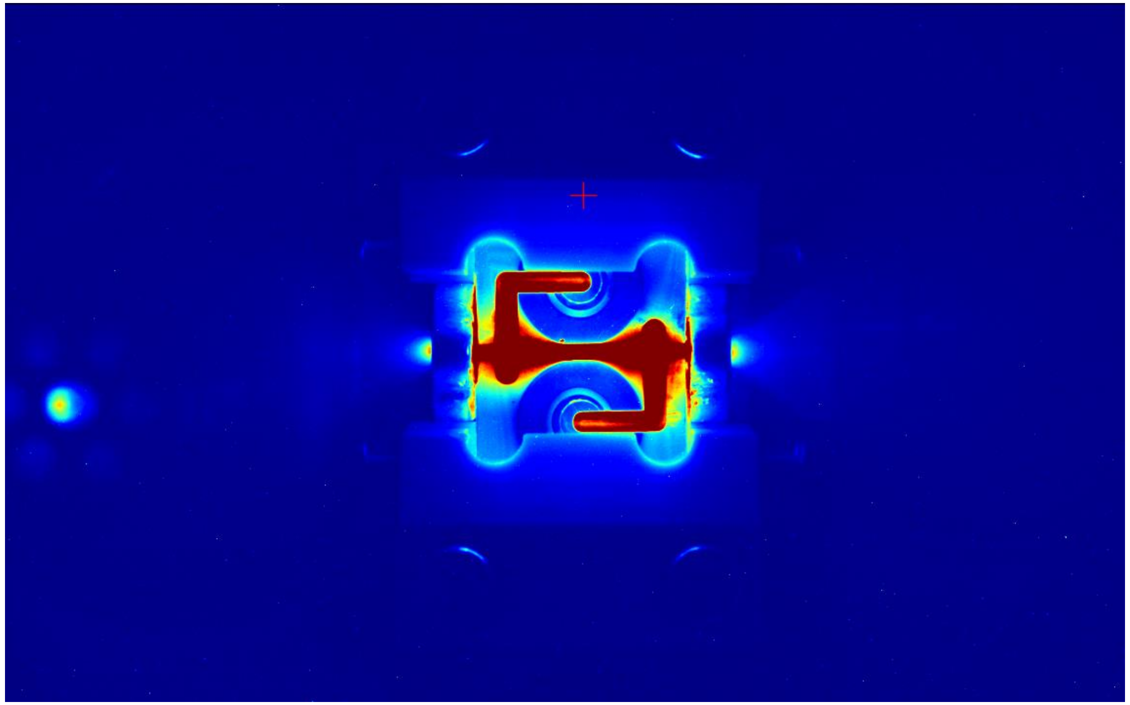


After removing correlation



Plasma Lens (University of Oslo)

- Double-plane optical beam enlargement without scattering
  - Creating strongly diverging beams without scattering
- Tests of non-linear plasma lens device concept
  - The prototype lens uses the Hall effect to create the nonlinearity by applying an external, transverse (dipole-like) magnetic field across the plasma.
  - We repeated the test for the plasma lens at CLEAR, for characterizing the transverse B-field profile in the active plasma using electron-beam deflection measurements.

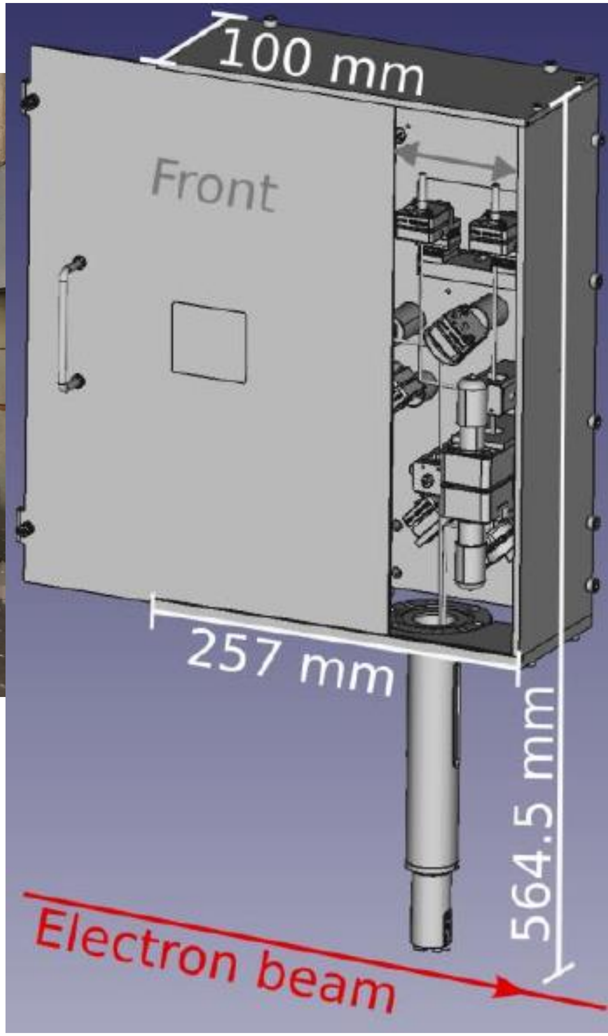


Bunch Profile Monitor for FCC-ee (KIT)

- FCC-ee requires a bunch-by-bunch diagnostics system to measure the bunch length with the data of all bunches available in a time scale of minutes.

- To fulfil these requirements, a new diagnostics system has been developed based on electro-optical (EO) near-field monitor to measure the longitudinal bunch profile.

- A similar EO system would be a promising candidate for FCC-ee, due to its potential for single shot bunch-by-bunch measurements at sub-ps resolution.



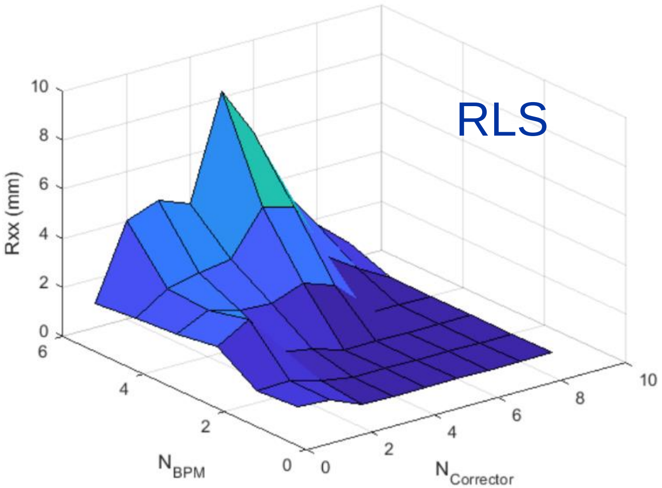
Beam Based Alignment

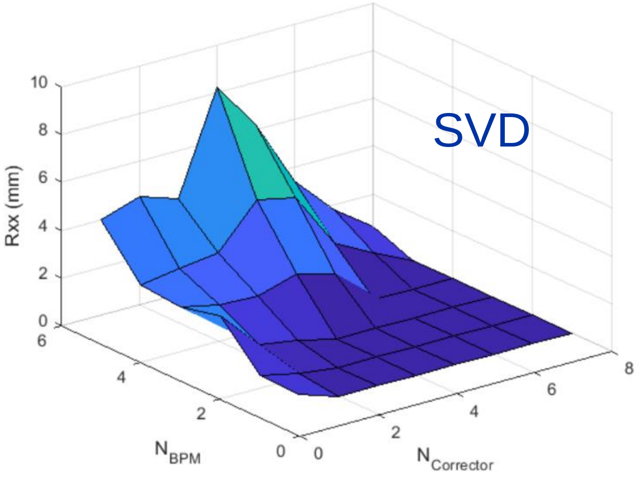
$$X = X_0 + R\Theta, \qquad R_{i,j} = \frac{\Delta x_i}{\Delta \theta_j},$$

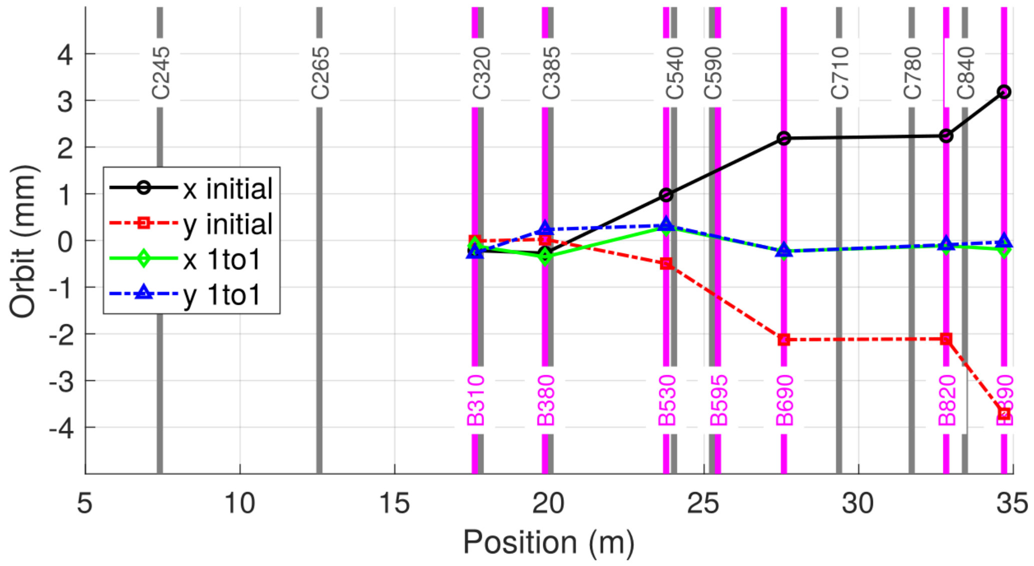
$$\Theta = (R^T R)^{-1} R^T \Delta X$$

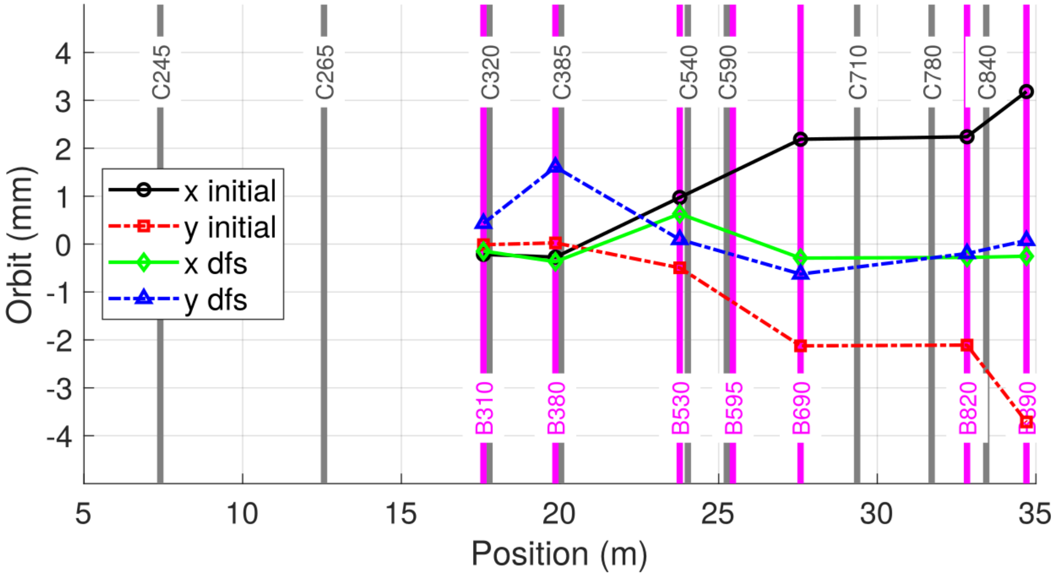
DFS: $$\begin{pmatrix} X \\ \omega(X - X') \\ 0 \end{pmatrix} = \begin{pmatrix} R \\ \omega(R - R') \\ \kappa I \end{pmatrix} \times \Theta,$$

- Operational BPMs allowed us to do high level beam physics.
- We have developed an automated response matrix generation tool.
  - Random or excitation in sequence of correctors for given machine setting
  - R: for nominal energy, R’ : for reduced energy
- Based on chose one can create response matrix based on different algorithms (RLS, SVD) apply one-to one steering or DFS
- Full process takes about 30 min







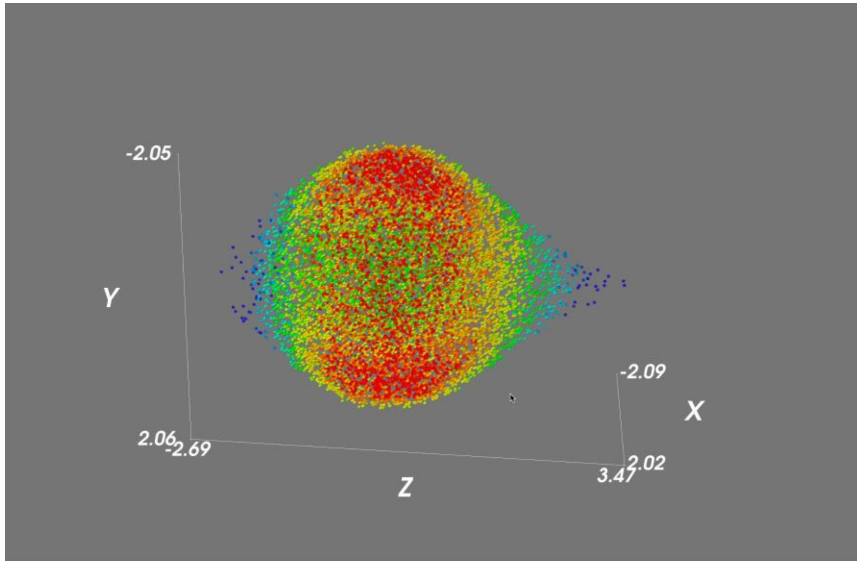


Uniform beam generation at CLEAR

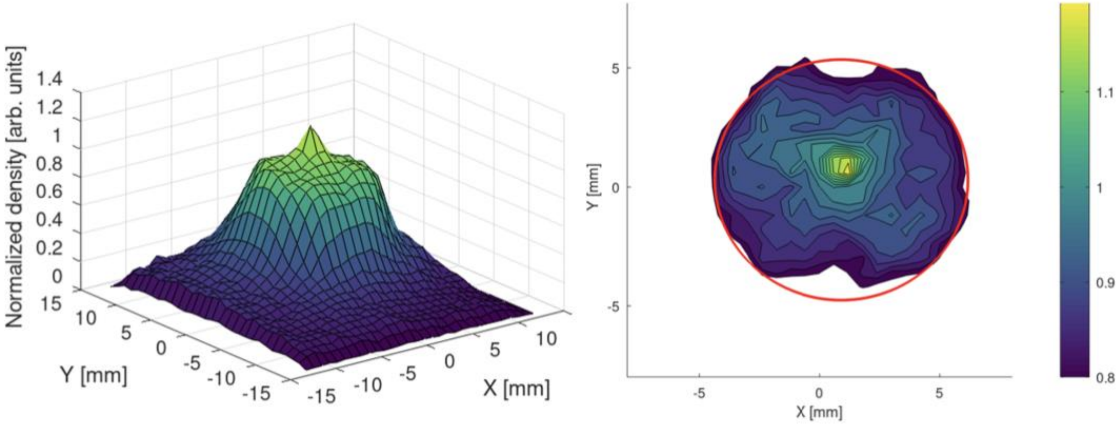
Credit A. Malyzhenkov

Utilizing space charge forces in the injector

2. Understanding 3D “bubble-beam” dynamics in Summer 2023

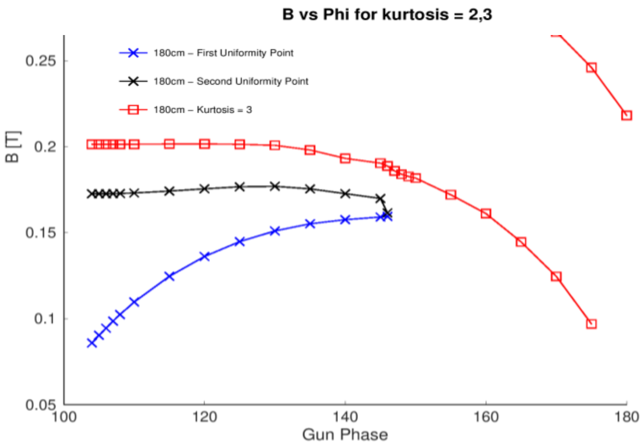


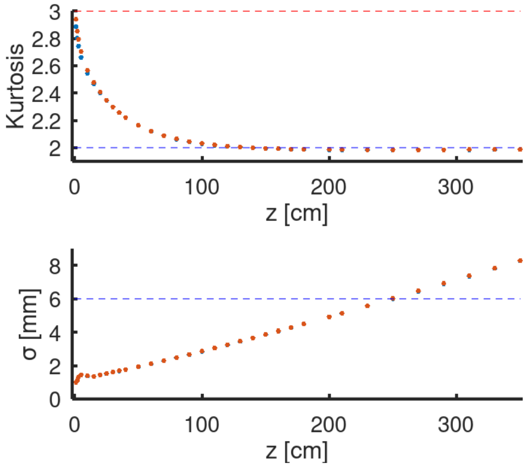
1. Initial results in April 2023



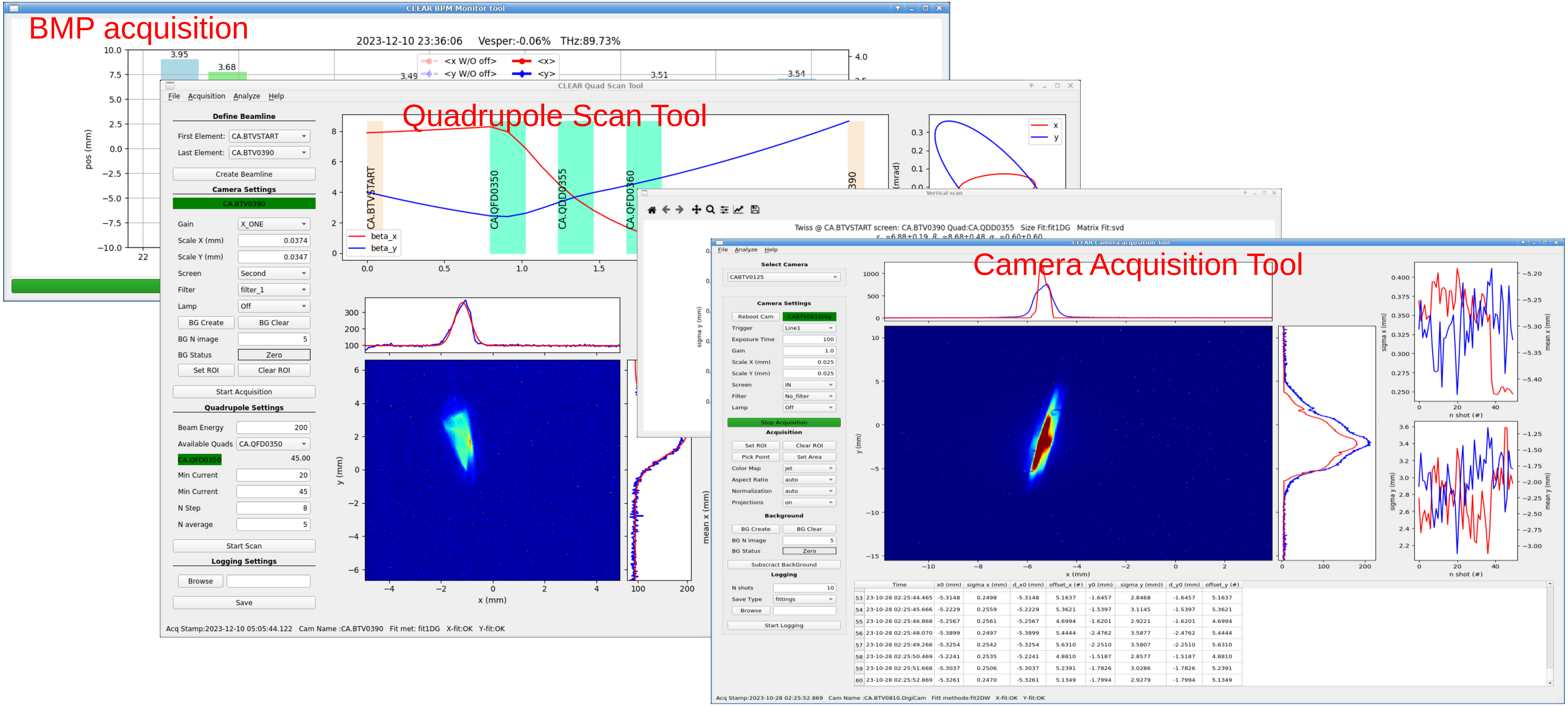
P. N. Burrows, P. Korysko[1], C. Robertson[1], JAI, University of Oxford, Oxford, UK
A. Aksoy[1], Ankara University, Ankara, Turkey
[1]also at CERN, Geneva, Switzerland

3. Search for the “golden point” with stable uniformity region (last experimental campaign of 2023)





Some Implementations to control system



Conclusions

- 2023 has been a very productive year with more than 95 % beam availability for 27 experiments
- We have performed many experiments with users from diversity of disciplines/groups about R&D for beam instrumentation and accelerators, and medical applications
  - P. Korysko will summarize medical experiments
- Except for a few experiments that were postponed because of delay in production, none of experiments were refused.
  - We saturated our beam time with price of doing most of the MDs in weekends as well as some experiments
- Current proposals show that 2024 will be more less similar and some experiments are quite laborious
  - W. Farabolini will summarize the plans for 2024

Thank you for your attention!

https://clear.cern