SuperKEKB Review of BT Group's Work
Done and to Be Done

D. Oumbarek Espinos, K. Kikuchi, K. Kodama, M. Tawada, T. Mimashi, T. Mori, T. Naito and T. Ueda

Speaker: Driss Oumbarek Espinos, BT group
14/01/2025

Main Ring Injection Kicker

LER Injection Kicker : Countermeasure for Self-firing

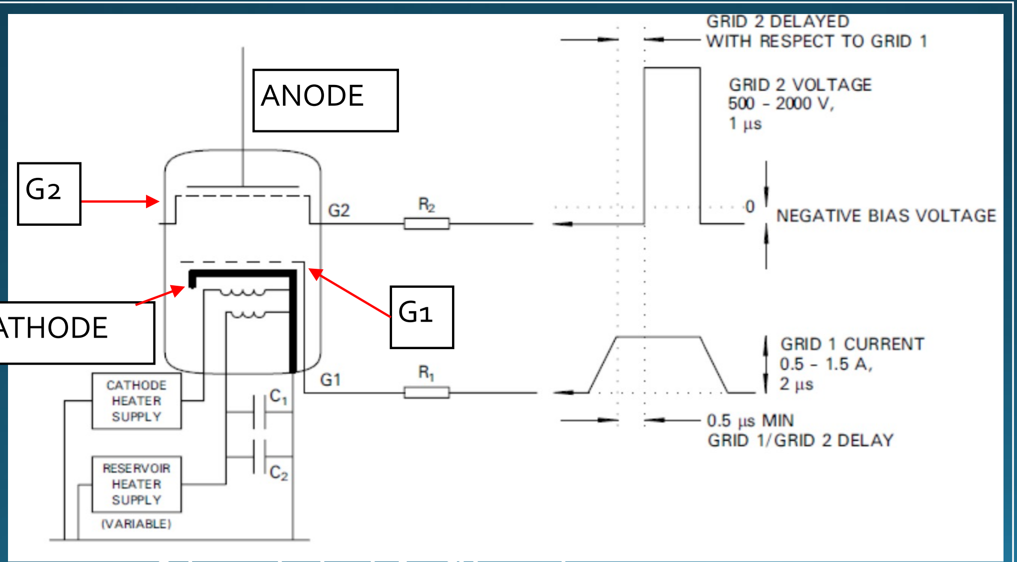
Work during the 2024 summer shutdown

PI: K.Kodama

❖ **The G1 trigger has been changed from DC primed to the pulsed trigger method.**

- DC primed grid is always in a standby state, which means it is easy to fire.
- Using the pulsed trigger method, both G1 and G2 are needed to trigger a fire event. Therefore, self-firing events are more difficult to occur

❖ The **2024ab** run had 12 times self-firing events in 5 months **(2.4 SF/月)**, while the **2024c** run, it was reduced to 6 times in 3 months **(2 SF/月)**.



Schematic circuit for CX1174 thyratron

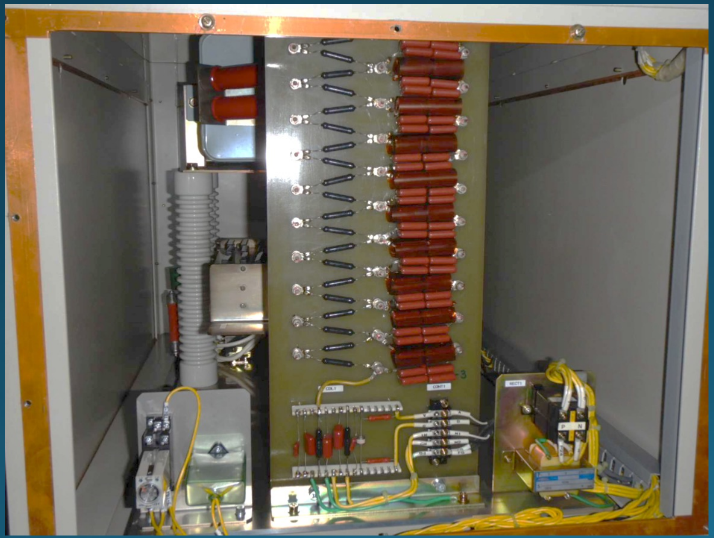
HER Injection Kicker : Modification for K4 dividers

PI: K.Kodama

❖ **Divider for voltage control feedback will be modified.**

- Capacitance of circuit elements sometime are damaged due to high leak current. That affect the output stability in the operations.

❖ **To prevent high leak current, resistances will be added to the dividers.**



Divider for Injection Kicker

Work to be performed during 2025 shutdown

Vertical Kicker

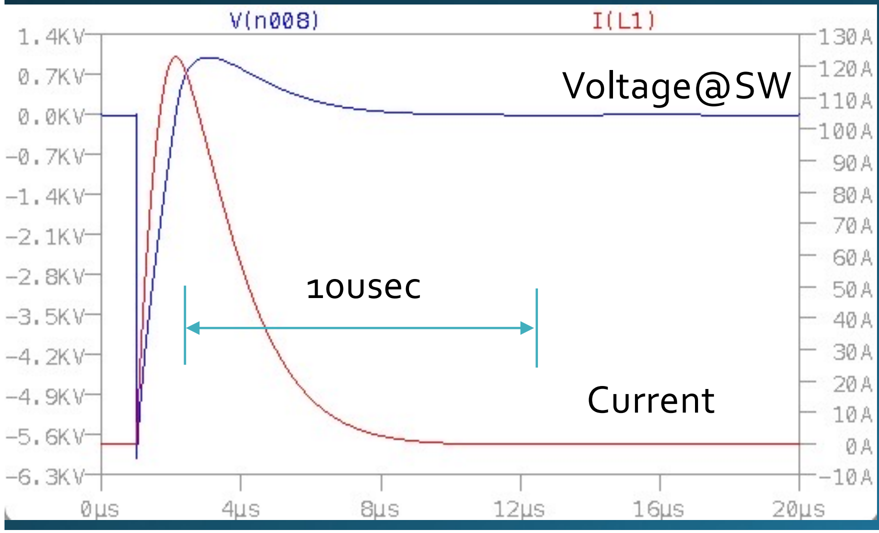
Vertical Kicker to Survey Vertical Aperture of the Ring

PI: K.Kodama, T.Naito

Vertical kickers were installed at HER (2024 spring) / LER (2024 Autumn), respectively.

To make 50 μrad kick angle for each beam and 1 Hz rep. rate by using existing kicker magnets, we fabricated semiconductor switch pulse power supplies.

	Coil Inductance	**Cable inductance**	**Total**	**Current for 50 μrad kick**
LER	16.7 μH	3.625 μH (2 Cable)	20.3 μH	221 A /4 turn = 55 A
HER	10.8 μH	7.85 μH (1 Cable)	19 μH	328 A /3 turn = 110 A



Required peak current for the existing kicker magnet.

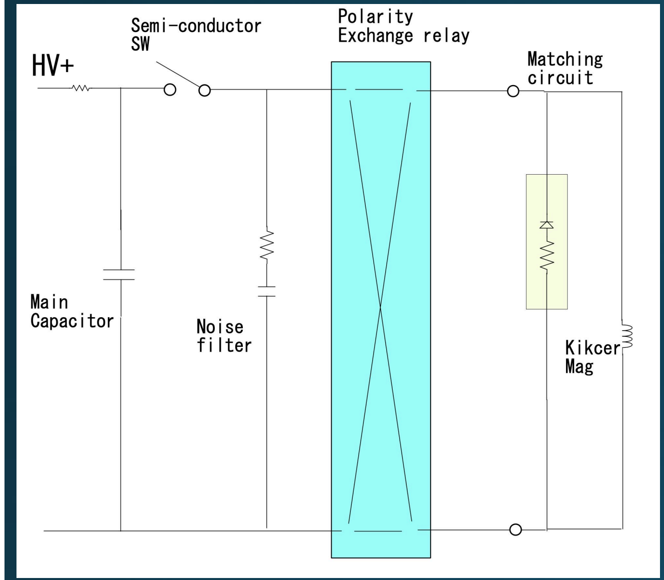
Simulation of the kicker pulse waveform: The pulse peak is 120A at 5.5kV, which depends on the inductance and the storage capacitor.

Work during 2024

Vertical Kicker to Survey Vertical Aperture of the Ring

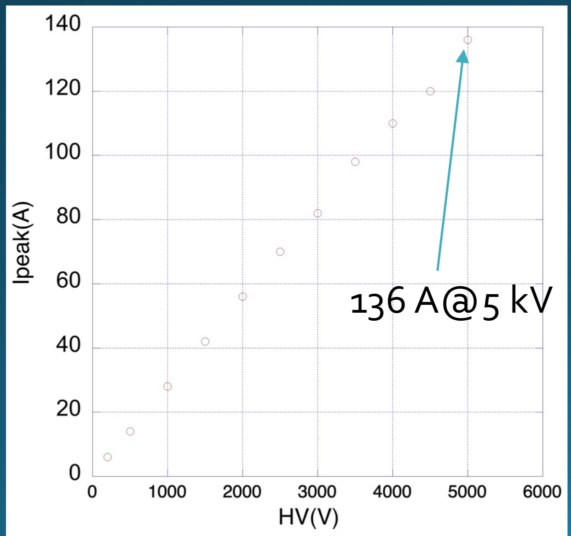
Semiconductor SW Evaluation

PI: K.Kodama, T.Naito

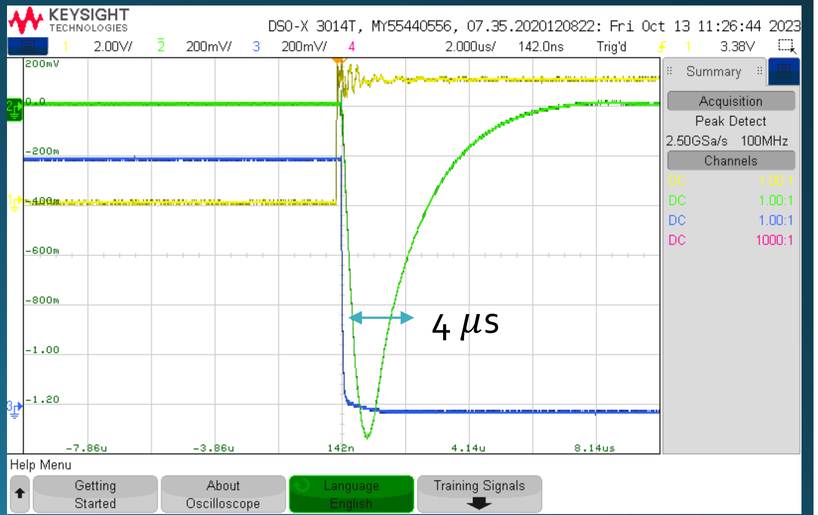


- The switching characteristics of the semiconductor SW is evaluated by using the dummy load.
- The V-I_{peak} shows a that the peak current is 136 A at 5 kV.
- The waveform pulse width is 4 μs (FWHM) by using 16 μH dummy load.

V-I_{peak} characteristics



Waveform characteristics



Vertical Kicker to Survey Vertical Aperture of the Ring

System Configuration

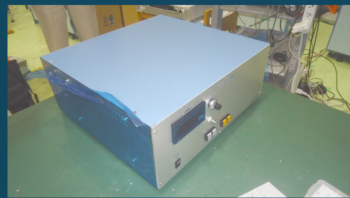
PI: K.Kodama, T.Naito

EtherNet

1 Hz Trigger

Kicker PS

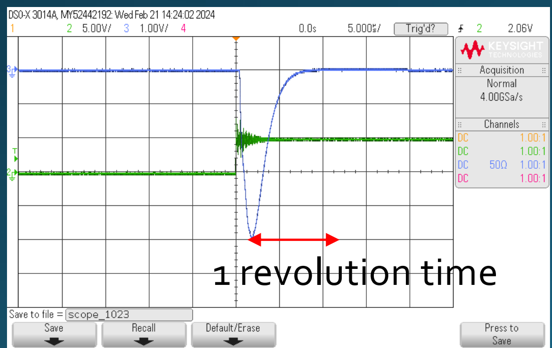
AC100V



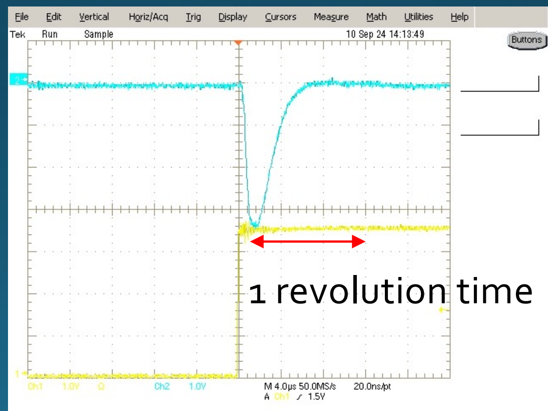
D7/D8
Klystron gallery

Event Receiver
(EVR)

20D HV cable(s)



HER kicker waveform
5 μs/div



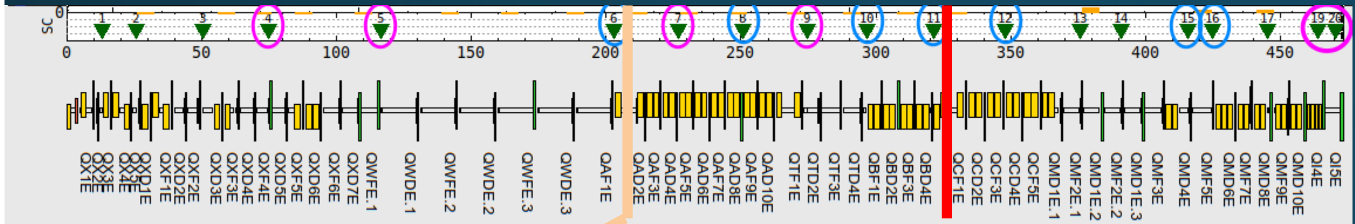
HER kicker waveform
4 μs/div

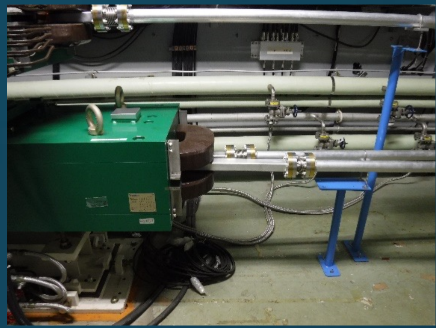
Diagnostics

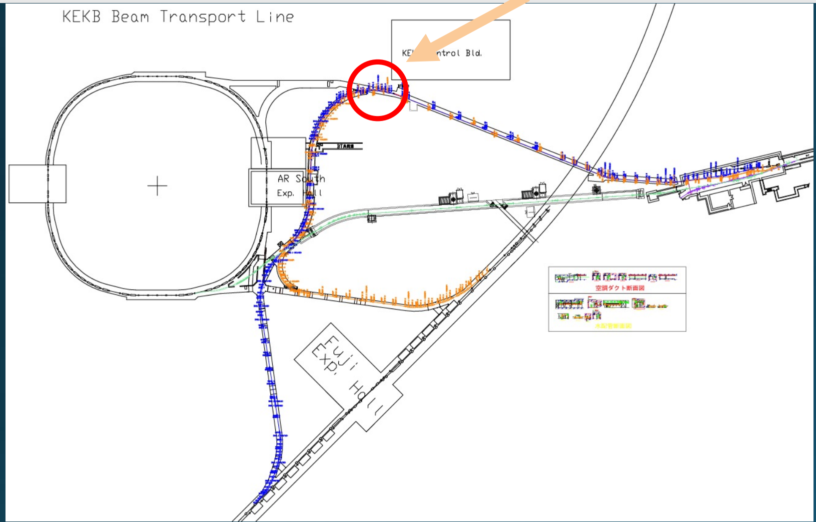
Synchrotron Radiation Monitor (SRM)

Additional SRM Installation at BTe

PI: T. Mori



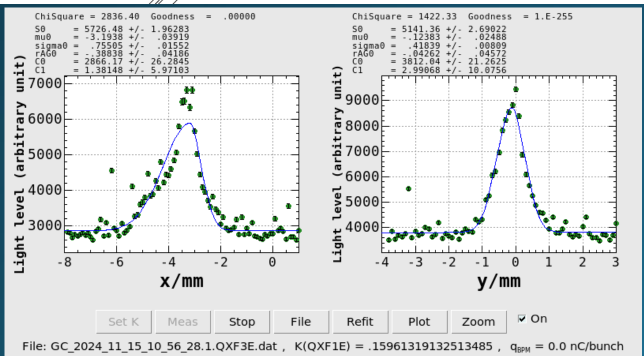




- Continuous beam size monitor.
- Branched beam duct
  - Obsolete AR-BT branch line
- Installation: 2024 summer
  - With Driss-san, Ueda-san
  - Calibration can be done with movable mirror

Work during 2024

- Different phase from SRM@BH3E.1
  - Useful for emittance optimization
- Consideration to add SRM to BTp.



Work to be done in 2025

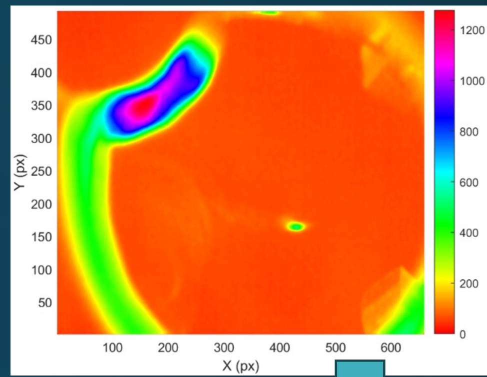
Diagnostics

Optical Transition Radiation (OTR) Screens

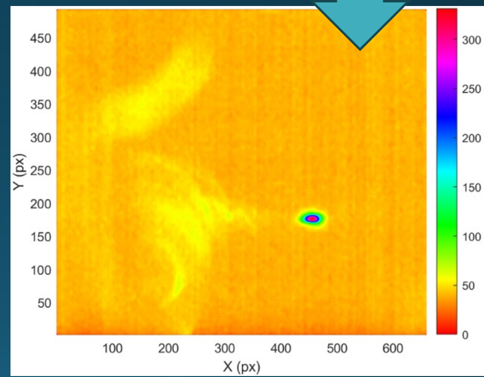
Data Pre/During/post – Treatment Improvements

PI: D. Oumbarek Espinos

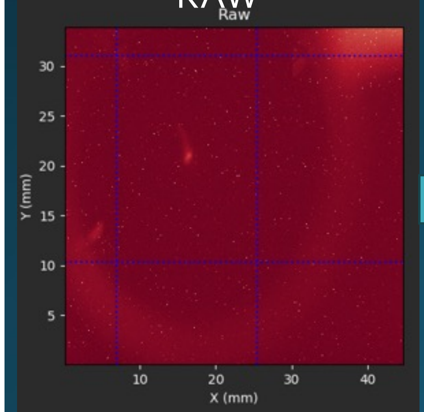
- Pre:
  - Image background removal.
  - smoothing of artificial signal peaks (new).
  - Tighter camera exposure times (new).
- During:
  - Automatic beam position detection and reduction of the image surface considered (treatment speed-up) (new).
  - Pixel intensity variation map dynamic background removal (new).
- Post:
  - Beam (single or double) isolation from background (new).



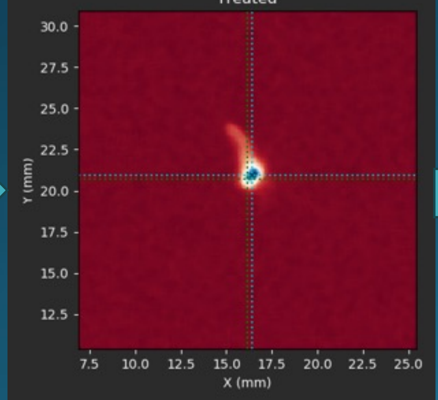
Tighter camera exposure time



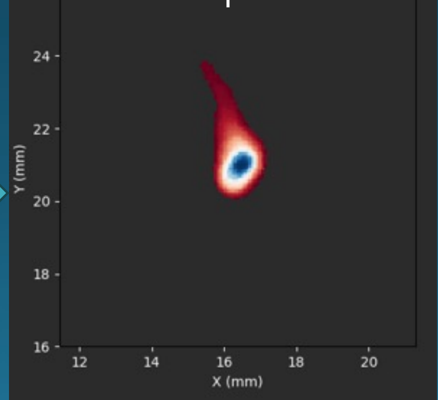
RAW



Treated



Beam separation



Work performed during 2024

New Tools Adapted to New Demands

PI: D. Oumbarek Espinos

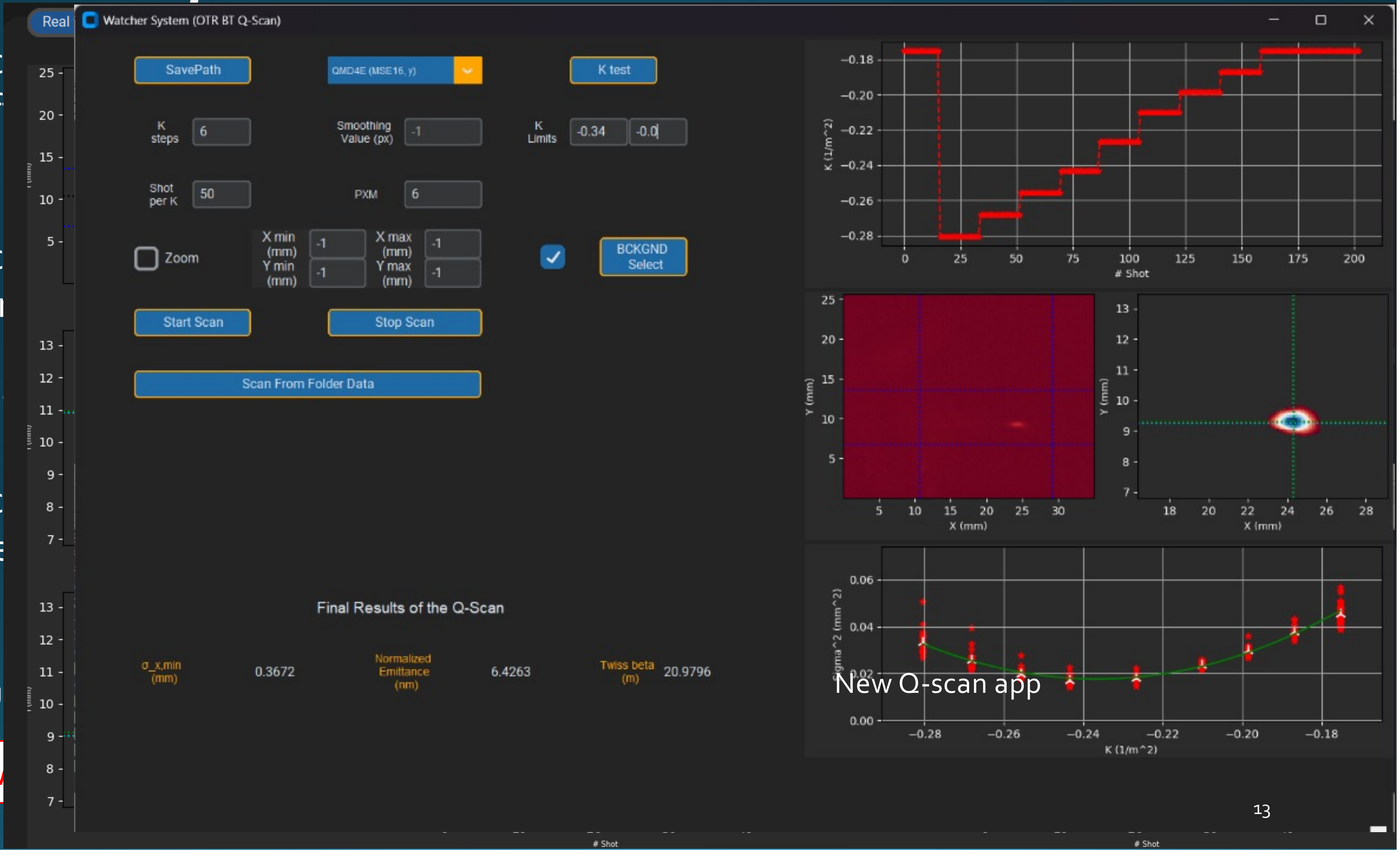
❖ New applic
plot the dif
>1 Hz).

❖ New applic
time in a si
the kickers
plotting of

❖ New applic
improveme

• Plans to pu

W



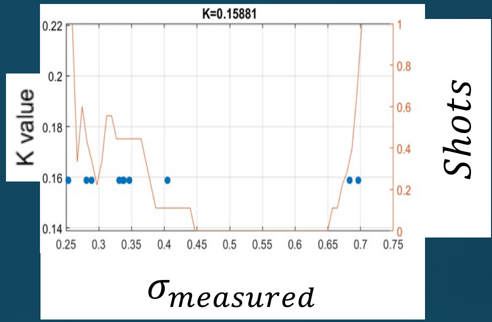
New Q-scan app

Statistical Significance Study of the Data

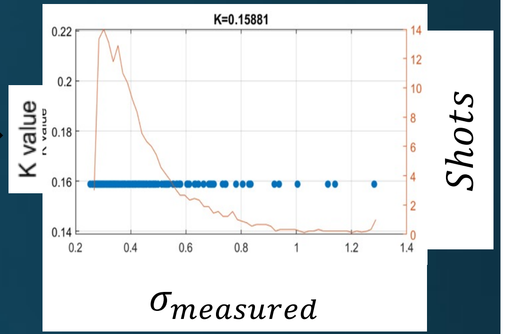
PI: D. Oumbarek Espinos

- Statistical significance studies done to determine the optimal number of shots needed for Q-scans. Improved precision, robustness and repeatability.
- We greatly increased the data taken and analyzed at all screens. Also, all raw data is saved to be able to go back to, if methods improve or any other reason.
- Source time related patterns observed and taken into account during studies. Allowing us to provide a better feedback to other groups.

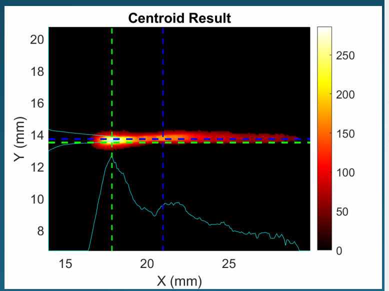
10 consecutive shots beam size distribution

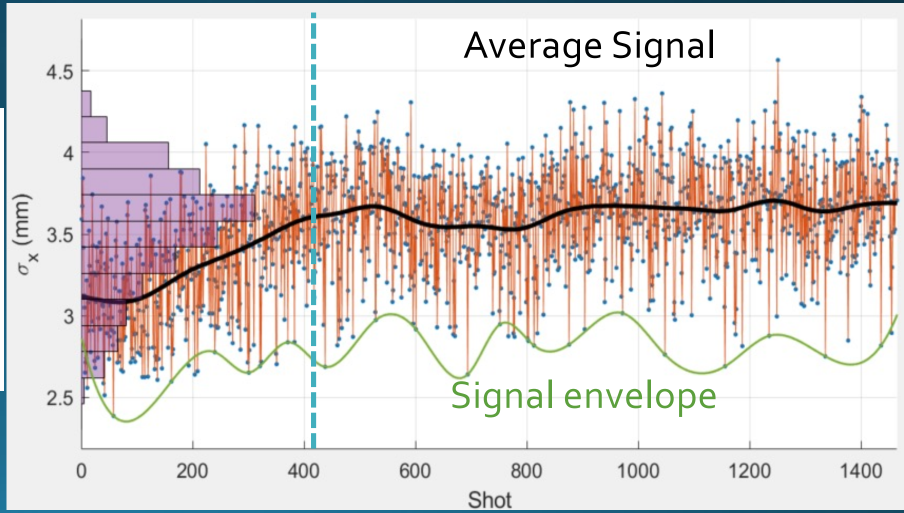


200 consecutive shots beam size distribution



Temporal trend of beam size for 1465 consecutive shots at 1 Hz





Work performed during 2024

More Parameters and Independent Agreement Between Methods

PI: D. Oumbarek Espinos

- Real time measurement of **beam surface, peak intensity, transverse size, peak position and center of mass position**.
- Using all the improvements named before, now the emittance measured by Q-scan and Wire-scanner consistently agrees within ~10%.

Example of emittance measurement at the entrance of BT e^+ line

Wire-scanner

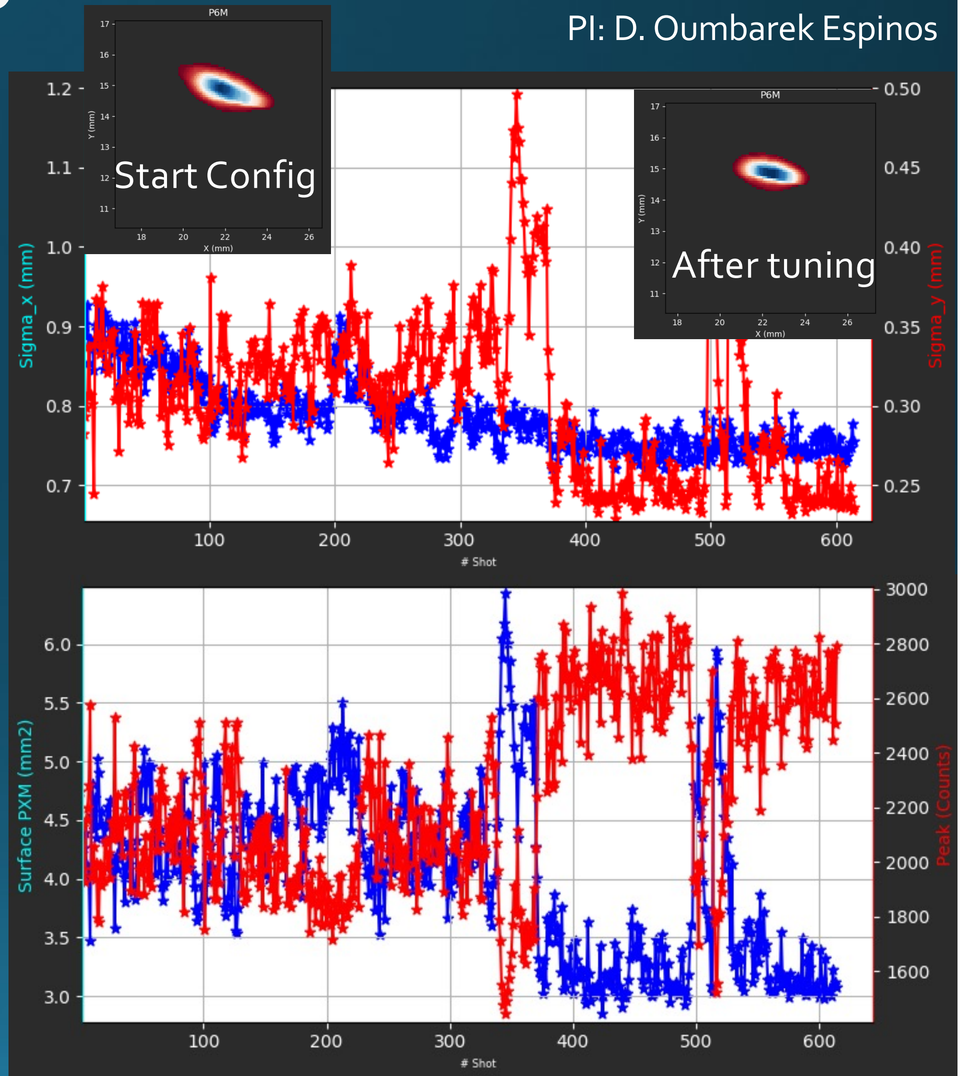
Results of measurement

β_x @MWP.1 m :	6.862
α_x @MWP.1 :	-.636
ε_x m :	1.5079E-8
$\Delta\varepsilon_x$ m :	1.4296E-9
$\gamma\varepsilon_x$ μm :	113.352
$\Delta\gamma\varepsilon_x$ μm :	10.746

Q-scan

$\gamma\varepsilon_{Q,x}$ = 103.21 μm

Work performed during 2024



Example of KBP orbit correction study (Iida-san, Yoshimoto-san).

Towards Automatization and Ease of Use

PI: D. Oumbarek Espinos

- Diagnostics data now saved together with relevant magnet data to structured files (.hdf5), making the file size smaller and things easier to find.

Work performed during 2024

- Matlab and Python libraries under development to allow easy re-analysis by anyone.
- Upgrades of the OTR setup to improve the alignment and reflections.
- Planned single button full BT e^+/e^- line beam characterization application.
- Planned the start of Machine Learning tools applied to "deep diagnostics".

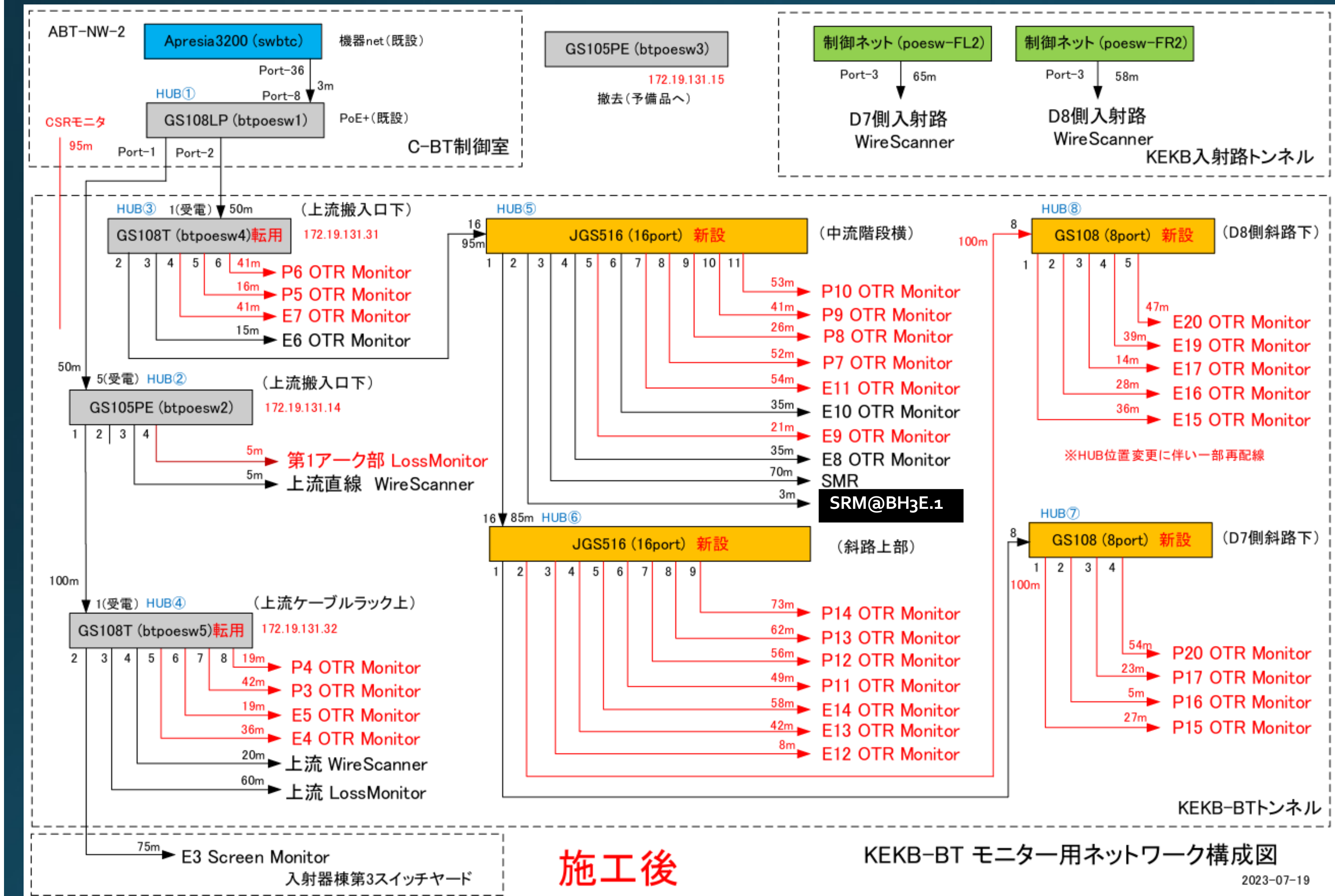
Work to be performed in the future

Diagnostics

Camera Network

BT Diagnostic Cameras Network

PI: T. Mori



40 cameras network map.

- Camera only on when their respective screen is in use.

❖ Some radiation related damage to the network hubs have been found and fixed

Work during 2024

- The simultaneous usage of a few cameras (OTR e^+, OTR e^- and SRMs) derives in communication errors and hang ups.
  - Software IOC issue?
  - Radiation damages of network hubs?

Work to be done in 2025

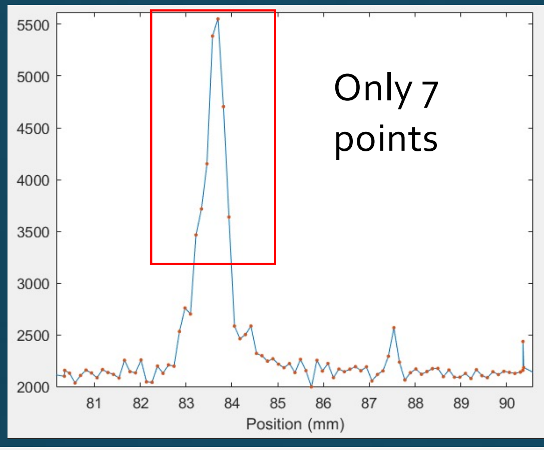
Diagnostics

Wire-Scanner

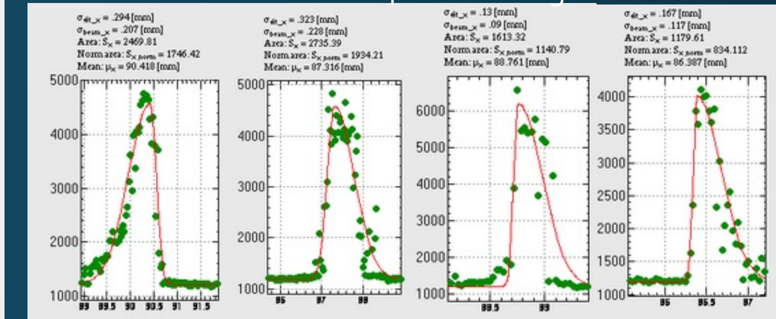
Wire Scanner Measurements Improvements

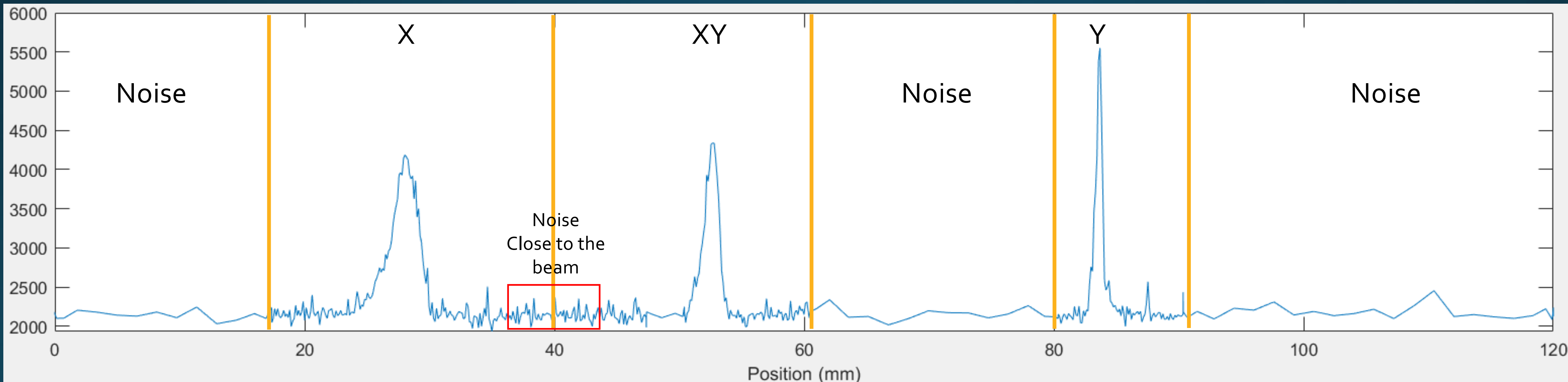
PI: D. Oumbarek Espinos

- Data treatment to improve Noise/Signal.
- Improvements of precision and resolution of Wire-scanner measurement.



Y measurement at the 4 wires during a wire-scan





Work to be performed during 2025

Diagnostics

BPM Improvements

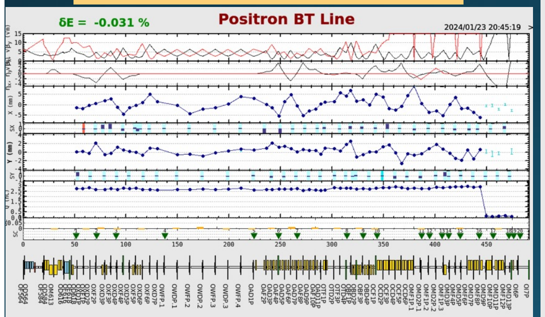
BPM Signal Isolation for e^+ Improved

PI: T. Mori

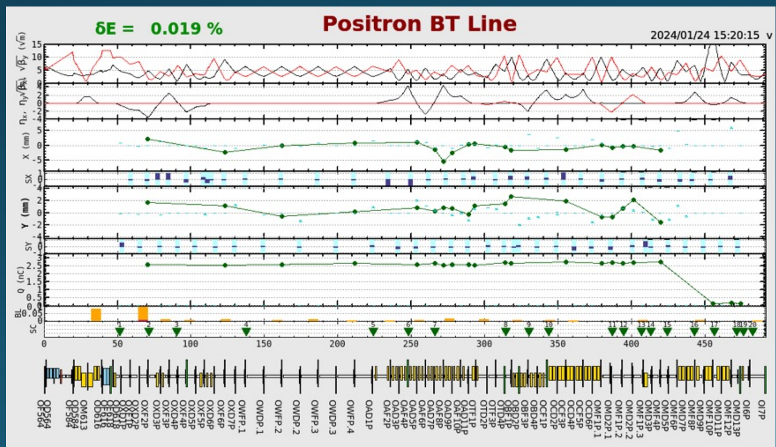
- ~15 BPM signals are combined into one oscilloscope per channel with different delays
- Signal delays designed for KEKB (single bunch operation) are not capable of 2-bunch operation for some partial overlaps of signals

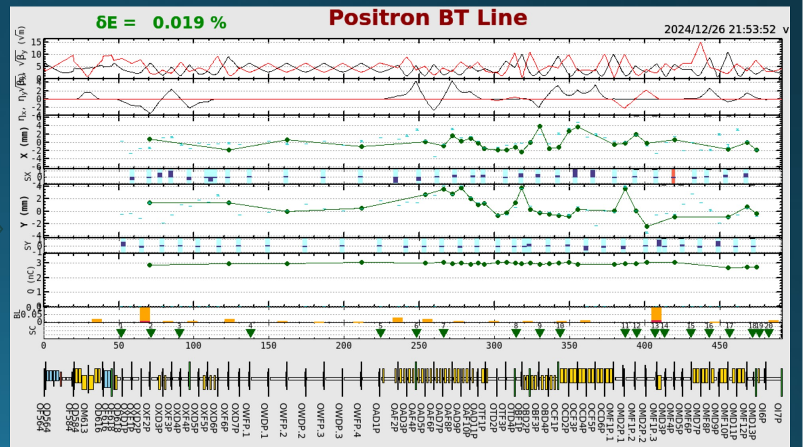
❖We adjusted some cable delays for signal isolation

1-bunch operation



2nd bunch for 2-bunch operation





Work during 2024

High Resolution BPM Platform Development

PI: M. Tawada, D. Oumbarek Espinos

- A new platform for fast high resolution BPM data acquisition is being developed.

- The acquisition card to be used is the ADQ35-PDRX

- AMD threadripper based platform

- Performance:
  - 4 channels
  - 12 bits resolution
  - 11 bits ENOB
  - 5 GSPS sampling rate
  - 14 Gbyte/s data streaming through PCIe

❖ Hardware already acquired, waiting for delivery.

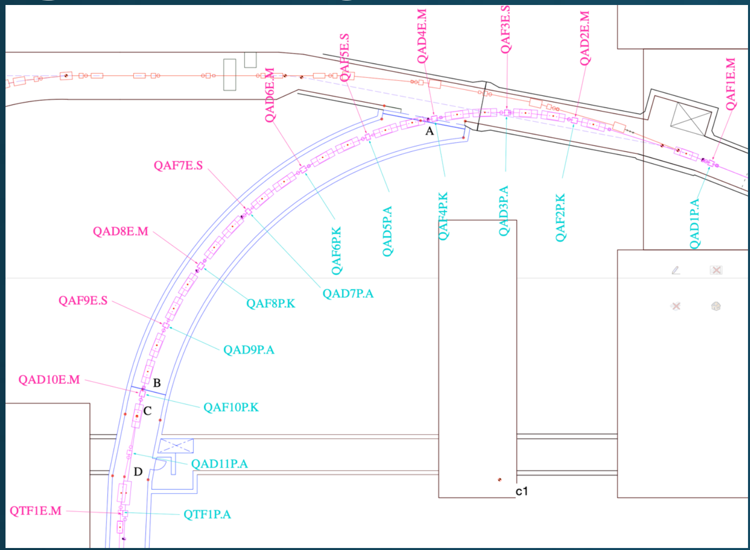
Work to be continued in 2025

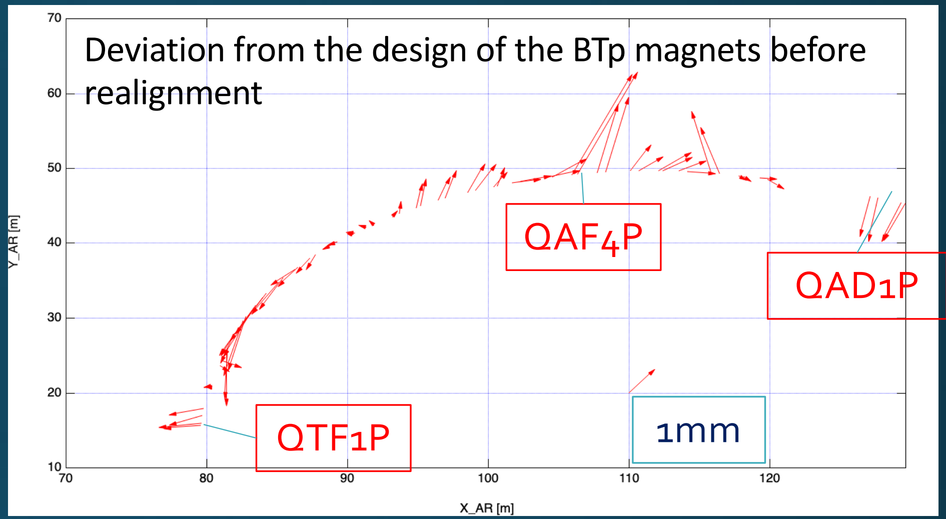
Beam Transport Magnetic Elements

Misalignments and Magnetic Field Deviations

Realignment for BT e^+/e^- in ARC1

PI: M. Tawada





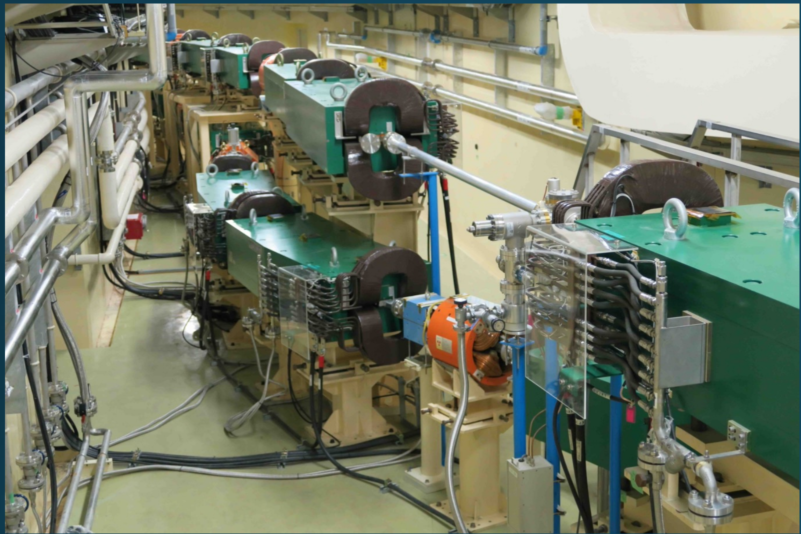
- While applying an offset for the bending magnet of ARC1 in BT e^+ line in 2023, a significant misalignment was observed.
- As a result, **a realignment was performed for the BT e^+ line magnets**, the shielding effect of CSR was not visible and the **vertical emittance growth in ARC1 disappeared**.

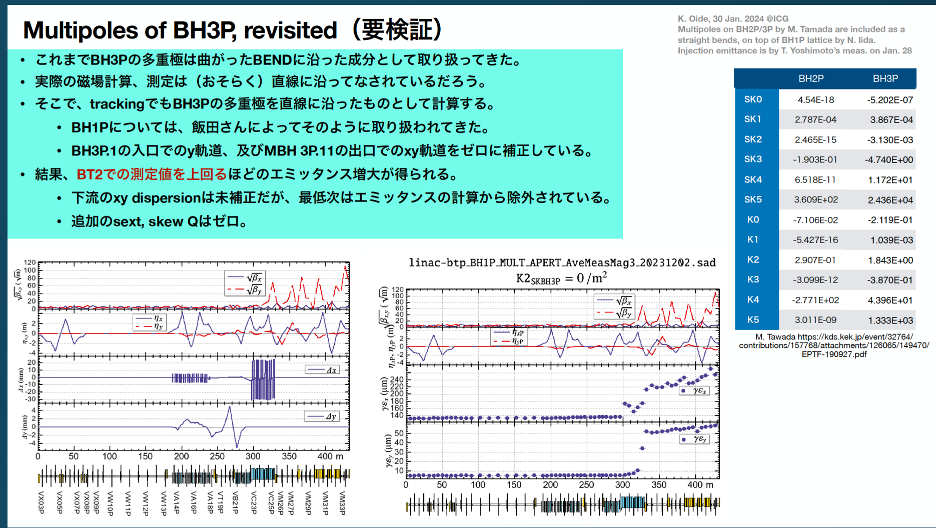
❖ We assume that a similar misalignment exists in BT e^- line, potentially causing vertical emittance growth.

Work to be performed in the future

Replacement the BH3P magnet poles

PI: M. Tawada





Multipoles of BH3P, revisited（要検証）

- これまでBH3Pの多重極は曲がったBENDに沿った成分として取り扱ってきた。
- 実際の磁場計算、測定は（おそらく）直線に沿ってなされているだろう。
- そこで、trackingでもBH3Pの多重極を直線に沿ったものとして計算する。
  - BH1Pについては、飯田さんによってそのように取り扱われてきた。
  - BH3P.1の入口でのy軌道、及びMBH 3P.11の出口でのxy軌道をゼロに補正している。
- 結果、BT2での測定値を上回るほどのエミッタンス増大が得られる。
  - 下流のxy dispersionは未補正だが、最低次はエミッタンスの計算から除外されている。
  - 追加のsext, skew Qはゼロ。

K. Oide, 30 Jan. 2024 @ICG
Multipoles on BH2P/3P by M. Tamada are included as a straight bends, on top of BH1P lattice by N. Iida.
Injection emittance is by T. Yoshimoto's meas. on Jan. 28

	BH2P	BH3P
SK0	4.54E-18	-5.202E-07
SK1	2.787E-04	3.867E-04
SK2	2.465E-15	-3.130E-03
SK3	-1.903E-01	-4.740E+00
SK4	6.518E-11	1.172E+01
SK5	3.609E+02	2.436E+04
K0	-7.106E-02	-2.119E-01
K1	-5.427E-16	1.039E-03
K2	2.907E-01	1.843E+00
K3	-3.099E-12	-3.870E-01
K4	-2.771E+02	4.396E+01
K5	3.011E-09	1.333E+03

M. Tawada https://kds.kek.jp/event/32764/contributions/157768/attachments/126065/149470/EPTF-190927.pdf

linac-btp_BH1P_MULT_APERT_AveMeasMag3_20231202.sad

$K2_{SKBH3P} = 0\,/m^2$

- The poles of BH2P and BH3P magnets are vertically asymmetrical, because spacers were inserted into only the upper pole to strengthen the magnetic field when increasing the beam energy from 3.5 GeV to 4 GeV.
- Oide-san's tracking simulation has pointed out that the **multipole components of the magnetic field could potentially lead to an increase in** the vertical **emittance**.

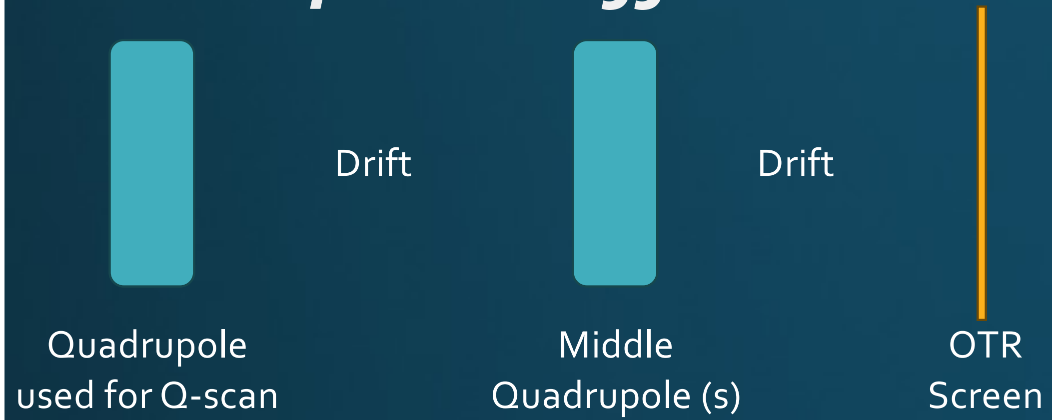
❖ The replacements of BH3P pole are planned to be carried out sequentially during the shutdown period.

❖ As for the BH2P, we will consider its replacement after reviewing the results of BH3P magnet pole exchange.

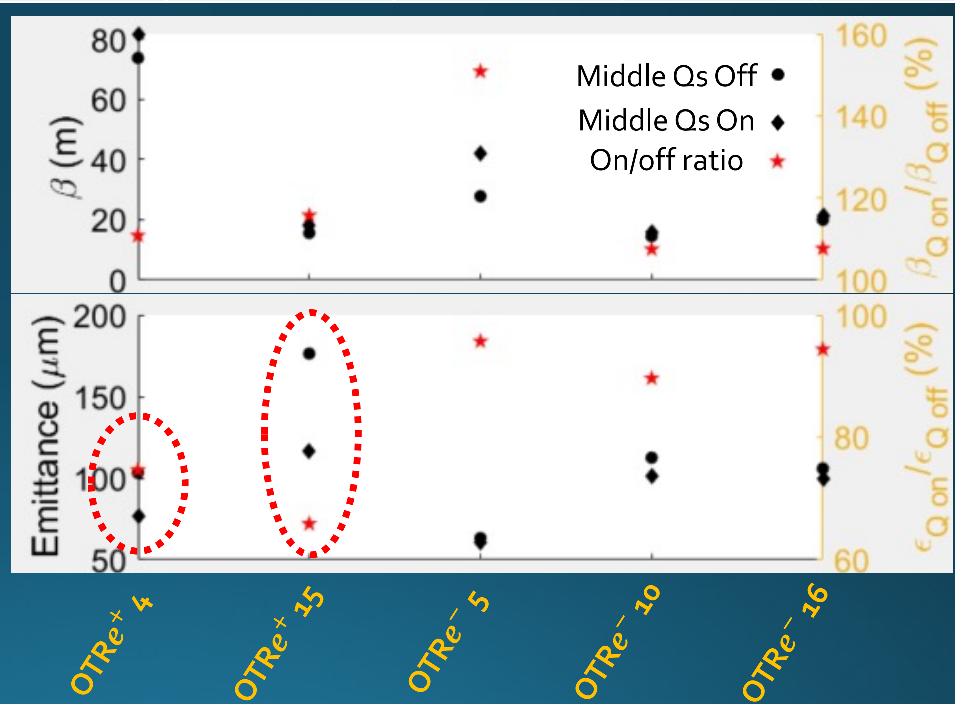
Work to be performed during 2025 summer shutdown

Quadrupoles Differences Between Model and Hardware

PI: D. Oumbarek Espinos



QXD7P state	$\beta_{Q,x}$ (m)	$\varepsilon_{Q,x}$ (nm)	$\gamma\varepsilon_{Q,x}$ (μm)	$\gamma\varepsilon_{Q,x,RMS\ error}$ (μm)
On	81.73	10.25	**77.0523**	**2.18**
Off	73.74	13.73	**103.2125**	**2.0597**



- Taking into account that a Q-scan should be independent of the middle magnets as long as they are properly characterized, one can use this technique to confirm the accuracy the Q's model.

❖ Some quadrupole magnets deviates from their expected behavior. Which also affected our emittance measurements.

❖ The test will be carried in other locations and the problematic magnets investigated.

Work performed during 2024 and to be continued during 2025

Preliminary BT e^+ Emittance Growth Re-measurements

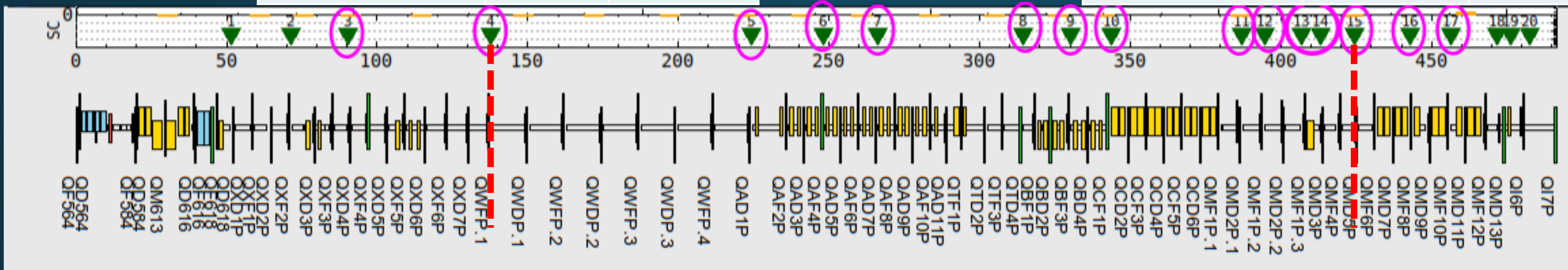
PI: D. Oumbarek Espinos

OTR e^+ 4 (3.14 nC)

Middle Q (QXD7P) state	$\beta_{Q,x}$ (m)	$\gamma\varepsilon_{Q,x}$ (μm)
On	81.73	**77.05**
Off	73.74	**103.21**

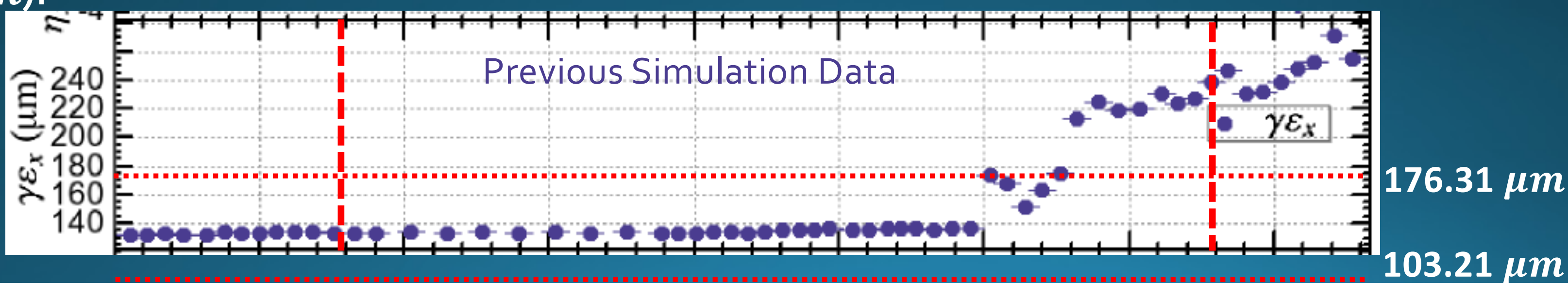
OTR e^+ 15 (3.30 nC)

Middle Q (QMD5P) state	$\beta_{Q,x}$ (m)	$\gamma\varepsilon_{Q,x}$ (μm)
On	18.07	**116.14**
Off	15.61	**176.31**



Work performed during 2024-2025

- Extremely recent data (taken the 20 of December and analyzed the 1st week of January).
- ❖ As previous data was taken with the middle Qs on, the new measurements in the same conditions only show a small change (**77.05 μm → 116.14 μm**), far from the data provided for the simulation.
- ❖ With a **middle Qs off** (**more accurate measurement**), an emittance growth **from 103.21 μm to 176.31 μm** is found, much less than the initially believed, **and on the same level as the one observed at BT e^- line (from 60 μm to 110 μm)**.



Support

- The group also gave everything to support and accommodate any request and to provide a swift response to any appearing issue.
- Of course, even without being PI, other members also helped.

Short Summary of 2024

- LER Kicker self-firing reduction.
- Vertical kickers installed at HER and LER and characterized.
- Additional SRM monitor installed at BT e^-.
- OTR data treatment overhauled improving accuracy, robustness and ease of use. Finally, agreement between different diagnostics achieved.
- Multiple new applications done for different uses of the OTR screens.
- A bigger focus on large quantity of data analyzed improving accuracy of studies and revealing more information.
- Radiation related camera network issues detected and dealt with.
- BPM signal isolation for e^+ improved.
- BT e^+ ARC1 magnet realignment performed and emittance growth reduced.
- Some magnets model difference with the real ones detected.

To Do in the Future

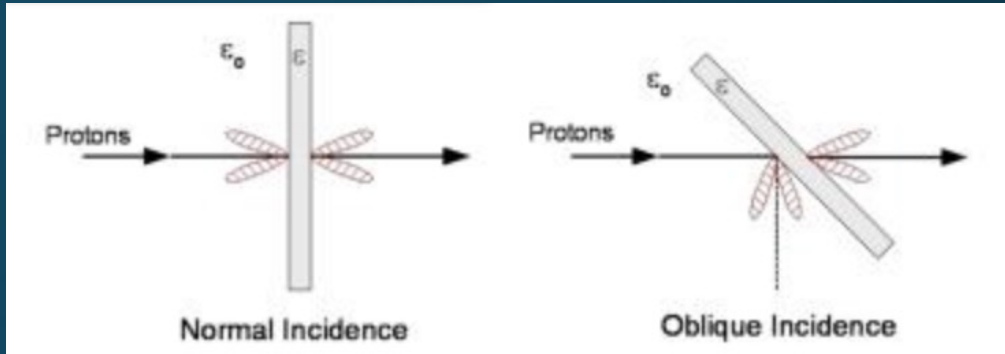
- HER Kicker hardware improvements for voltage feedback and leaks.
- Development of multiple SRM emittance variation diagnostic.
- Unification of the different OTR diagnostic tools.
- Matlab and Python libraries to be develop to allow easy re-analysis by anyone.
- Single button full BT e^+/e^- line beam characterization application.
- Start of Machine Learning tools applied to “deep diagnostics”.
- Upgrades of the OTR setups to improve the alignment and reflections.
- Improvements of the Wire-Scanner precision and robustness.
- Solve the diagnostic camera network issues.
- Realignment of BT e^- ARC1 to reduce emittance growth.
- BH3P poles replacement and consideration of same work at BH2P.
- Study of detected quadrupoles difference between model and reality.

Thank you for your time and attention !

Additional Slides

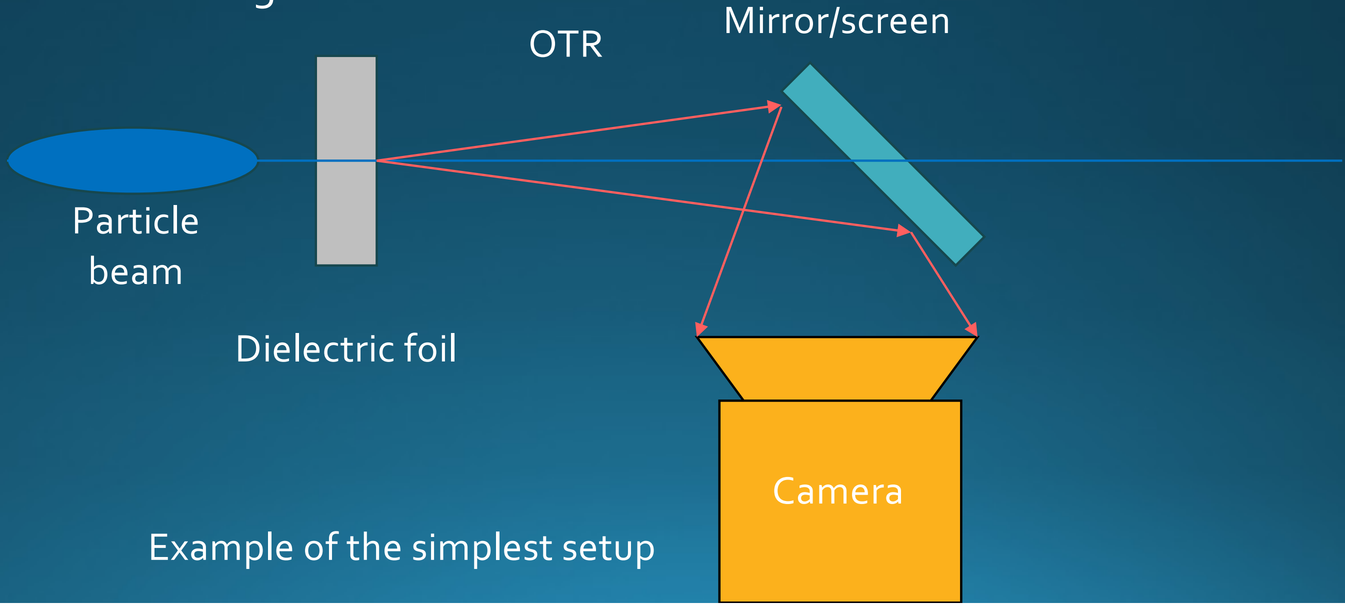
Optical Transition Radiation (OTR)

The transition radiation (TR) is generated when a charged particle beam transits the interface of two media with different dielectric constants



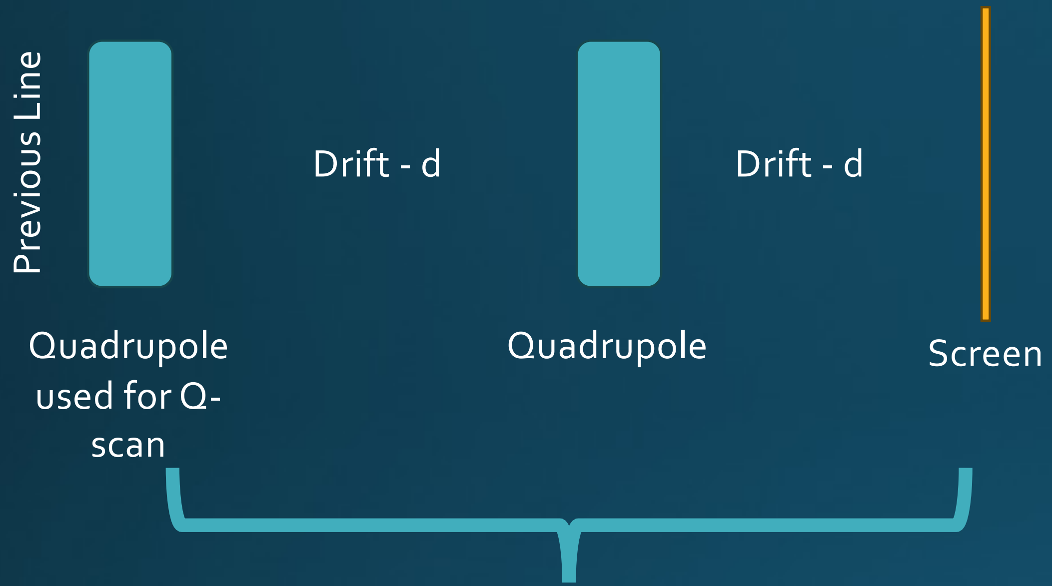
https://www.slideserve.com/laura-bass/optical-transition-radiation-measurements-of-pbar-transfers

The existence of transition radiation was theoretically predicted by Frank and Ginzburg in 1945



Example of the simplest setup

Reminder of the Equations



$$S = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \; transport\ matrix\ from\ Q\ to\ screen$$

Measurement fit

$$\sigma^M_{ii} = k^2\sigma^Q_{ii}S^2_{ij} + 2S_{ij}k(S_{ii}\sigma^Q_{ii} + S_{ij}\sigma^Q_{ij}) + S^2_{ii}\sigma^Q_{ii} + 2S_{ii}S_{ij}\sigma^Q_{ij} + S^2_{ij}\sigma^Q_{jj} = A(k-B)^2 + C$$

From fit values and the matrix term S_{12} one gets the beam emittance at the Q-scan quadrupole

$$\beta = \frac{\sigma^Q_{ii}}{\epsilon} = \sqrt{\frac{A}{C}}$$

$$\epsilon = \sqrt{\sigma^Q_{ii}\sigma^Q_{jj} - \sigma^{Q2}_{ij}} = \sqrt{\frac{AC}{S^4_{ij}}}$$

If the intermediate quadrupole is well characterized and without significant higher multipolar terms, both measurements (with the middle Q on and off) should give the same beta and emittance results, as the results are given in a position before the middle Q.

Fit Error Propagation

$$\beta = \frac{\sigma_{ii}^{Q}}{\epsilon} = \sqrt{\frac{A}{C}}$$

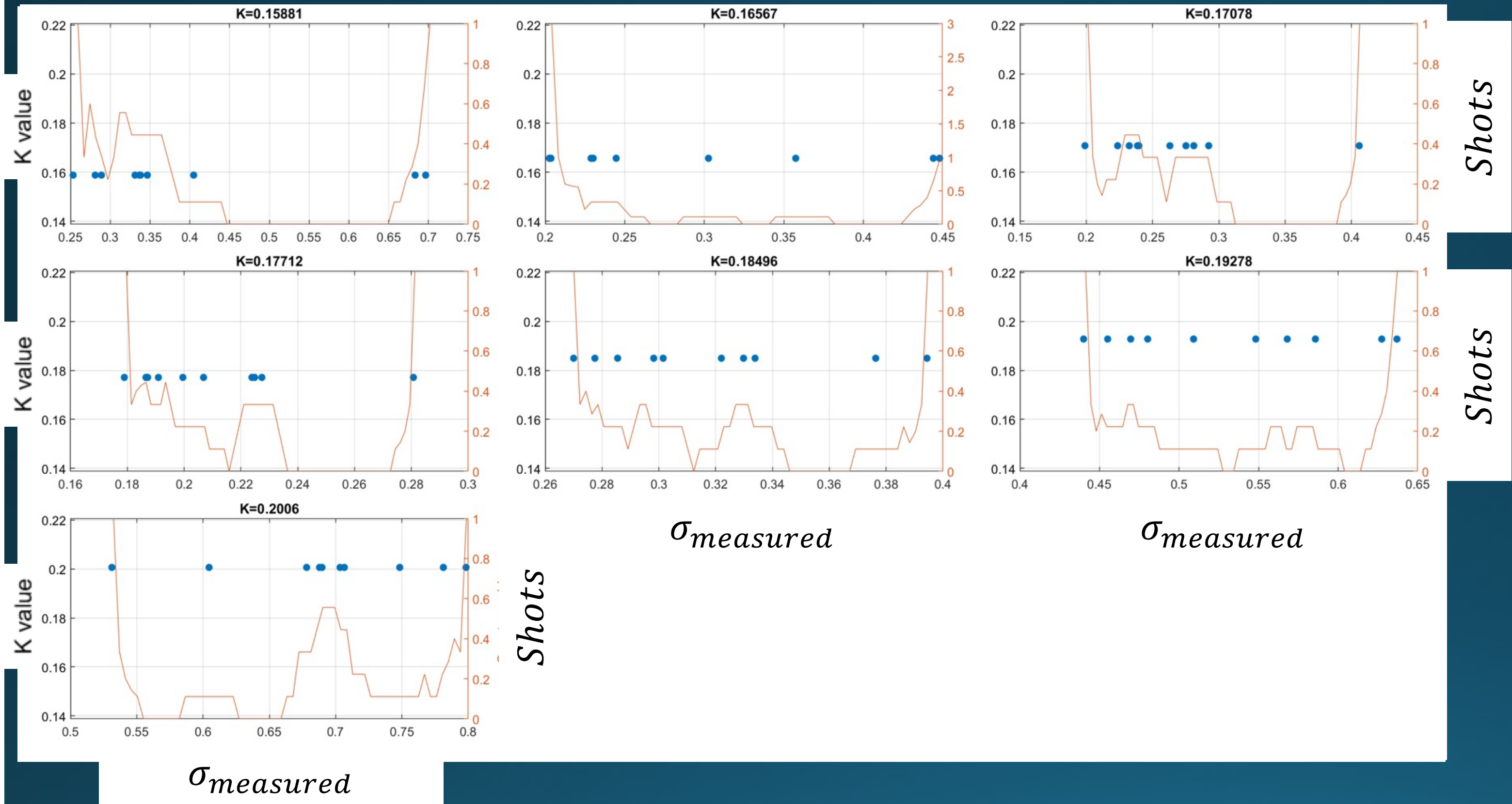
$$\boldsymbol{\beta}_{\boldsymbol{Q,x,RMS\ error}} = \sqrt{\left(\frac{\delta \boldsymbol{\beta}_{\boldsymbol{Q,x}}}{\delta A} A_{RMS,error}\right)^2 + \left(\frac{\delta \boldsymbol{\beta}_{\boldsymbol{Q,x}}}{\delta C} C_{RMS,error}\right)^2} = \sqrt{\left(\frac{1}{2\sqrt{AC}} A_{RMS,error}\right)^2 + \left(-\frac{\sqrt{A}}{2C^{3/2}} C_{RMS,error}\right)^2}$$

$$\epsilon = \sqrt{\sigma_{ii}^{Q}\sigma_{jj}^{Q} - \sigma_{ij}^{Q2}} = \sqrt{\frac{AC}{S_{ij}^{4}}}$$

$$\boldsymbol{\epsilon}_{\boldsymbol{Q,x,RMS\ error}} = \sqrt{\left(\frac{\delta \boldsymbol{\epsilon}_{\boldsymbol{Q,x}}}{\delta A} A_{RMS,error}\right)^2 + \left(\frac{\delta \boldsymbol{\epsilon}_{\boldsymbol{Q,x}}}{\delta C} C_{RMS,error}\right)^2} = \sqrt{\left(\frac{\sqrt{C}}{2S_{12}^{2}\sqrt{A}} A_{RMS,error}\right)^2 + \left(\frac{\sqrt{A}}{2S_{12}^{2}\sqrt{C}} C_{RMS,error}\right)^2}$$

With $C_{RMS,error}$ and $A_{RMS,error}$ the error coming from the fit.

10 Shots Statistical Significance



200 shots per k

Using 200 shots per K the distribution of $\sigma_{x,RMS}$ clearly shows a peak and always on the lower side.

However, it can also be seen that there is quite a bit of jitter shot-to-shot.

10 shots per K

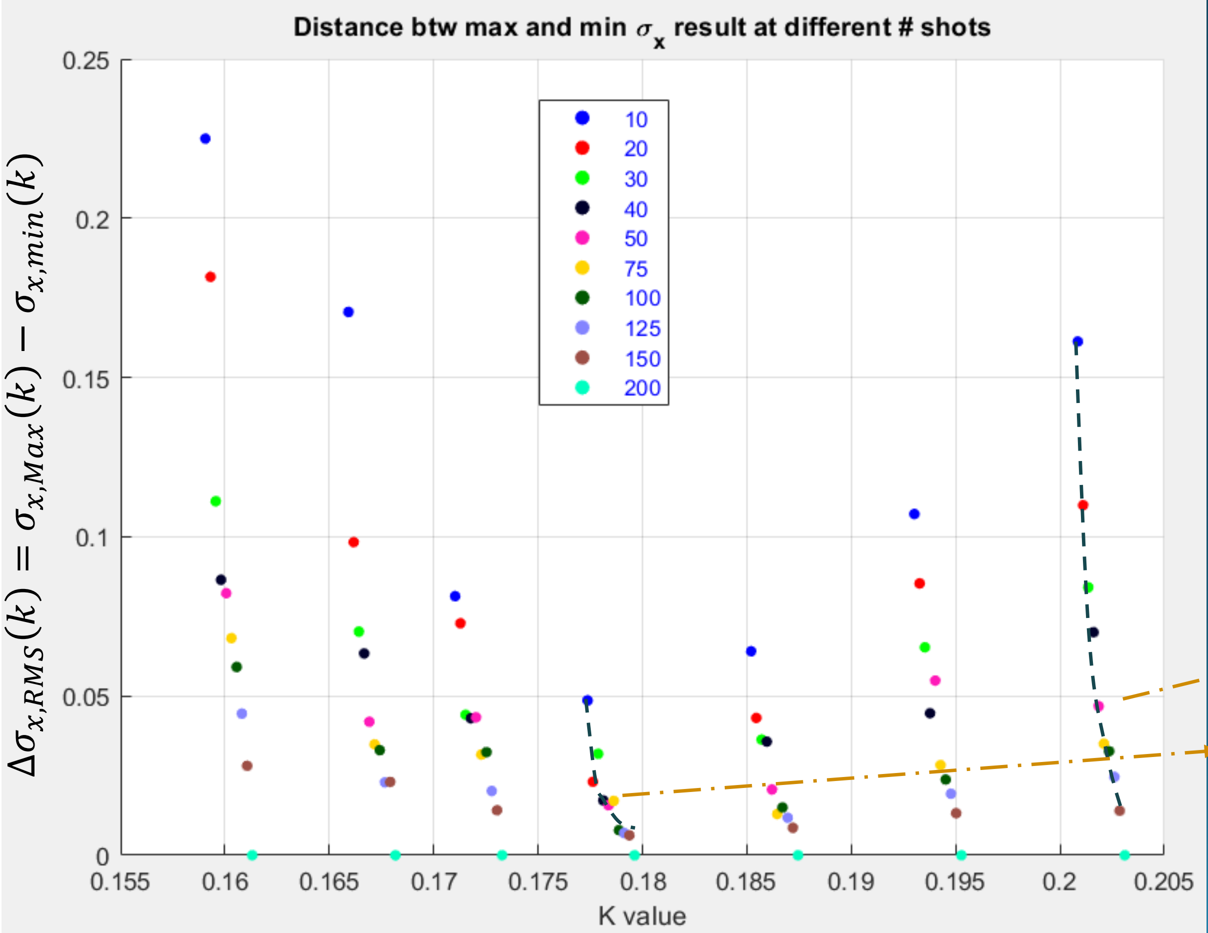
No clear distribution peak visible.

The range of $\sigma_{x,RMS}$ values can be quite large.

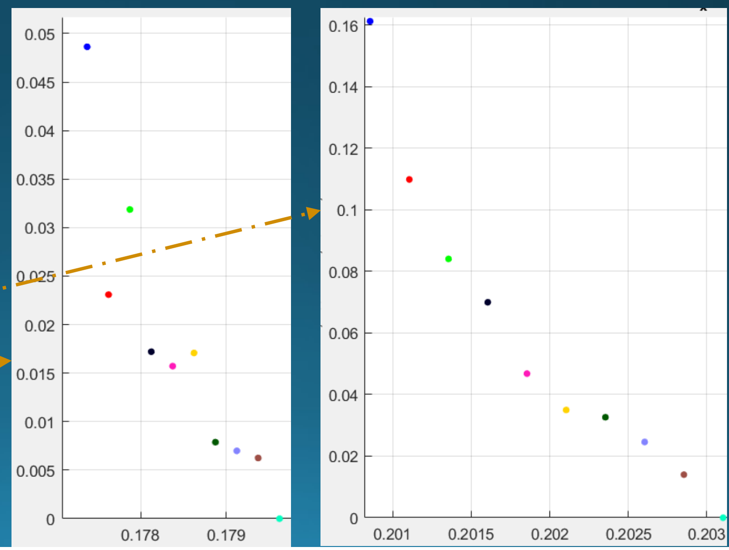
- 10 shots per K gives a quite poor insight of the real beam behavior.
- It is clear that 10 shots is not enough.
- While the 200 shots per K case gives $\sigma_{x,min}^2 = 0.0467\ mm^2$, this specific 10 shots per K case gives $\sigma_{x,min}^2 = 0.0626\ mm^2$, i.e., 1.34 times higher !

Measurement-to-Measurement Variation

Cases studied: 10, 20, 30, 40, 50, 75, 100, 125 and 150 shots per K
50 measurements for each case.

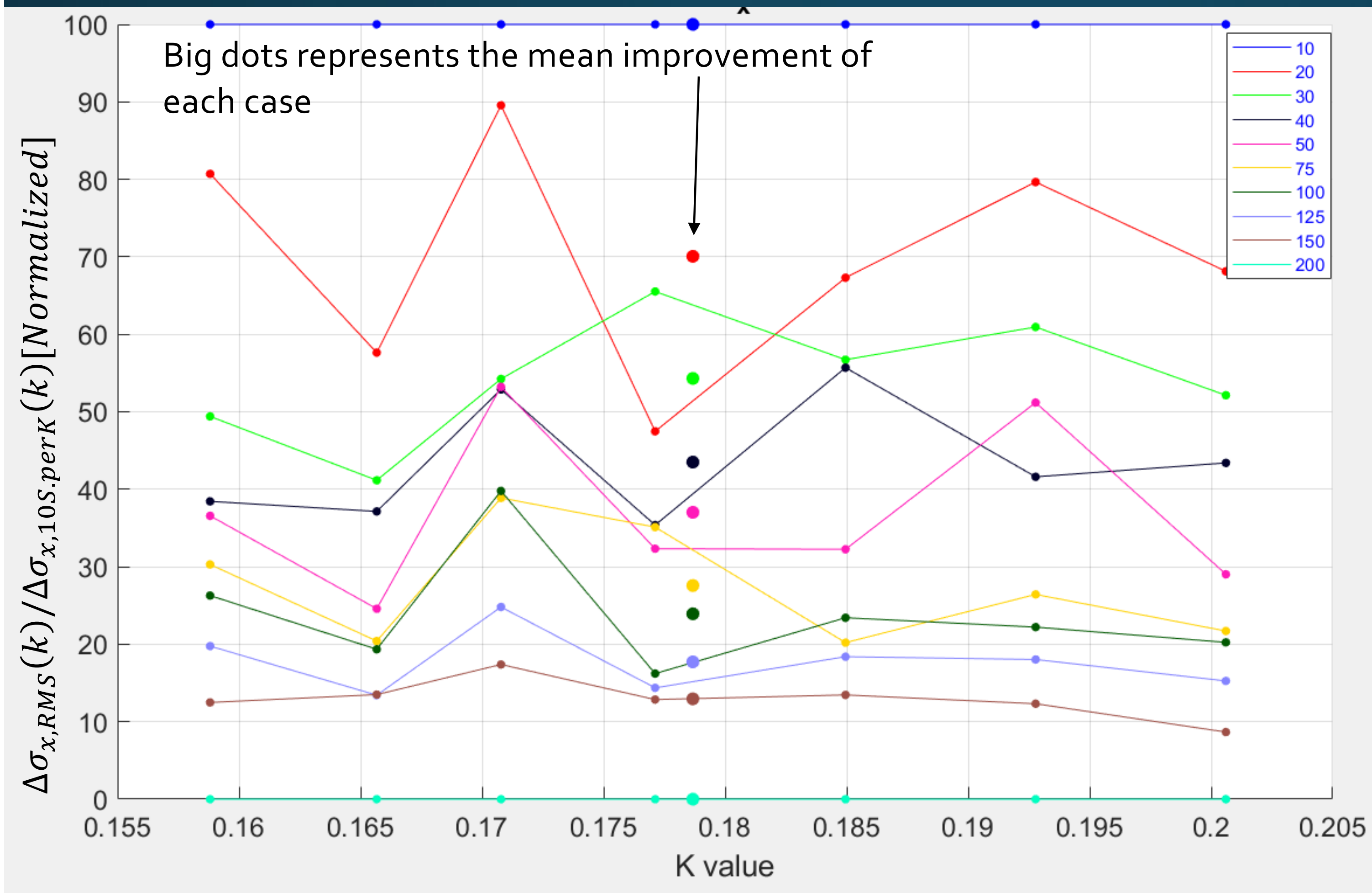


- When the beam is more focused the improvements due to increase of the number of shots are smaller.
- This is due to the resolution limit of our screen.
- But when the beam is big enough (defocused) one can clearly see the decrease of $\Delta\sigma_{x,RMS}(k)$ per case.



Measurement-to-Measurement Variation

Cases studied: 10, 20, 30, 40, 50, 75, 100, 125 and 150 shots per K, 50 measurements for each case.

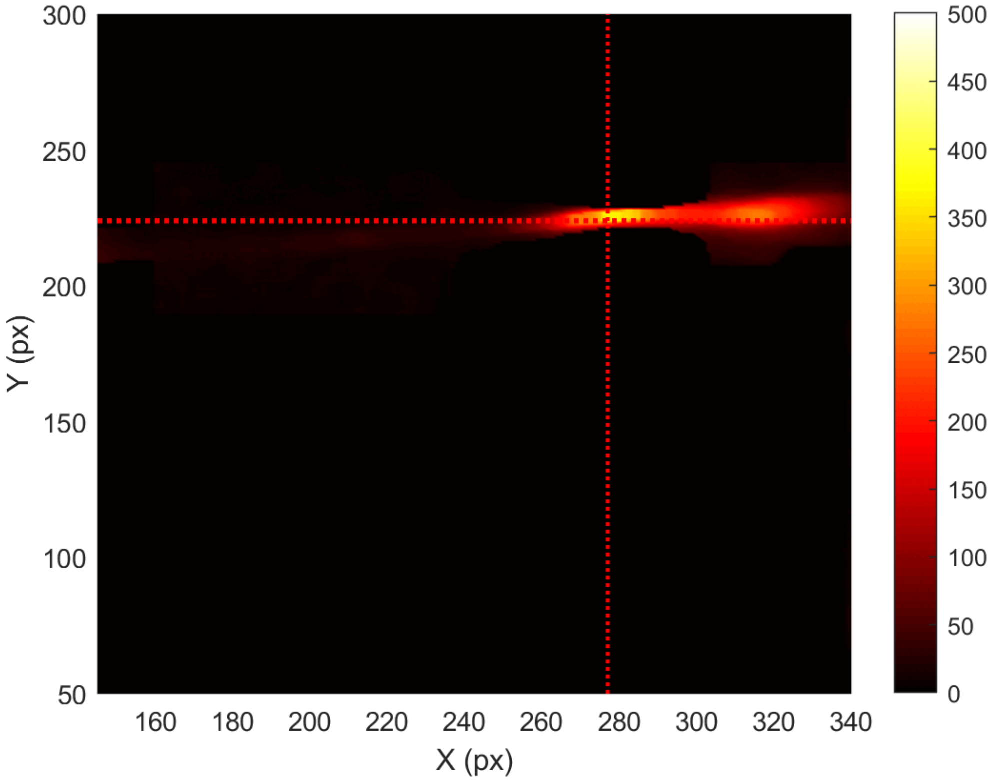


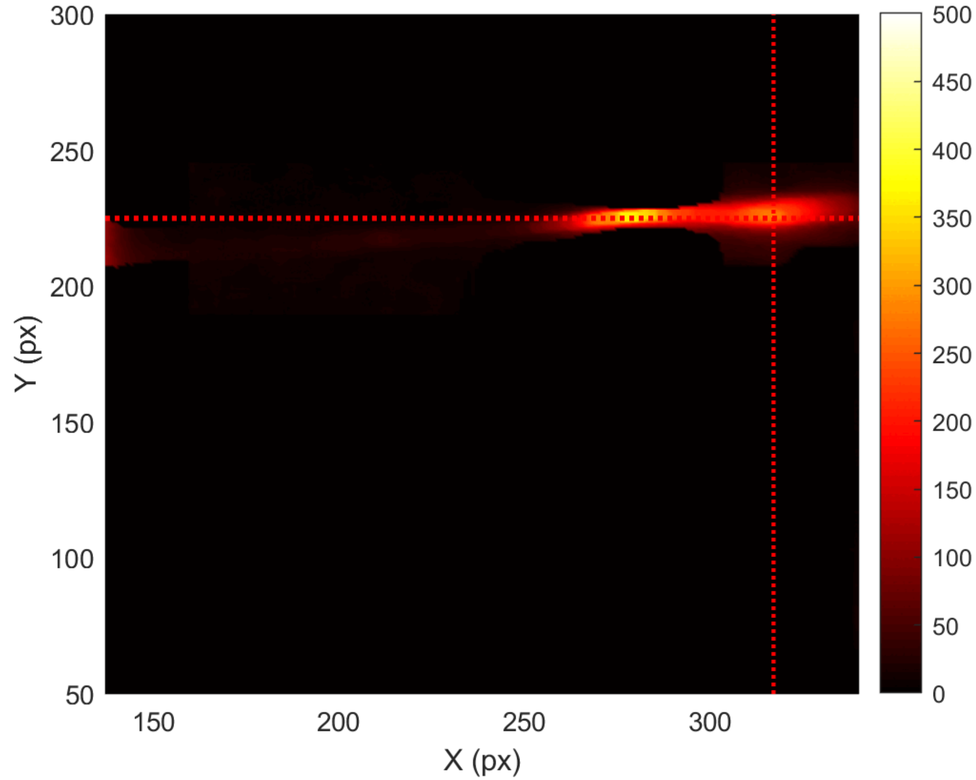
Plot showing $\Delta\sigma_{x,RMS}(k)$ normalized by the values of the 10 shots per K case, thus, showing the improvement in % of the variation Measurement-to-Measurement (M2M) when increasing the number of shots.

❖ For HER, the compromise between "data taking time" and accuracy seems to be at **50 shots per K**

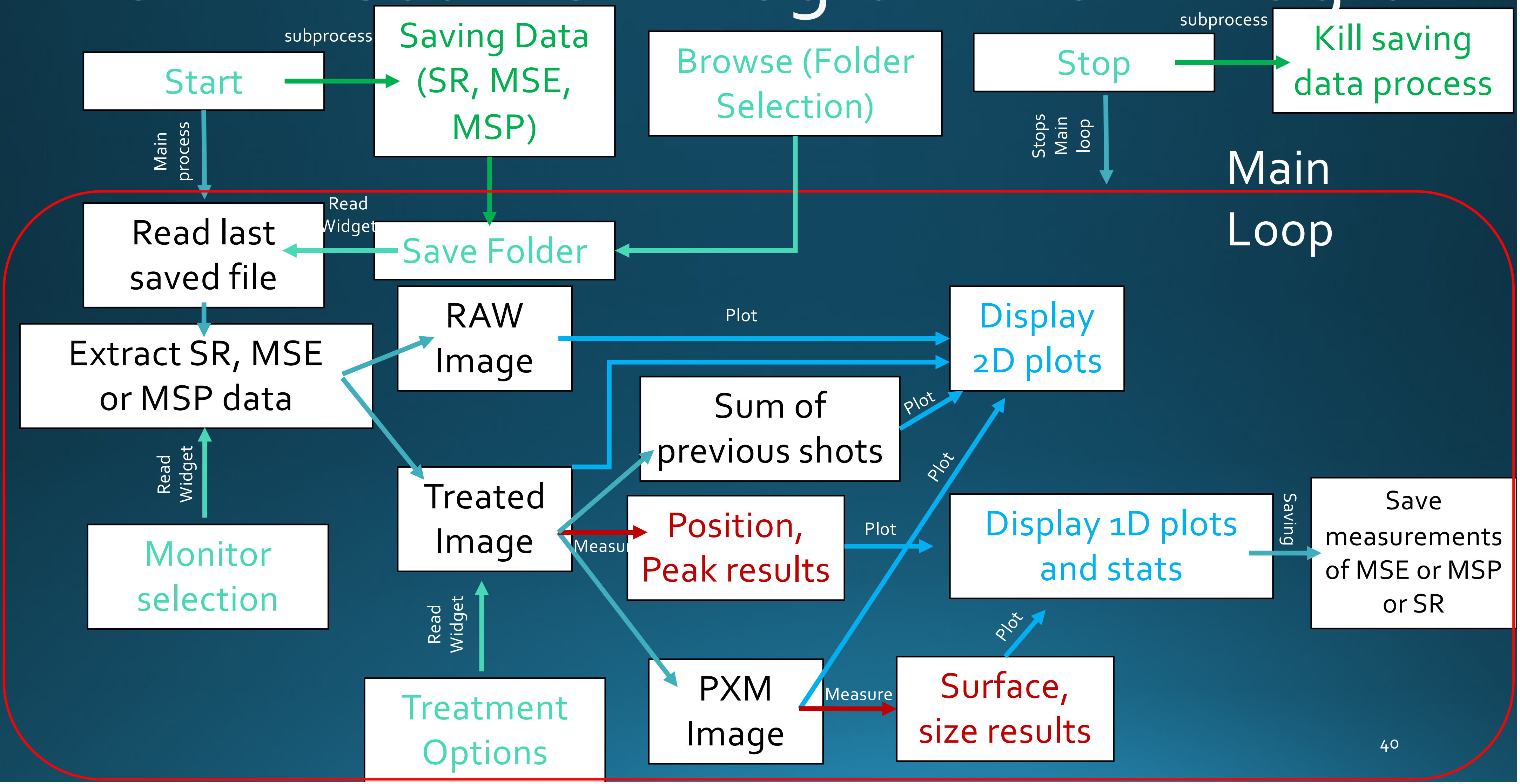
Finding the Transverse Beam Center: Sweeping box

- ❖ The sweeping box can keep up with the beam center without problems.
- ❖ The transverse projection mistakes multiple times reflections or noise with the real beam.





BT OTR Visualizer: Program Flow Diagram



Replacement the BH3P magnet poles

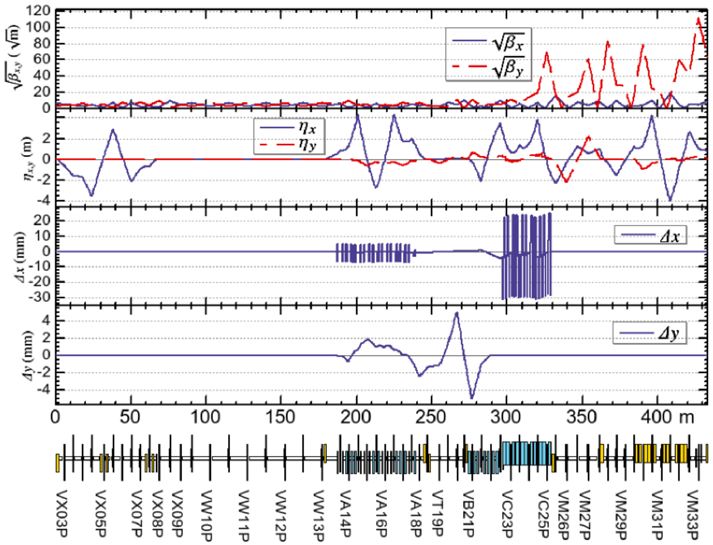
Multipoles of BH3P, revisited（要検証）

- これまでBH3Pの多重極は曲がったBENDに沿った成分として取り扱ってきた。
- 実際の磁場計算、測定は（おそらく）直線に沿ってなされているだろう。
- そこで、trackingでもBH3Pの多重極を直線に沿ったものとして計算する。
  - BH1Pについては、飯田さんによってそのように取り扱われてきた。
  - BH3P.1の入口でのy軌道、及びMBH 3P.11の出口でのxy軌道をゼロに補正している。
- 結果、BT2での測定値を上回るほどのエミッタンス増大が得られる。
  - 下流のxy dispersionは未補正だが、最低次はエミッタンスの計算から除外されている。
  - 追加のsext, skew Qはゼロ。

K. Oide, 30 Jan. 2024 @ICG
Multipoles on BH2P/3P by M. Tamada are included as a straight bends, on top of BH1P lattice by N. Iida.
Injection emittance is by T. Yoshimoto's meas. on Jan. 28

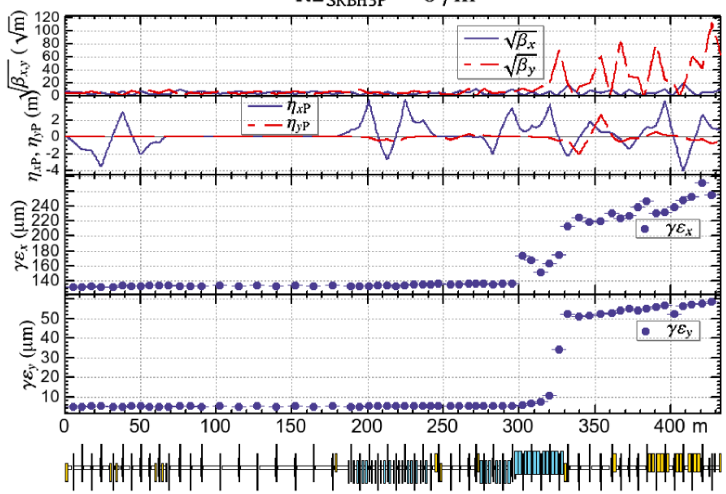
	BH2P	BH3P
SK0	4.54E-18	-5.202E-07
SK1	2.787E-04	3.867E-04
SK2	2.465E-15	-3.130E-03
SK3	-1.903E-01	-4.740E+00
SK4	6.518E-11	1.172E+01
SK5	3.609E+02	2.436E+04
K0	-7.106E-02	-2.119E-01
K1	-5.427E-16	1.039E-03
K2	2.907E-01	1.843E+00
K3	-3.099E-12	-3.870E-01
K4	-2.771E+02	4.396E+01
K5	3.011E-09	1.333E+03

M. Tawada https://kds.kek.jp/event/32764/contributions/157768/attachments/126065/149470/EPTF-190927.pdf



linac-btp_BH1P_MULT_APERT_AveMeasMag3_20231202.sad

$K2_{SKBH3P} = 0\,/\mathrm{m}^2$



Preliminary Emittance Growth Remeasurements

PI: D. Oumbarek Espinos