GSI Helmholtzzentrum für Schwerionenforschung GmbH

На пути к FAIR. Введение в эксплуатацию CRYRING@ESR

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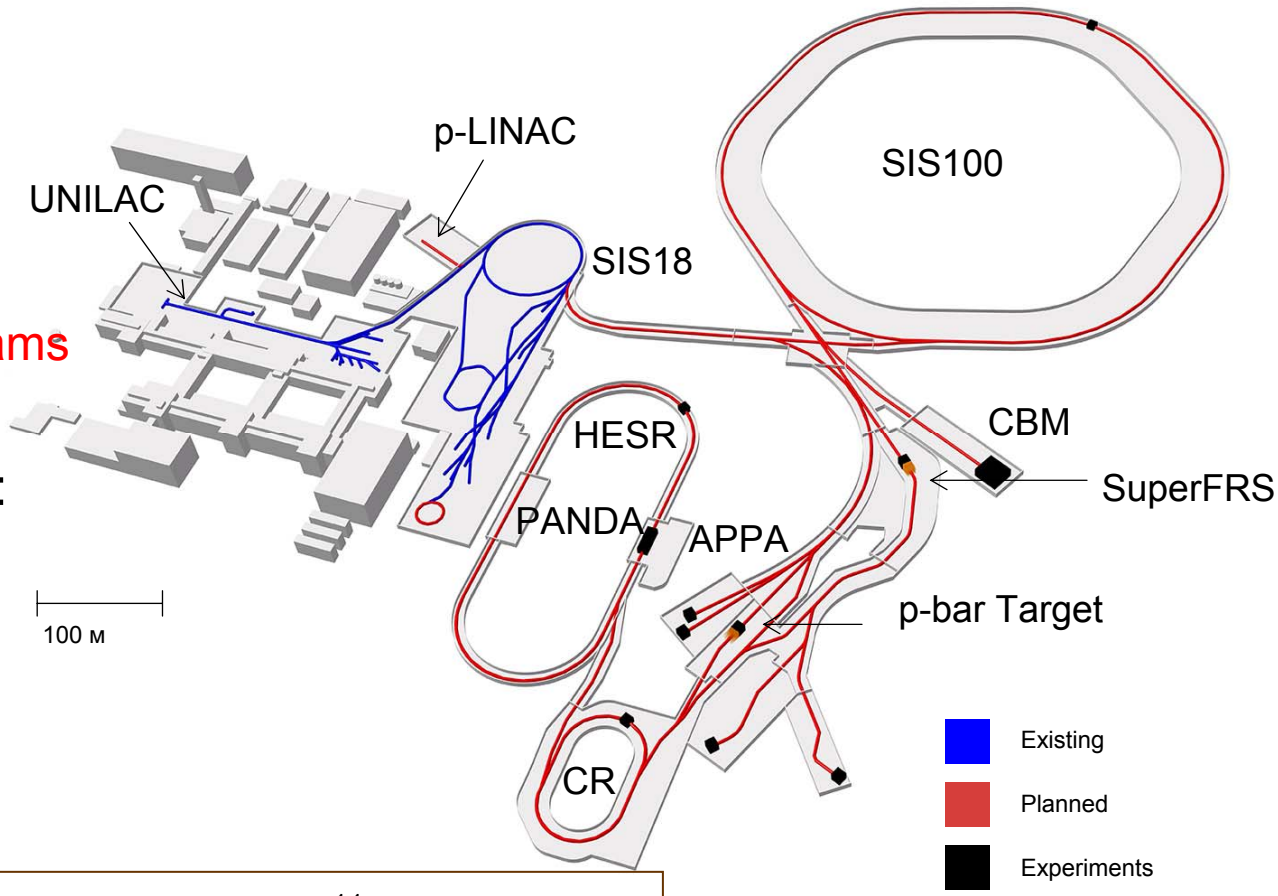
Ускорители FAIR

- Beams:
  - Anti protons
  - Protons to uranium
  - RIBs
- Beam quality:
  - Cooled anti proton beams
  - Cooled, intense RIBs
- Beam pulse structure:
  extreme short pulses to quasi continuous



- Design ion beam: U^{28+} with 2.7 GeV/u, $5x10^{11}$ Ions/Cycle
- Protons up to 29 GeV
- Heavy ion beams up to about 11 GeV/u

Параметры FAIR

	SIS18	SIS100	CR	HESR
Circumference [m]	216	1083	215	575
Max. beam magnetic rigidity [Tm]	18	100	13	50
Injection energy of protons or anti protons [GeV]	0.07	4	3	3
Final energy of protons or antiprotons [GeV]	4	29	3	14
Injection energy of heavy ions [GeV/u]	0.0114	0.2	0.74	0.74
Final energy of heavy ions U(28+) [GeV/u]	0.2	2.7		
Final energy of heavy ions U(/73+/92+) [GeV/u]	1	11	0.74 (92+)	0.2-4.9 (92+)
Max. beam intensity for protons or antiprotons /cycle	$5*10^{12}$	$2*10^{13}$	10^{8}	10^{10}
Max. beam intensity of ^{238}U-ions /cycle	$1.5*10^{11}$	$5*10^{11}$	10^{8}	10^{8}
Required static vacuum pressure [mbar]	$< 10^{-11}$	$<5*10^{-12}$	$<10^{-9}$	$<10^{-9}$

Научная программа на FAIR

The Mission

Study strongly interacting matter on (almost) all scales

Nuclear Structure & Astrophysics
(Rare-isotope beams)

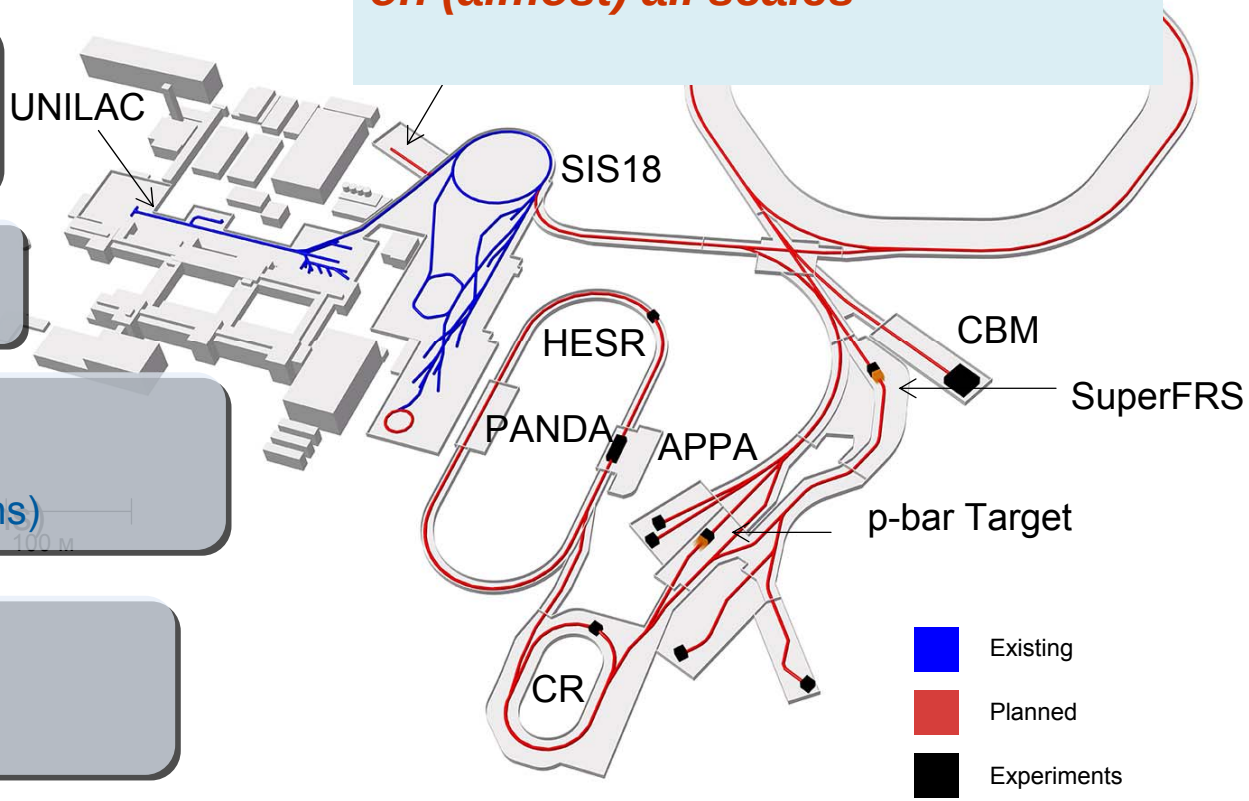
Hadron Physics
(Stored and cooled
14 GeV/c anti-protons)

QCD-Phase Diagram
(HI beams 2 to 45 GeV/u)

Fundamental Symmetries & Ultra-High EM Fields
(Antiprotons & highly stripped ions)

Dense Bulk Plasmas
(Ion-beam bunch compression & petawatt-laser)

Materials Science & Radiation Biology
(Ion & antiproton beams)



FAIR Requirements for SIS18

	Today	FAIR Booster	Today	FAIR Booster
Reference Ion	U^{73+}	U^{28+}	P	P
Maximum Energy	1 GeV/u	0.2 GeV/u	4 GeV	4 GeV
Maximum Intensity	$4x10^{9}$	$1.5x10^{11}$	$2x10^{11}$	$2.5x10^{12}$
Repetition Rate	0.3 - 1 Hz	2.7 Hz	0.3 – 1 Hz	2.7 Hz

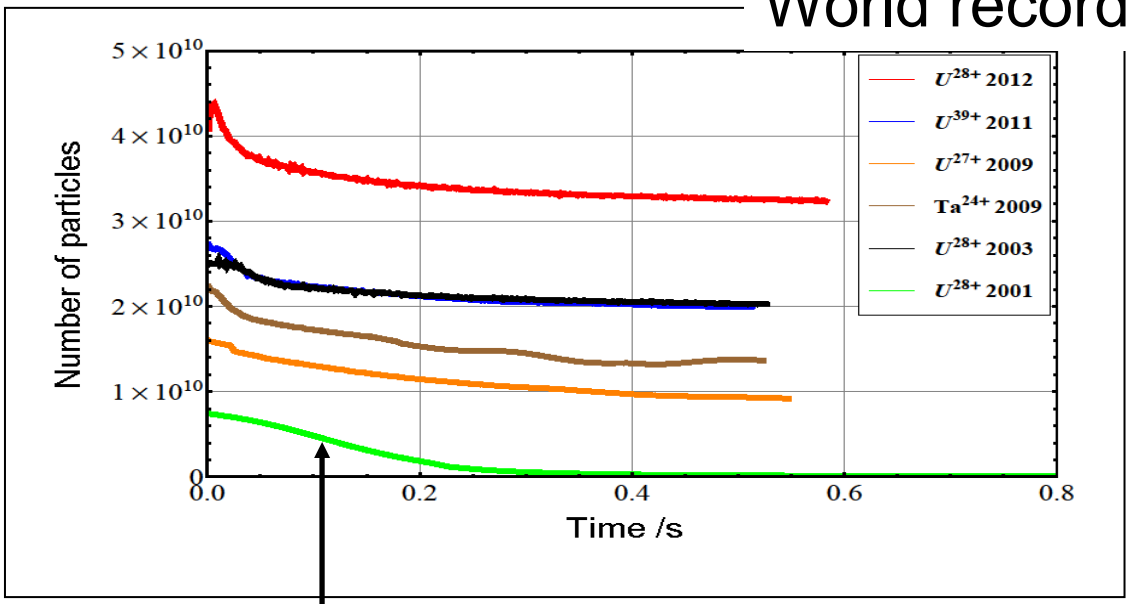
Main challenge: Intermediate charge state heavy ions, dynamic vacuum and ionization beam loss

Status U^{28+} -Beam Intensity

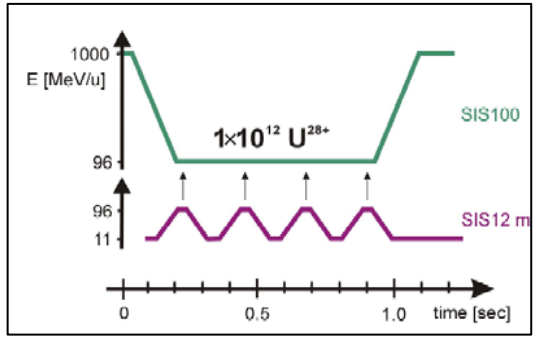
World record intensity for intermediate charge state heavy ions in heavy ion booster.

The feasibility of high intensity beams of intermediate charge state heavy ions has been demonstrated.

World record



2001 FAIR conceptual design report (FAIR proposal)



Stacking in SIS100 (4x)

Further upgrade measures are required for reaching the goal for the most heavy ions (e.g. Uranium with 1.5×10^{11} per cycle at a (high) repetition rate of 2.7 Hz.)

Staged Beam Intensity Increase

Case a) Experiment Operation 2018 – 2021 (FAIR Phase 0)

Basis:

Operation with TK stripper (highly charged ions)
Routine operation with high ramp rates (1.3 T/s > 10 T/s)
No high repetition modes (limit 1 Hz) (or with restricted intensity per cycle)
Operation with two Rf harmonics (enhanced space charge limit)
Improved slow extraction efficiency
Enhance gas pressure in post stripper

Case b) Booster Operation 2021... (FAIR Module 1 – First FAIR Experiments)

Basis:

Operation without TK stripper (intermediate charge states)
Routine operation with high ramp rates (10 T/s)
Maximum repetition rate (2.7 Hz)
Operation with two Rf harmonics
Improved slow extraction efficiency
Enhanced gas pressure in post stripper

Recommissioning of the existing facility in 2018 and Operation in Phase 0

SIS18 and ESR need to be „recommissioned“ in 2018

- The complete control system is been modernized now (LSA Framework).
- New FAIR timing system will be used (BUTIS, White Rabbit).
- Many old front end electronics are being replaced.

Good news:

- The new data supply has been already tested in various machine experiments and works very well.
- Many modern devices already use new frontends today
- The CRYRING was successfully tested (only basic operation) some weeks ago with new software and FAIR timing system.

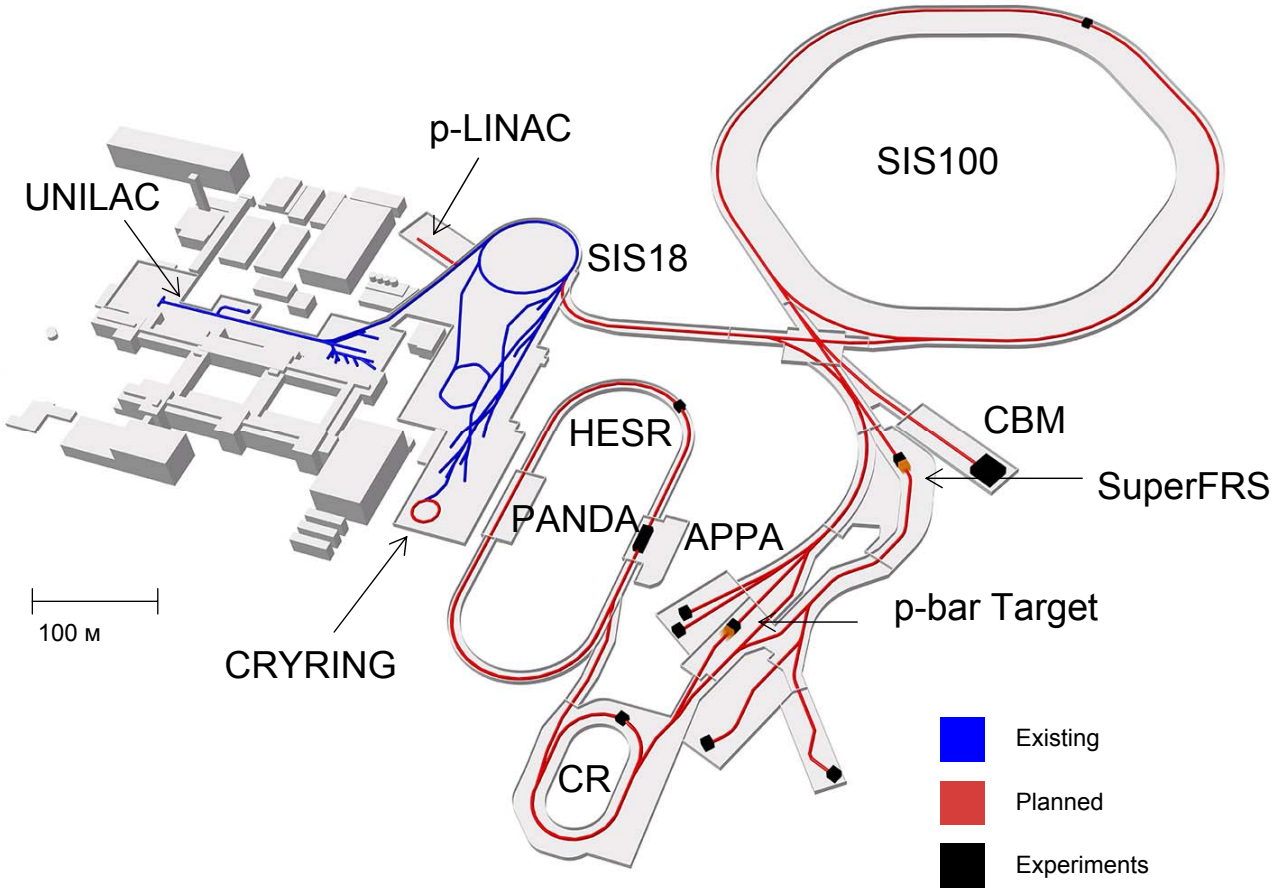
FAIR status summary

- Planed upgrade of SIS18 will be finished till 2018. Further steps will follow to reach full FAIR performance.
- Many UNILAC improvements. Alvarez upgrade design not fixed yet.
- Procurements are progressing well for SIS100, HEBT, HESR
- Procurements for Super-FRS started. Major procurements start on short term.
- CR technical design report and engineering layout completed.
  - FOS devices or prototypes for German in-kind components to CR built.
- P-Linac and pbar target were limited to the continuation of started activities but recent UNILAC improvements can somewhat compensate for the delay.

Ожидание

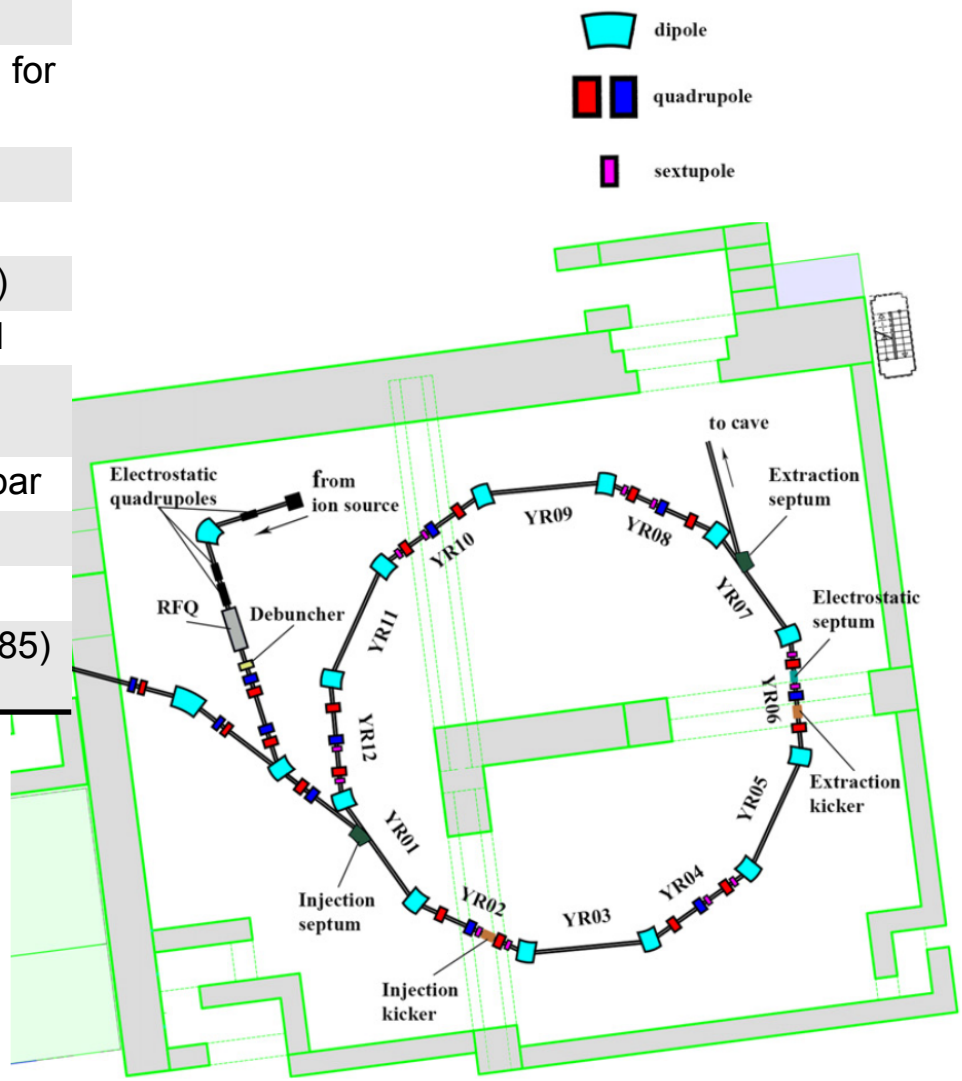
Статус

Ускорители FAIR



CRYRING@ESR

Circumference	54.17 m (ESR/2)
Rigidity	0.054 – 1.44 Tm (0.8 Tm for protons/antiprotons)
Maximum energy for p, pbar	30 MeV
- for $^{12}C^{6+}$	24.7 MeV/u
- for $^{238}U^{92+}$ ($^{238}U^{89+}$)	14.8 MeV/u (13.9 MeV/u)
Lowest energy	Charge exchange limited
Magnet ramping (de- and acceleration)	1 T/s (4 T/s, 7 T/s)
Vacuum pressure	N_2 equiv. 10^{-12} – 10^{-11} mbar
Beam injection	Multiturn and fast
Beam extraction	slow and fast
Ion source for stand alone operation	Yes (300 keV/u, A/q < 2.85)



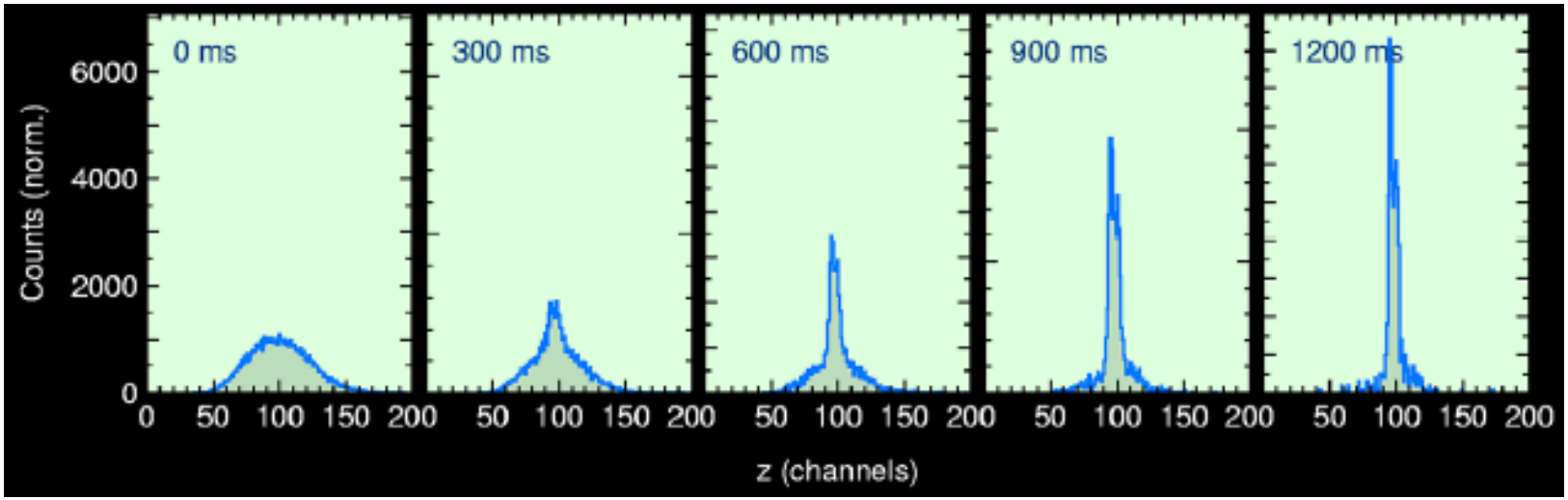
CRYRING timeline

- Design and construction started in 1986
- First beam stored in January 1991
- Electron cooler started in May 1993
- Start of experimental programme in June 1993
- Continuous improvements of power supplies, electron cooling, ion sources, diagnostics, control system, vacuum system …
- Swedish Research Council decided to stop funding in June ‘03
- First discussions about transferring CRYRING to FAIR in summer 2003

- Layout of the CRYRING modified to fulfill FAIR needs.
  - Debuncher replaced by electrostatic quadrupoles
  - Ring circumference increased to optimize the injection from ESR
  - Control system upgraded

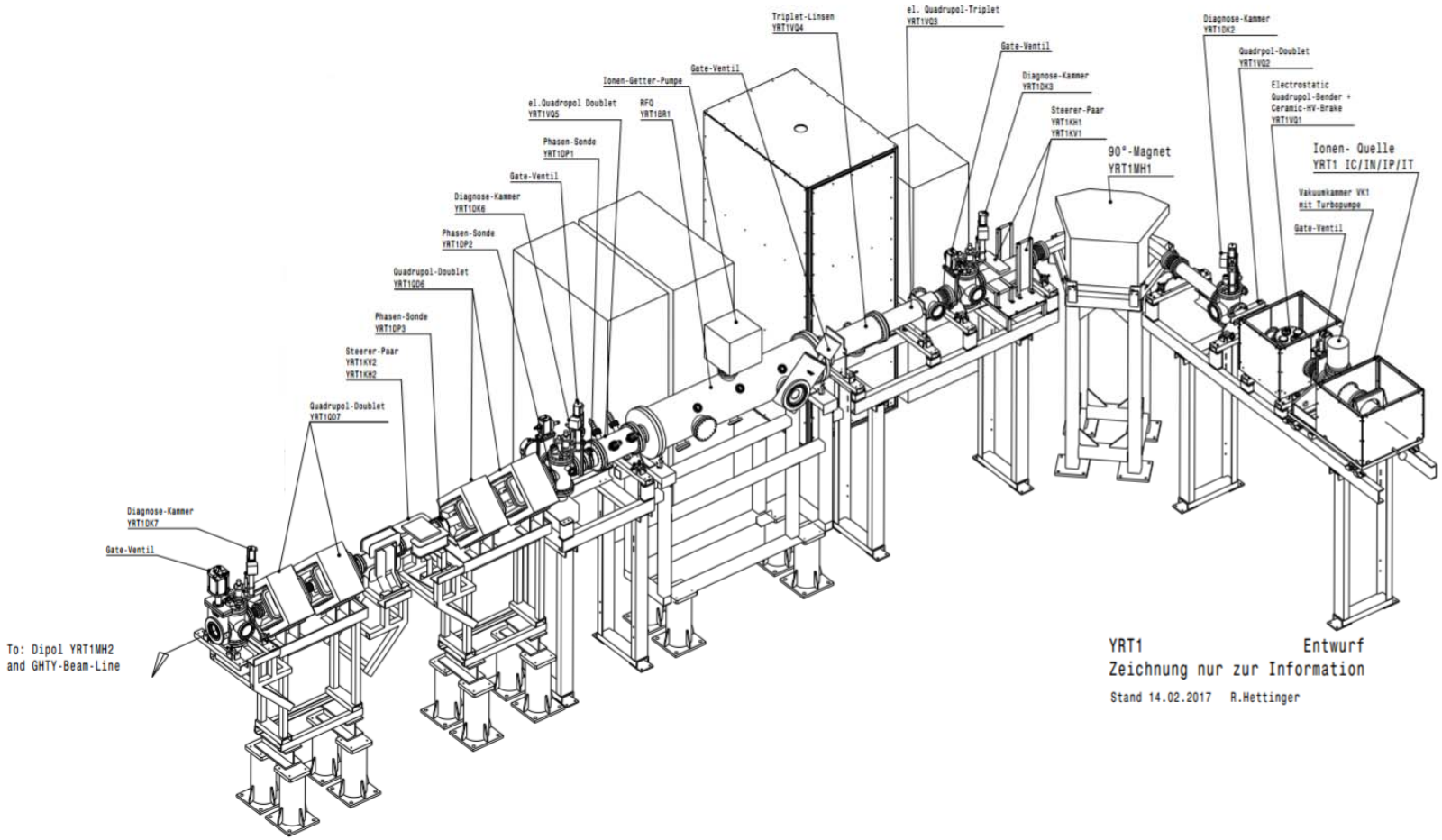
Electron Cooling of H^-

- Beam energy: 3 MeV
- Electron current: 18 mA
- Initial beam width (FWHM): 9 mm
- Initial emittance 10 π mm mrad
- Final beam width (FWHM): 1.5 mm
- Final emittance 0.25 π mm mrad
- Acceptance 50 π mm mrad



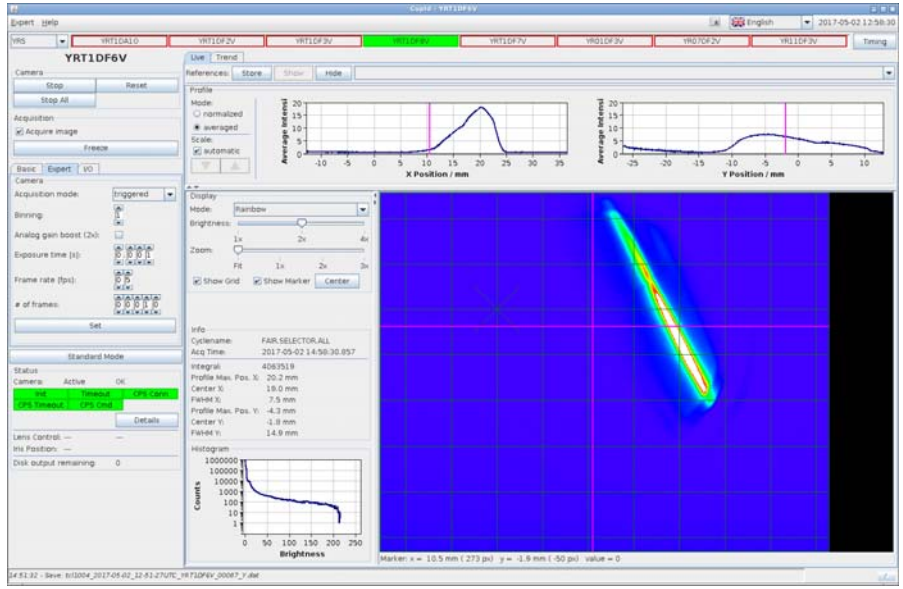
Введение в эксплуатацию

Часть инжекционной линии от локального источника до 35°-диполя



Введение в эксплуатацию

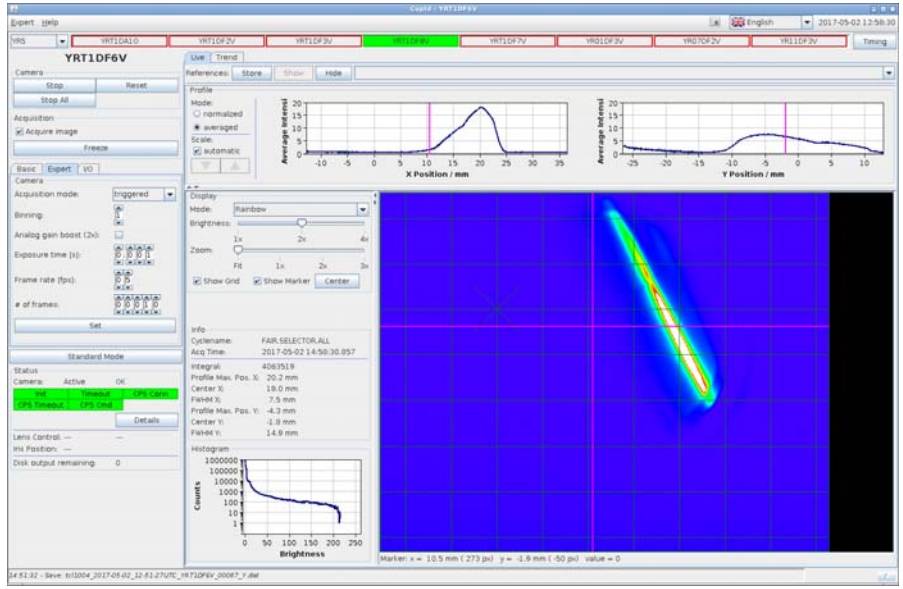
Профиль пучка на экране YRT1DF6V



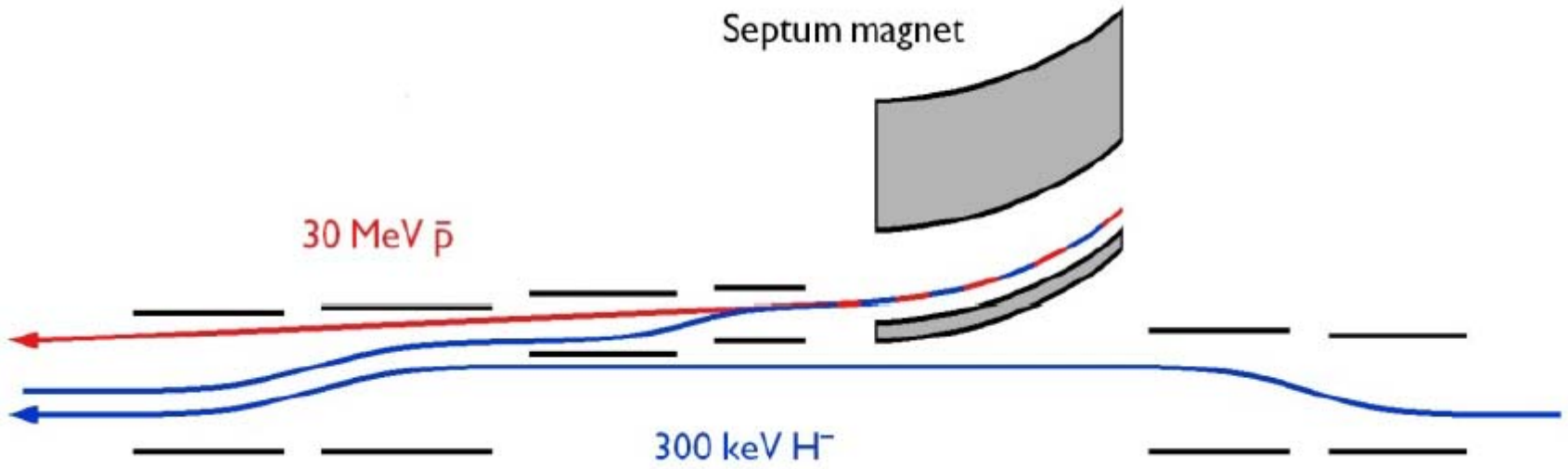
Введение в эксплуатацию

- $\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$
- NB! Electrostatic vs Magnetic quadrupoles!
- The incline depends on the voltage on the plates of the electrostatic quad

Профиль пучка на экране YRT1DF6V



Injection



Birds-eye view of the injection section:

- kicker injection of 30 MeV antiprotons (red)
- multiturn injection of 300 keV H– ions (blue, two turns are shown schematically)

Some theory

equation of motion: $x''(s) - k(s)x(s) = 0$

general solution of Hill equation

$$(1) \qquad x(s) = \sqrt{\varepsilon}\,\sqrt{\beta(s)}\cos(\psi(s)+\phi)$$

$$(2) \qquad x'(s) = -\frac{\sqrt{\varepsilon}}{\sqrt{\beta(s)}}\left\{\alpha(s)\cos(\psi(s)+\phi)+\sin(\psi(s)+\phi)\right\}$$

from (1) we get

$$\cos(\psi(s)+\phi) = \frac{x(s)}{\sqrt{\varepsilon}\,\sqrt{\beta(s)}}$$

Insert into (2) and solve for ε

$$\alpha(s) = \frac{-1}{2}\beta'(s)$$

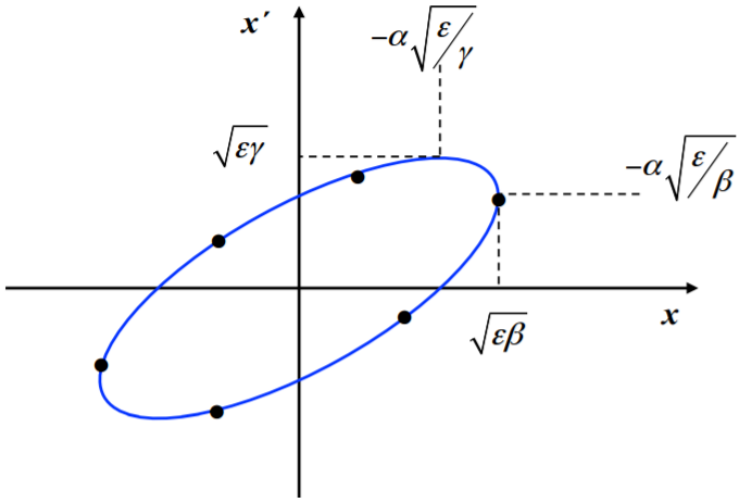
$$\gamma(s) = \frac{1+\alpha(s)^2}{\beta(s)}$$

$$\varepsilon = \gamma(s)\,x^2(s) + 2\alpha(s)x(s)x'(s) + \beta(s)\,x'^2(s)$$

* ε is a constant of the motion … it is independent of „s“
* parametric representation of an ellipse in the x x ‘ space
* shape and orientation of ellipse are given by α, β, γ

Some theory

$$x(s) = \sqrt{\varepsilon} * \sqrt{\beta(s)} * \cos(\psi(s) + \varphi)$$

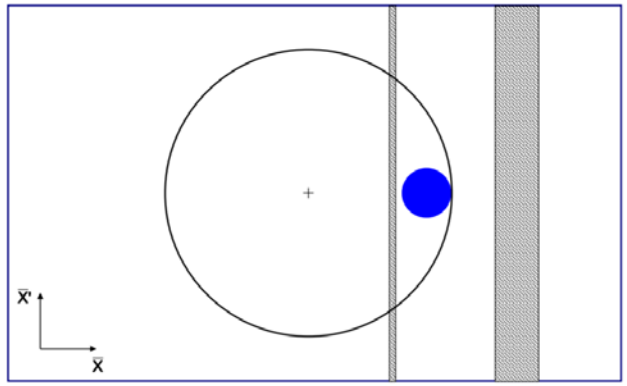


***Liouville:** in reasonable storage rings area in phase space is constant.*

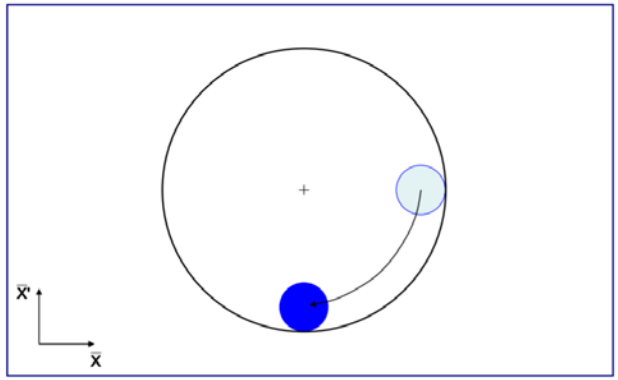
$$A = \pi * \varepsilon = const$$

- Emittance ~10π mm mrad
- Acceptance 50π mm mrad

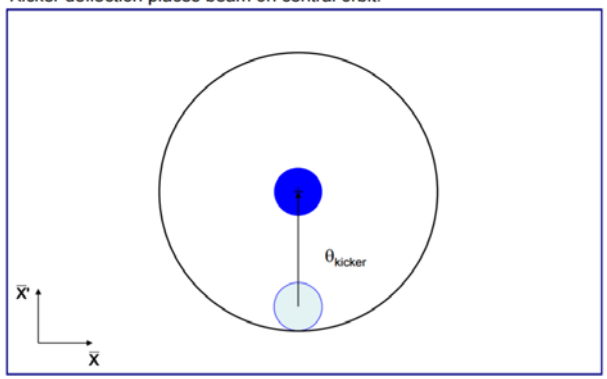
Normalised phase space at centre of idealised septum



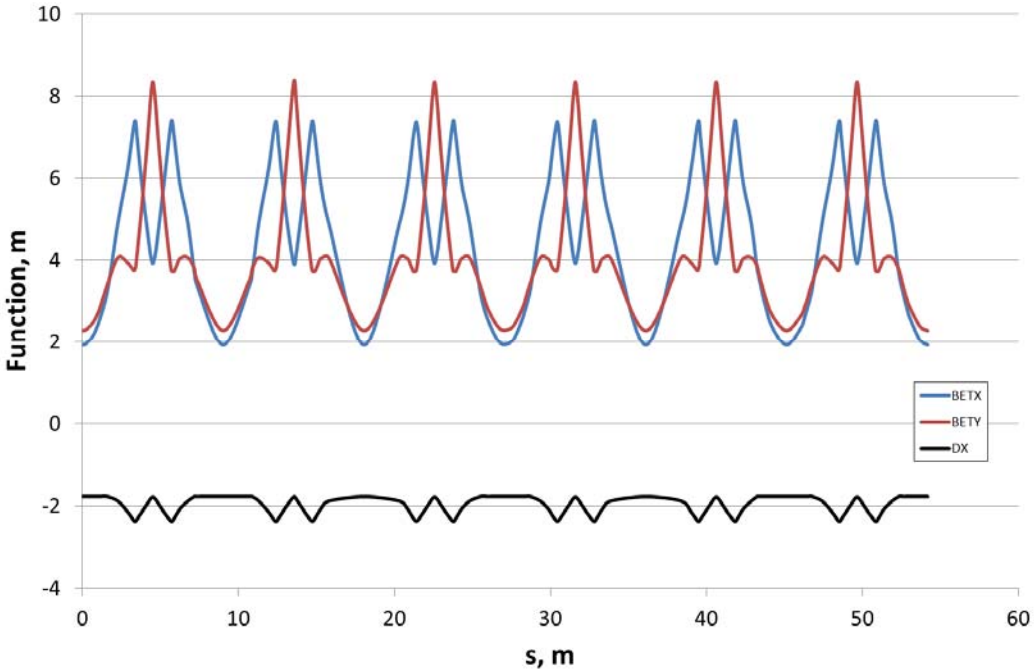
μ/2 phase advance to kicker location



Kicker deflection places beam on central orbit:



Lattice parameters

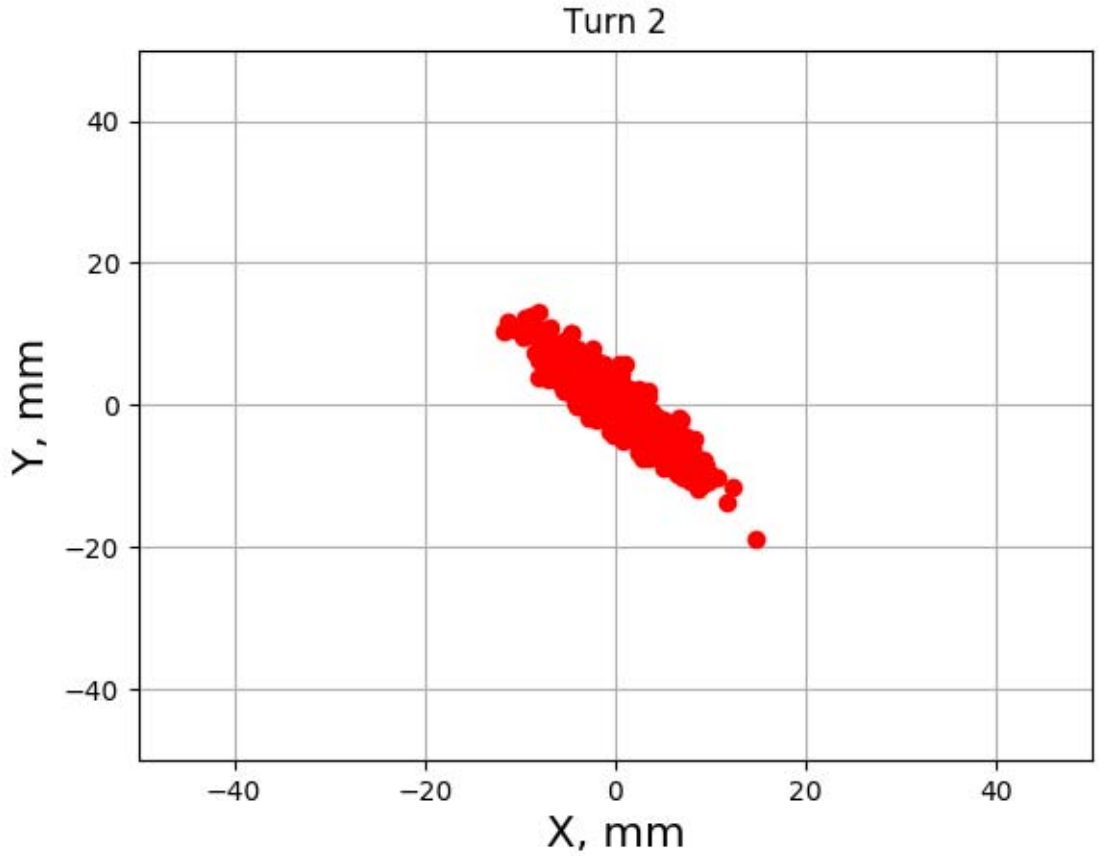


- Emittance 10e-6
- Acceptance 50e-6
- Qx=Qy=2.42
- Max dispersion: ~2.4
- dp/p ~0.01

$$\sigma=\sqrt{\varepsilon\beta}+\left(D\frac{\Delta p}{p}\right)^2$$

When injecting to a ring, the beam parameters should be matched to avoid losses and emittance blow up

What happens at injection?



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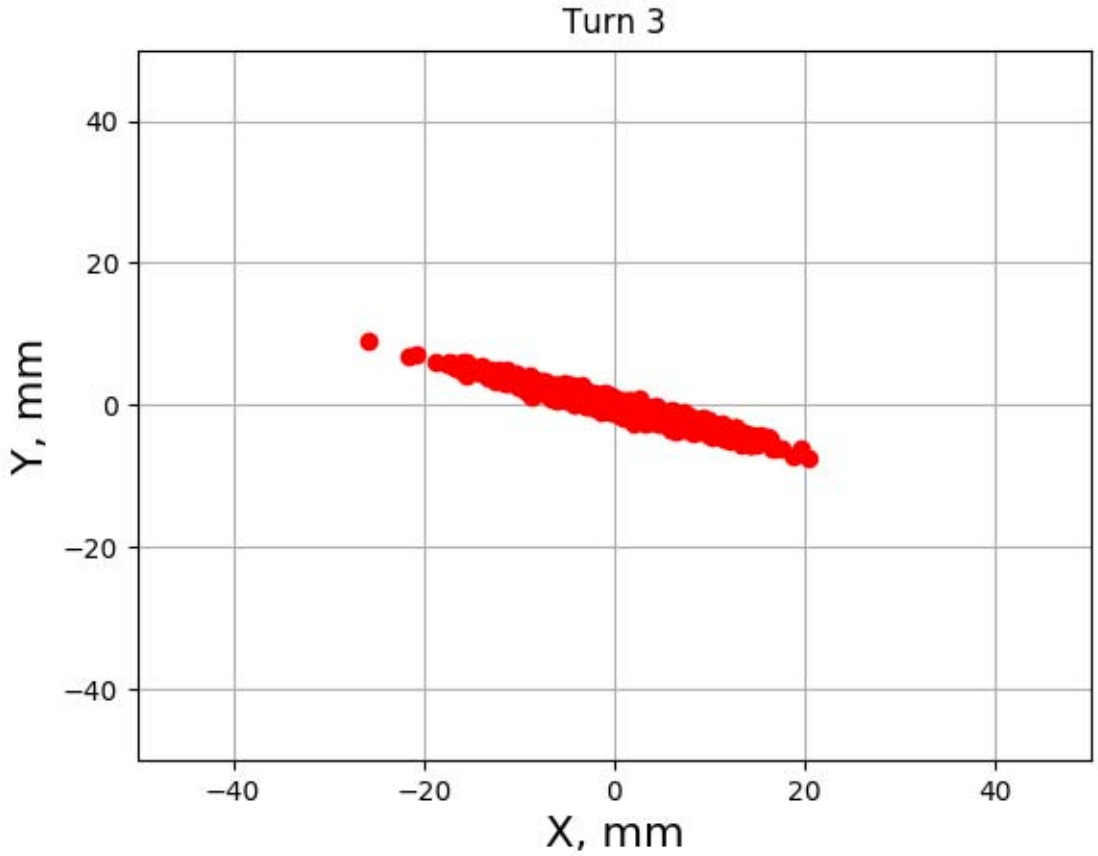

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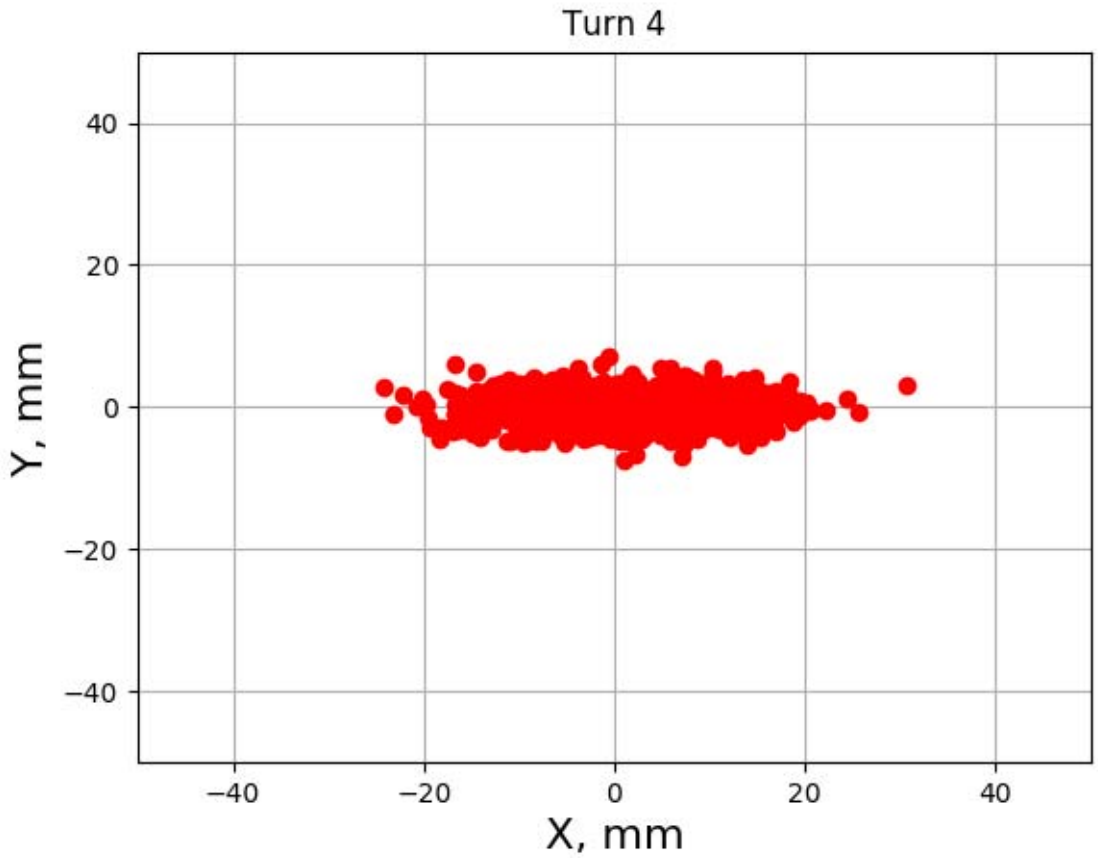

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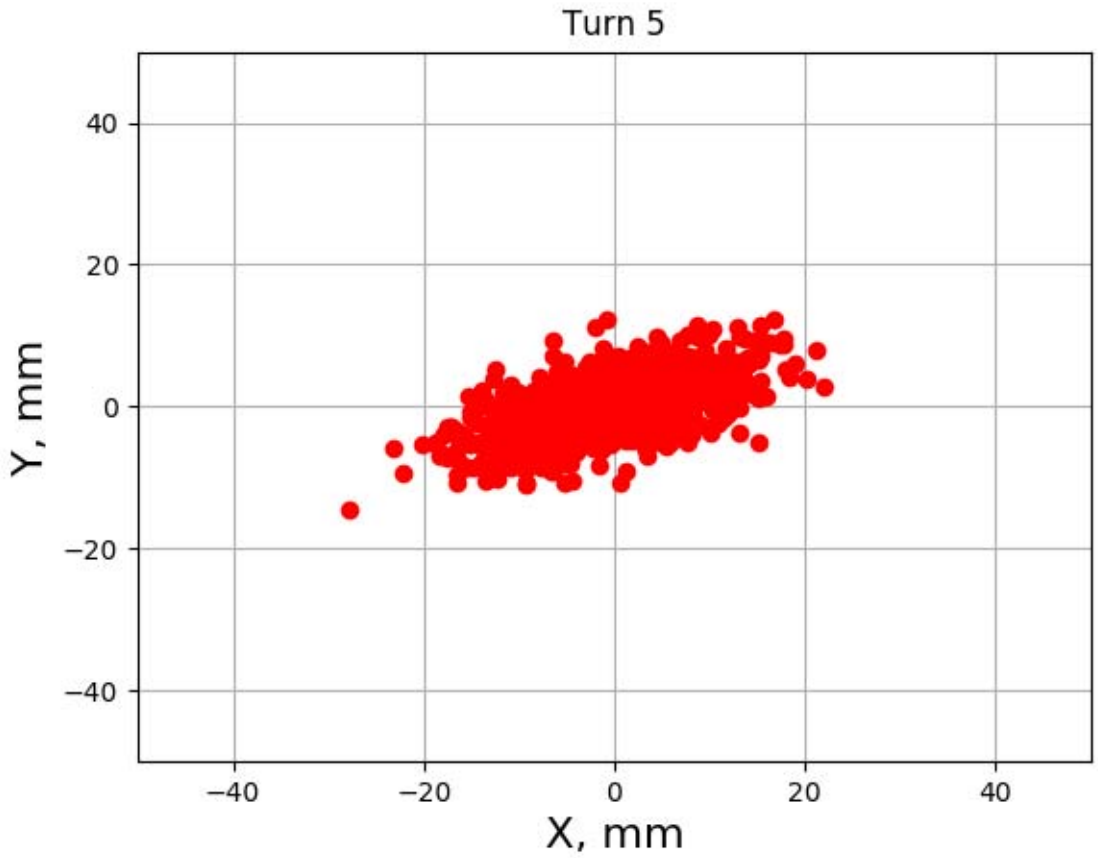

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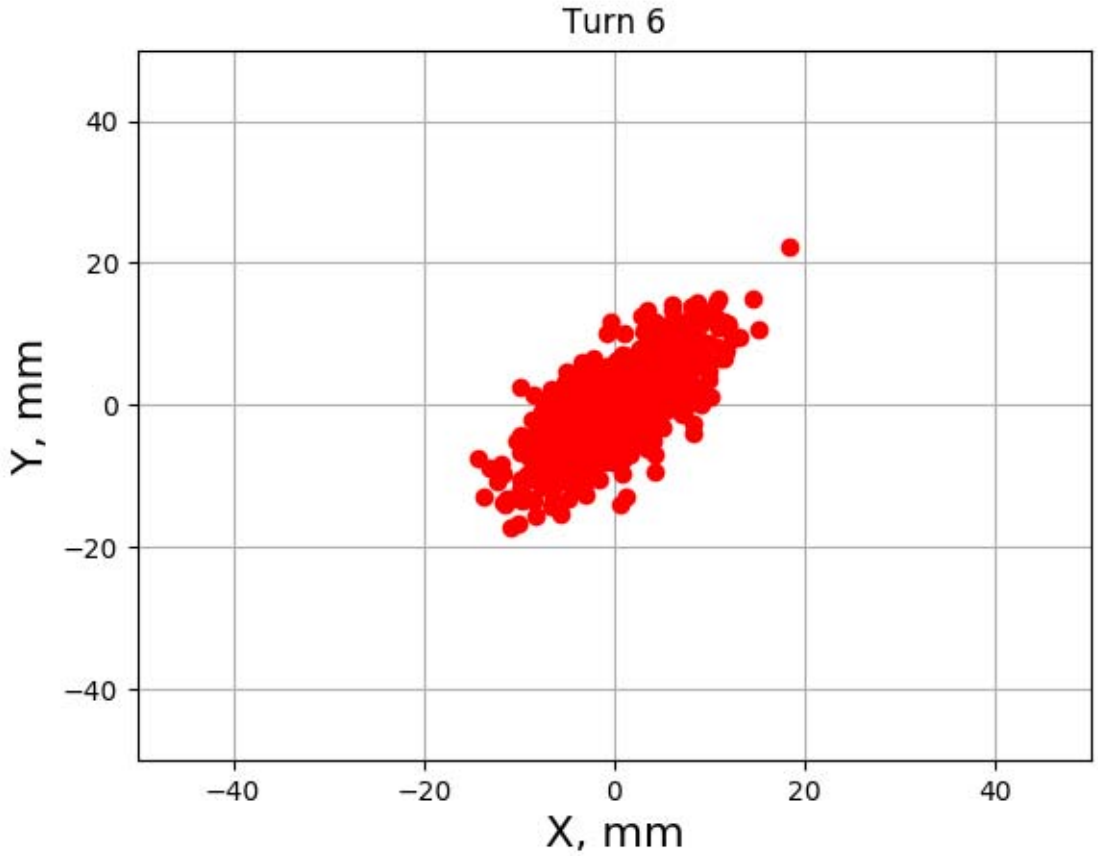

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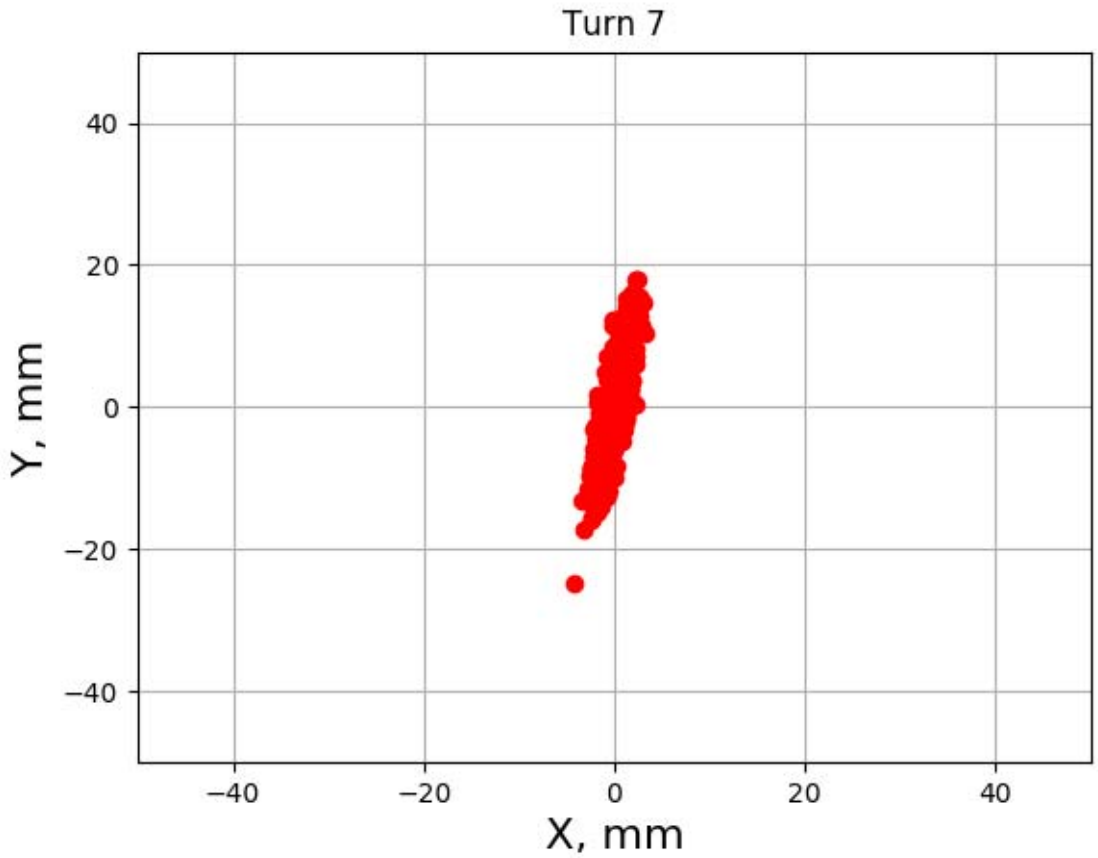

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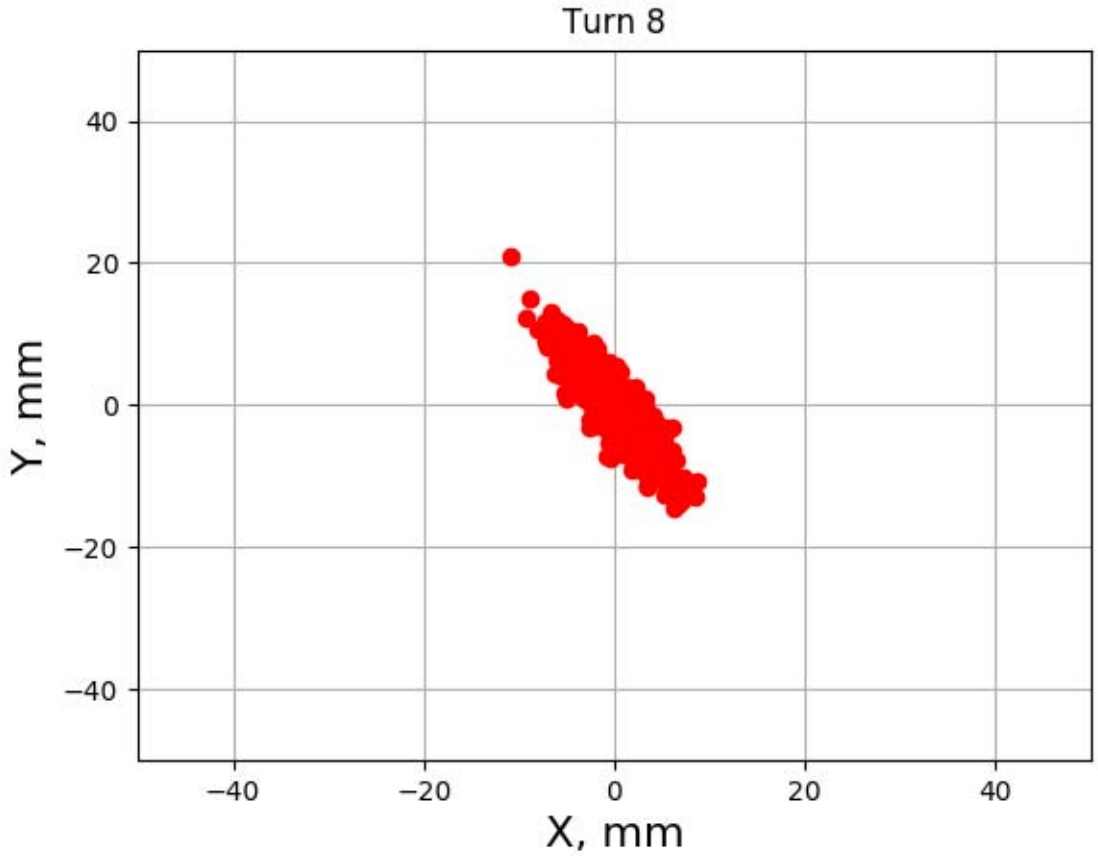

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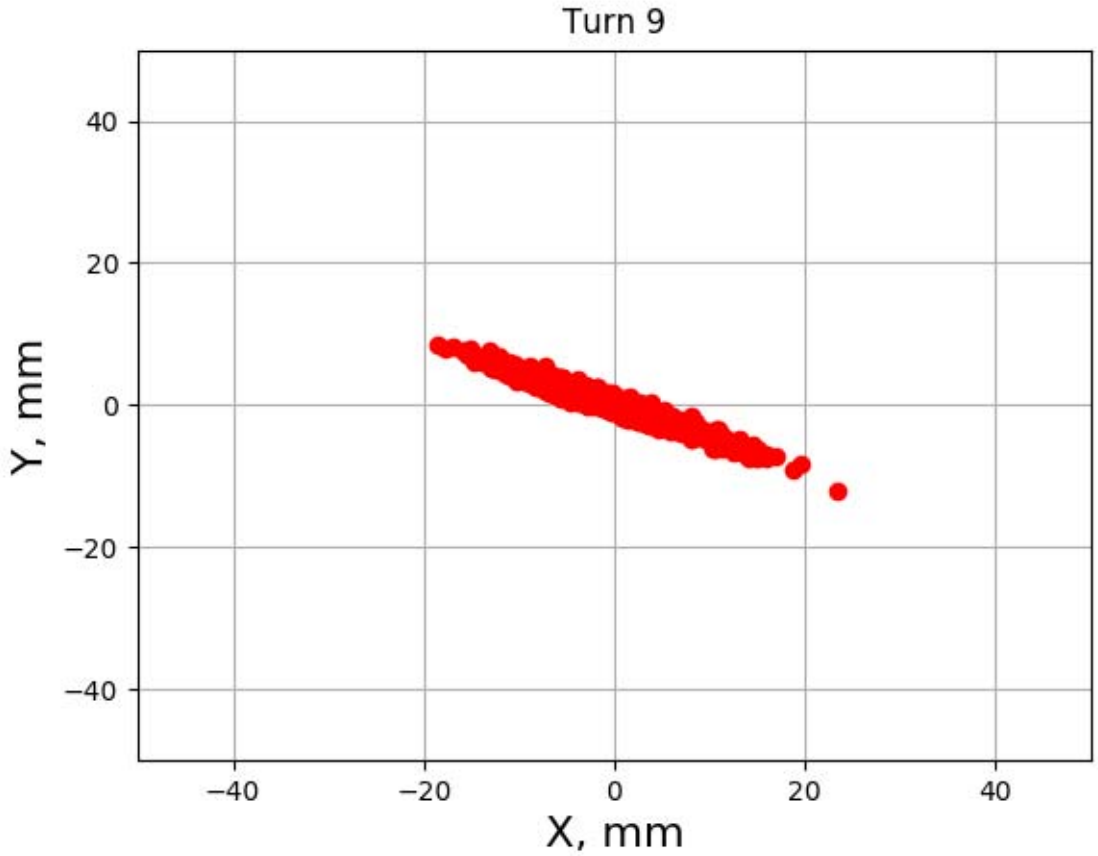

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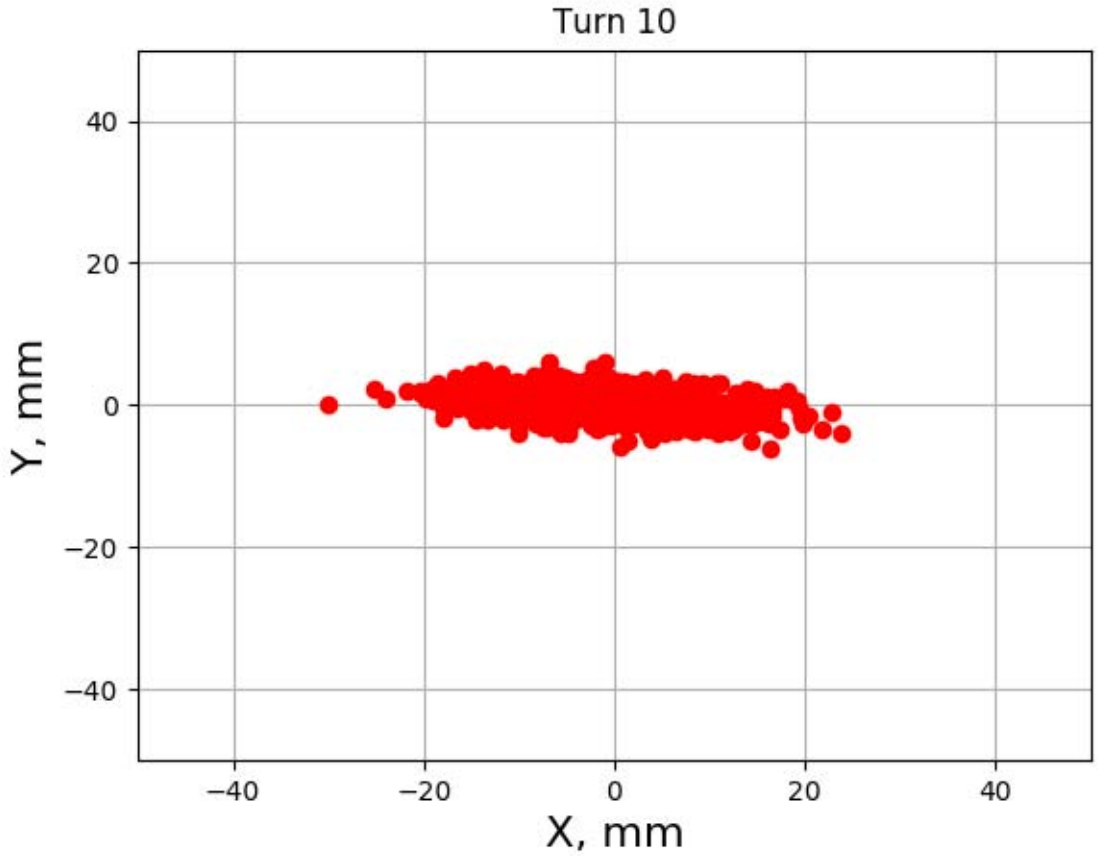
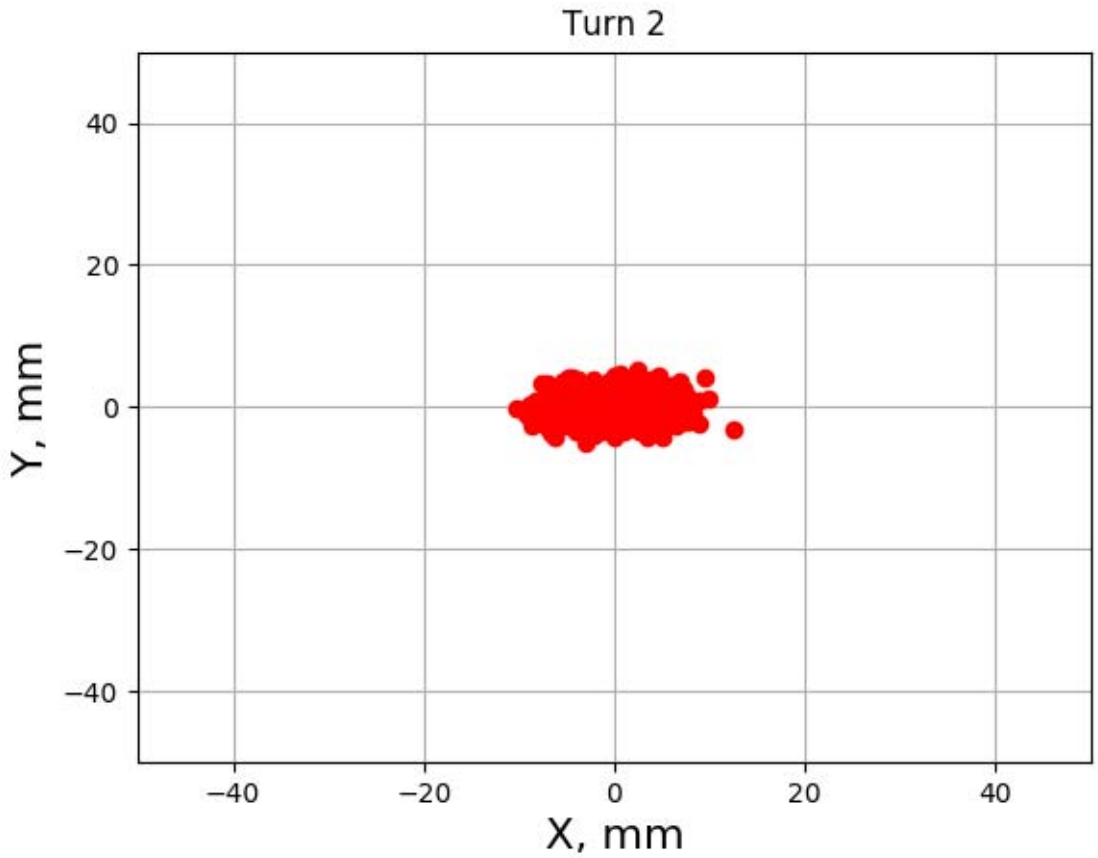


Let’s turn quadrupoles and match beta functions:



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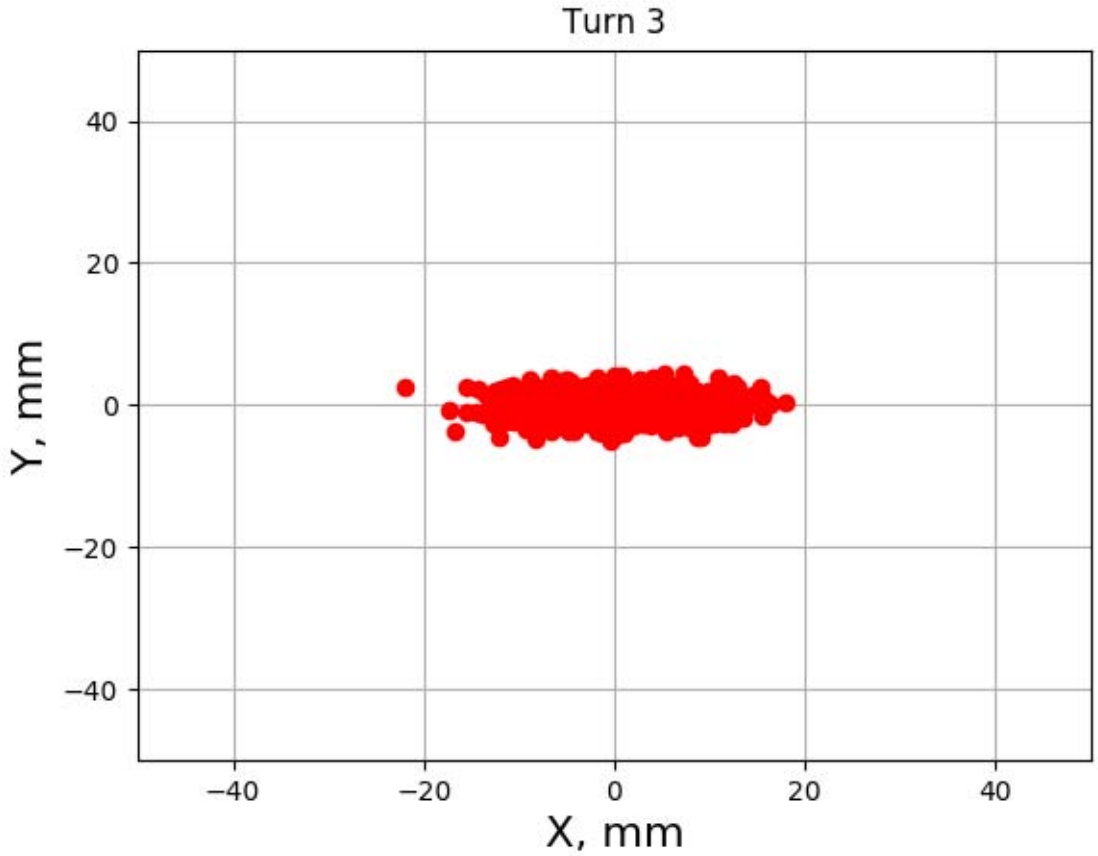

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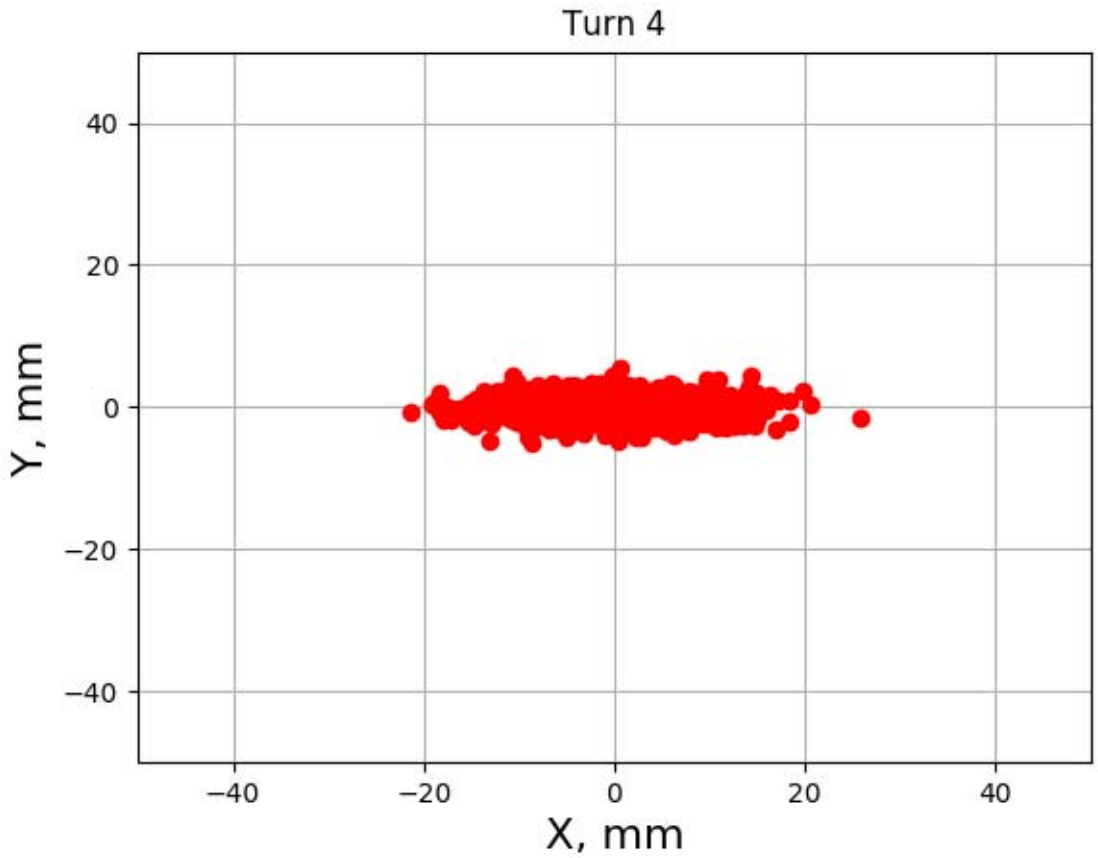

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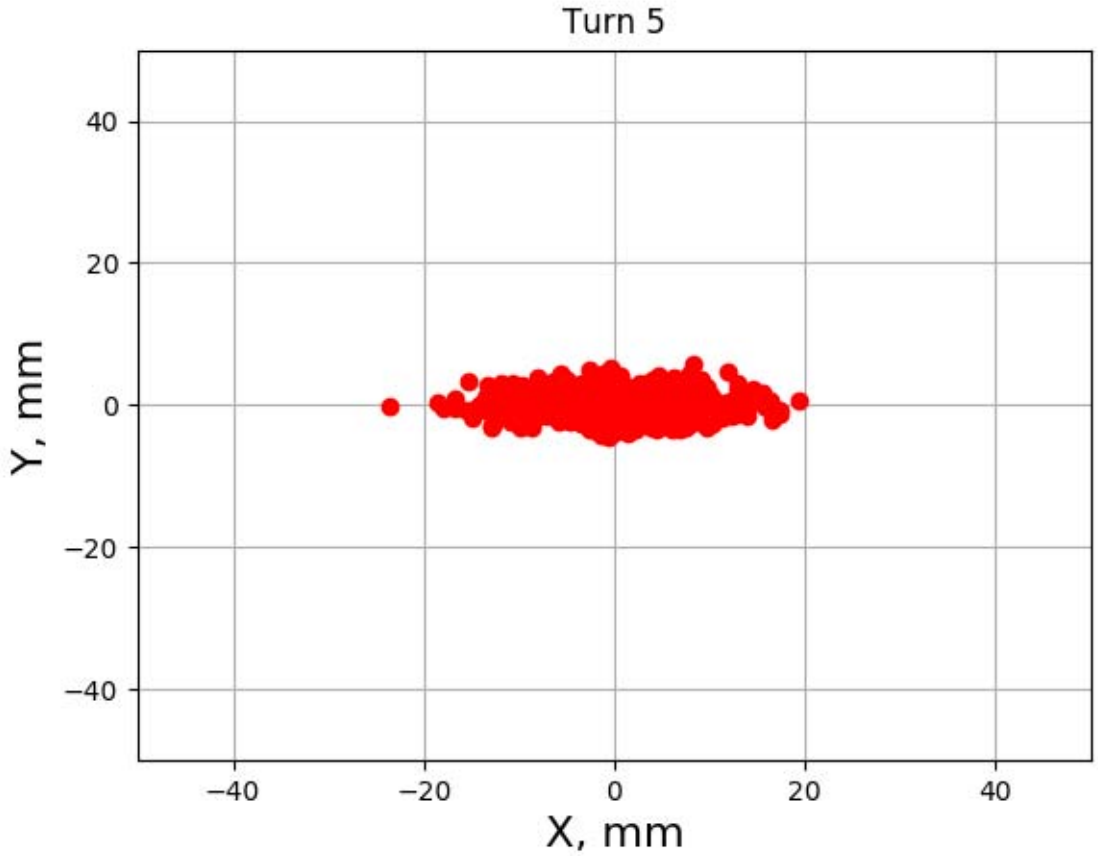

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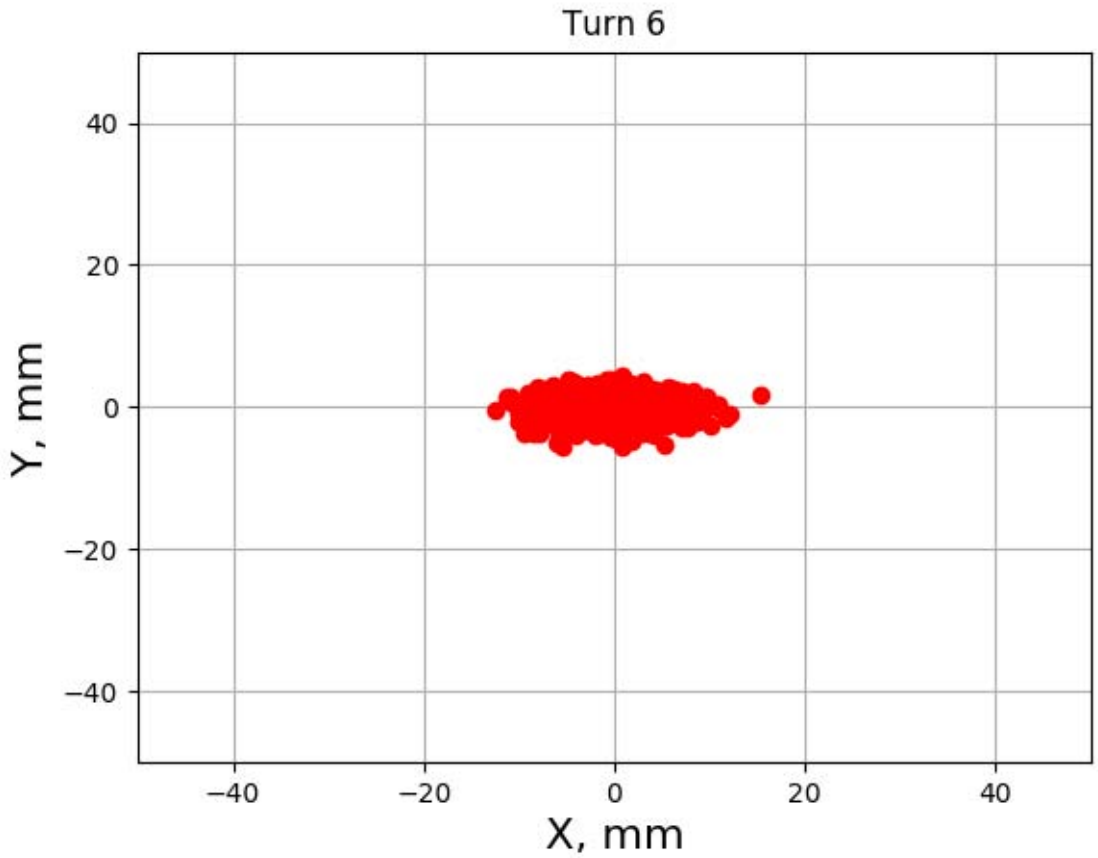

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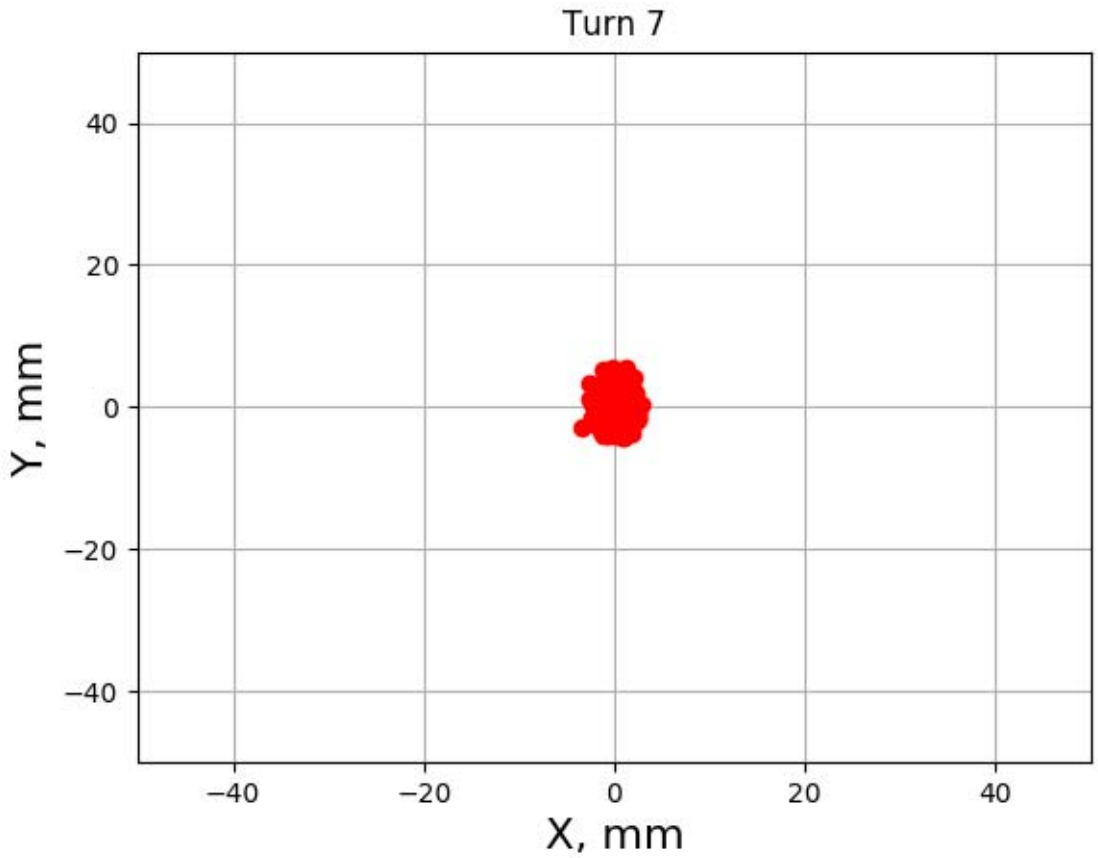

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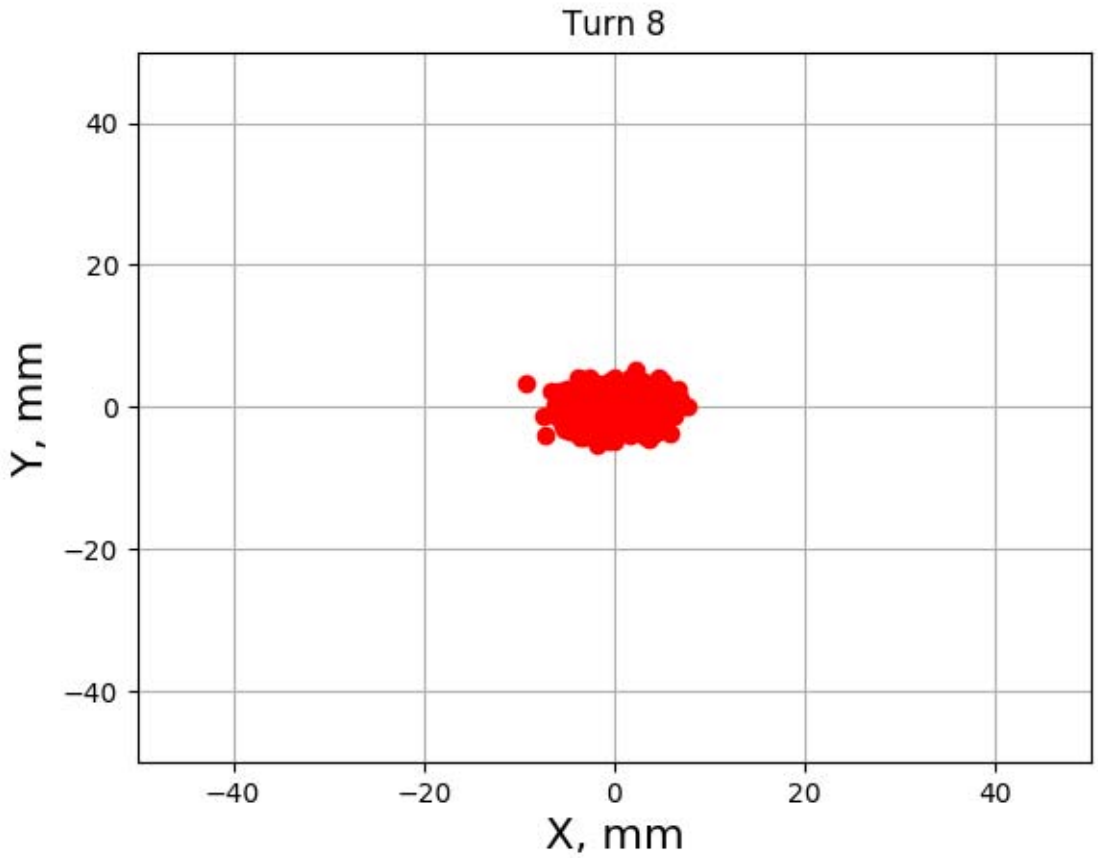

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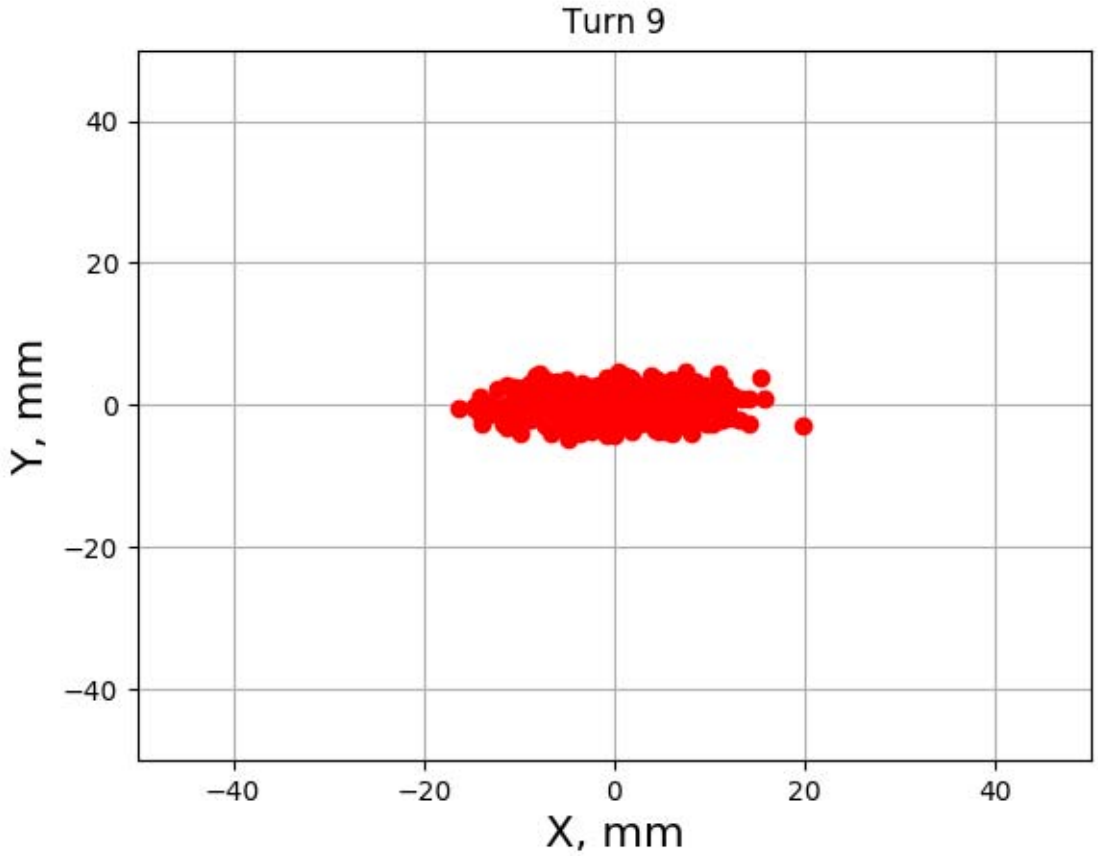
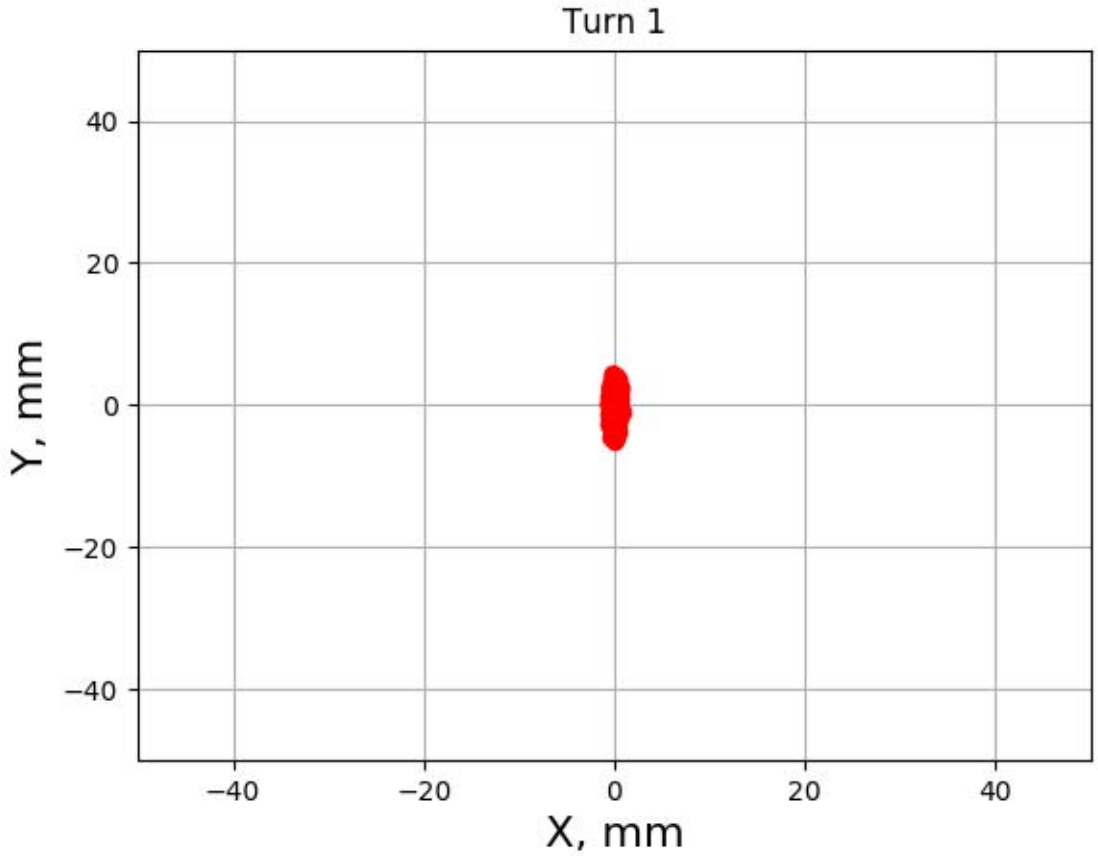


Let’s take dispersion into account:



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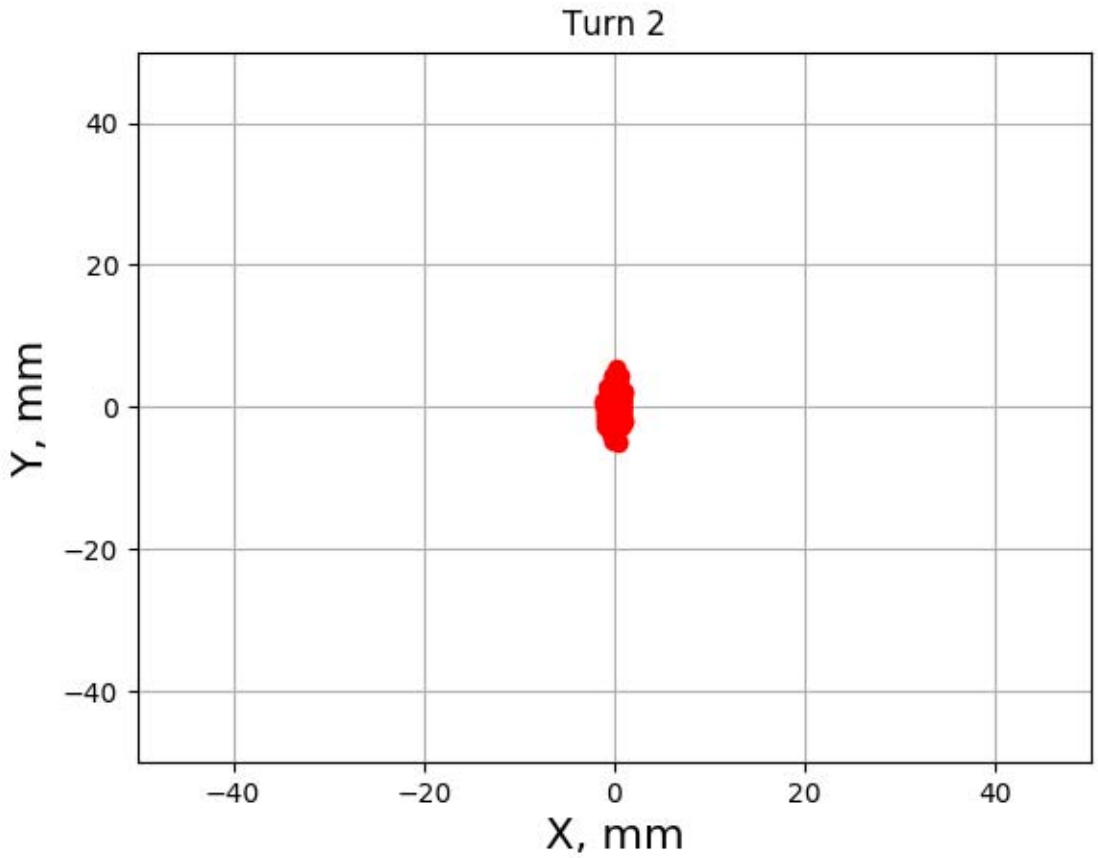

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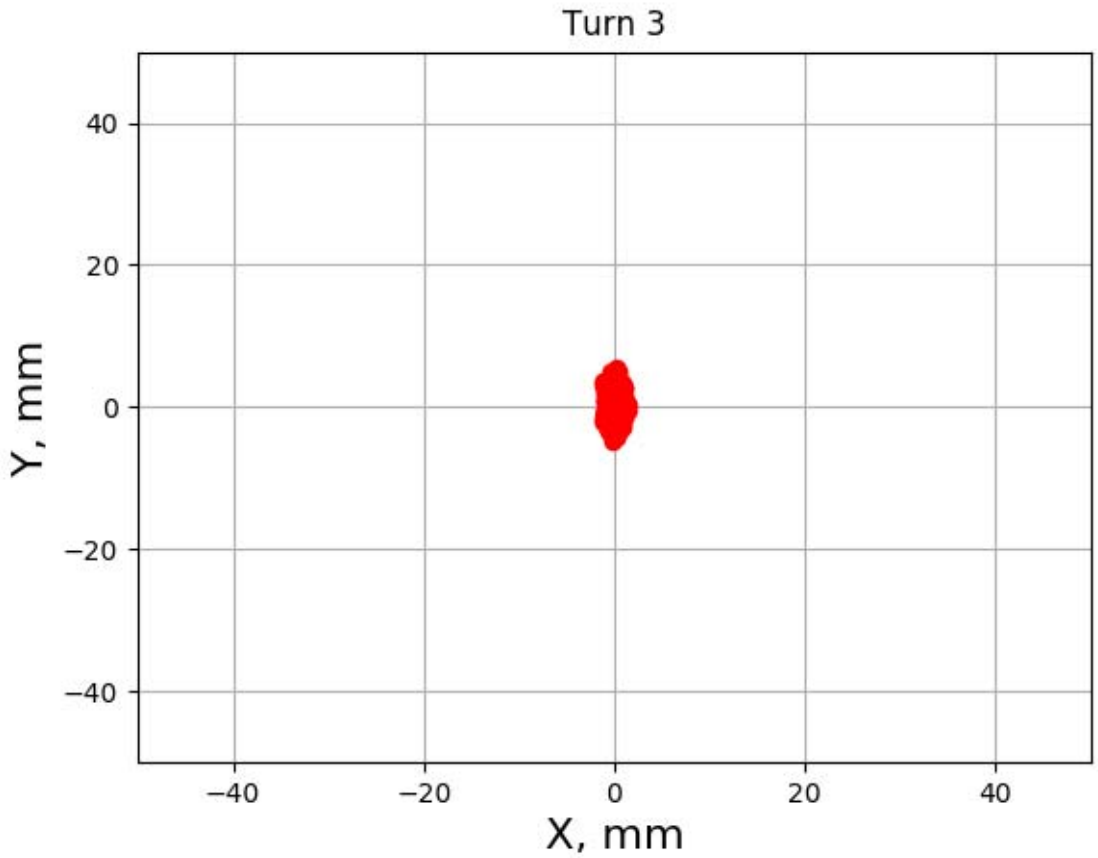

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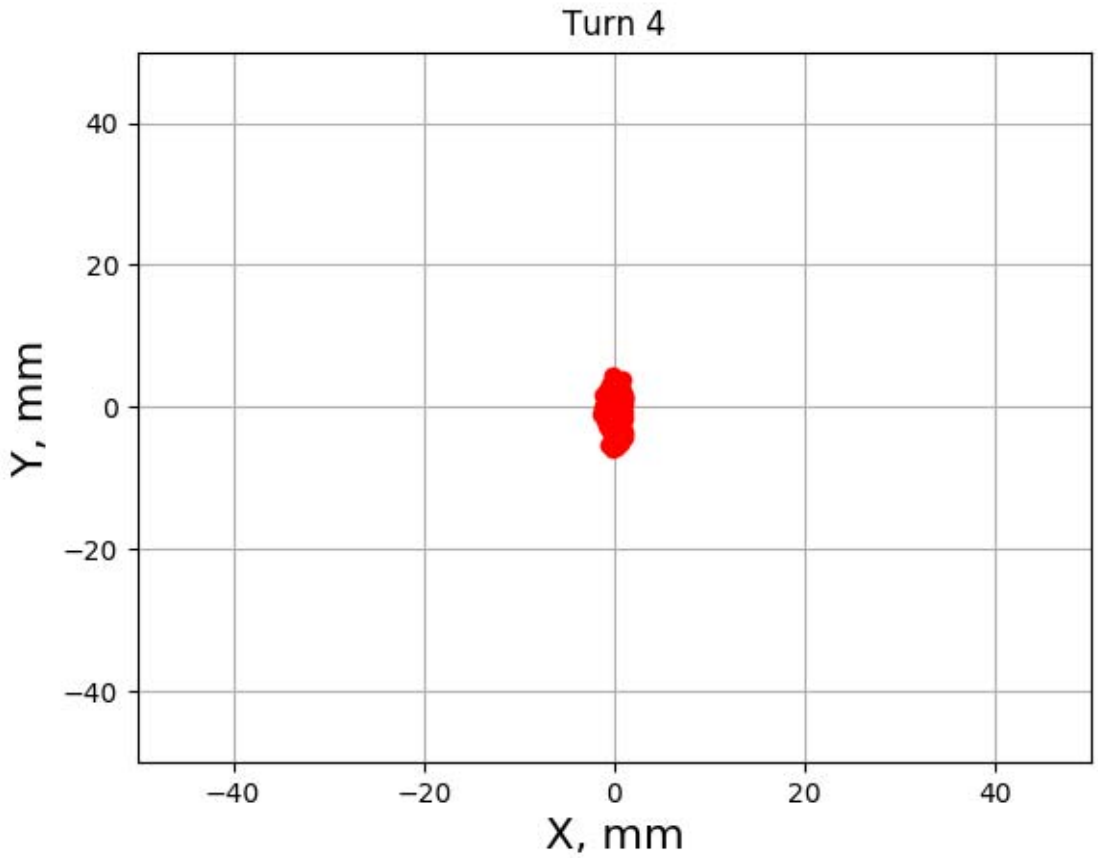

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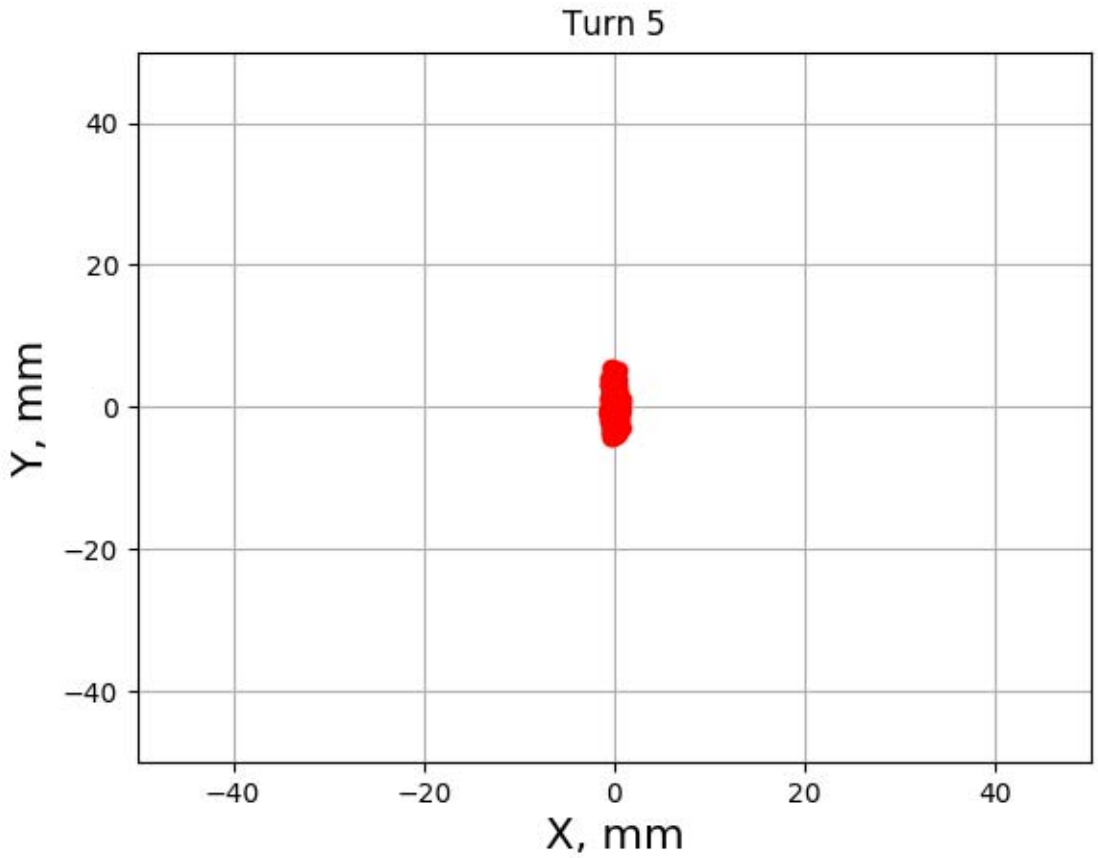
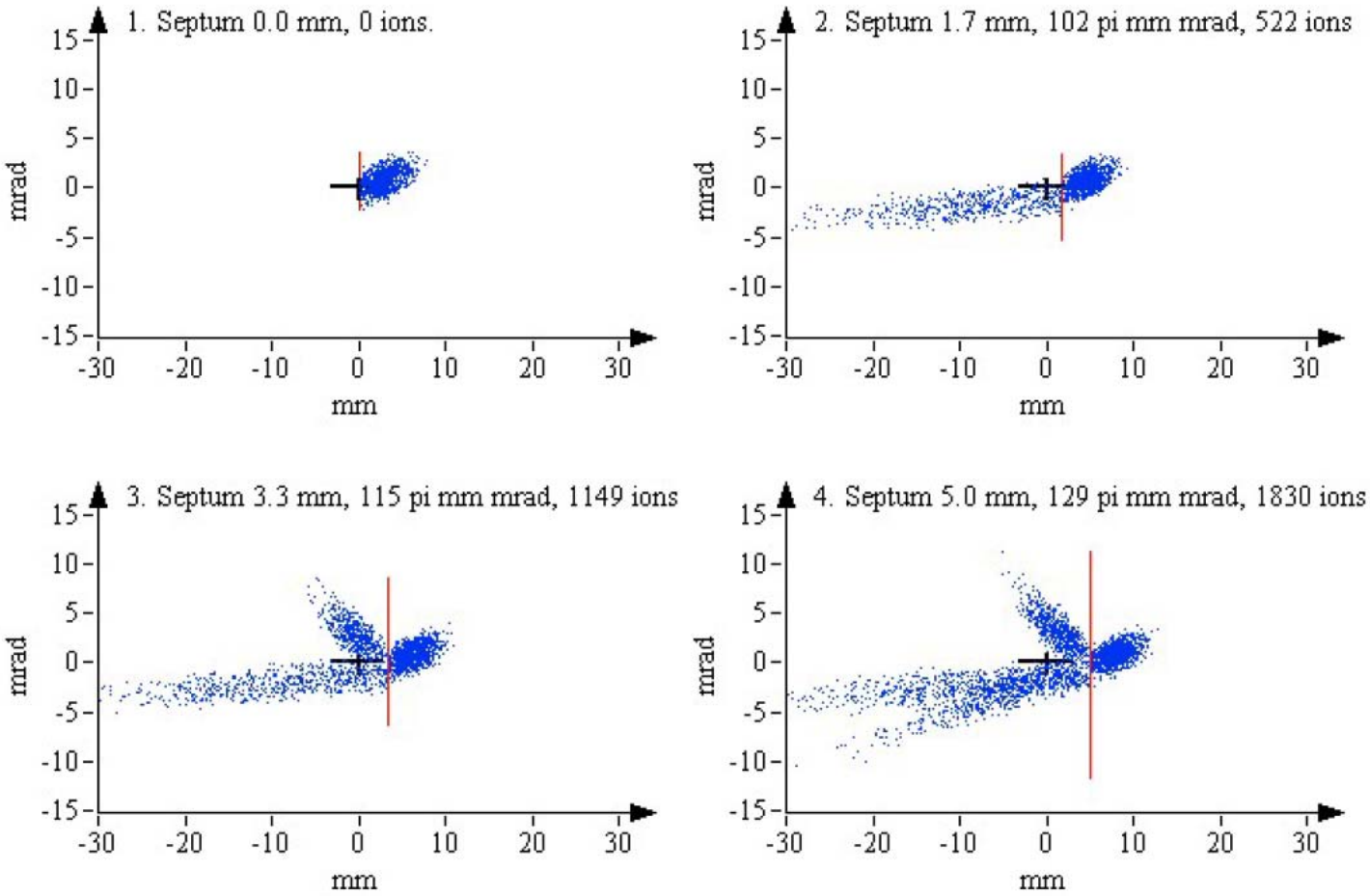


Multi-turn injection (TDR)

Controlled with electrostatic bumpers that create and orbital bump decreasing with time



Beam time results

- We managed to repeat the results from last beam time: second turn on BPMs in front of the Cooler.
- A lot of modification in the new control system was made and tried out.
- Ramping of the ring magnets was implemented.
- Next beam time is planned for 28th of August for another 3 weeks.

Plans for summer and know bugs

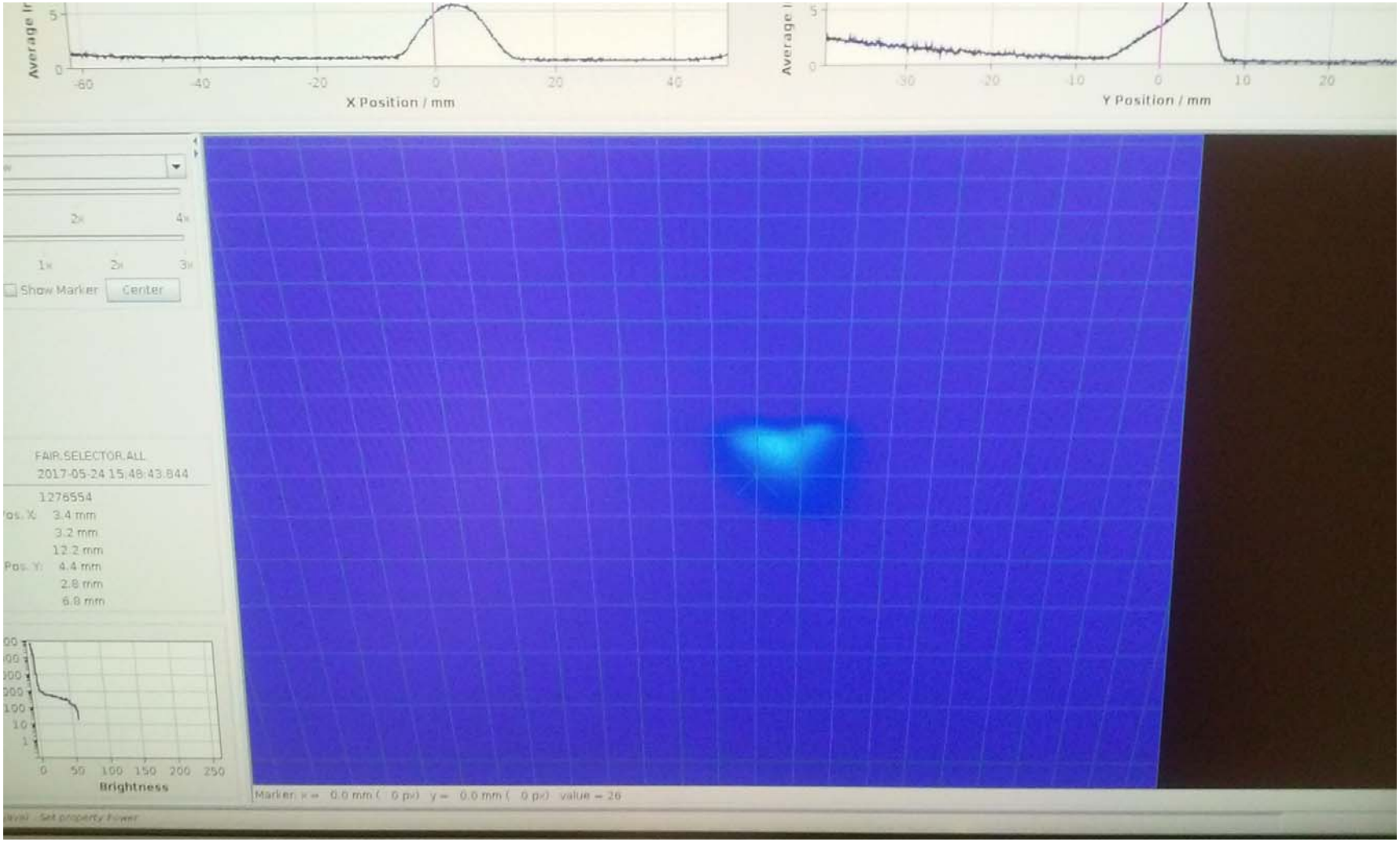
- Vacuum:
  - The next baking session of the Ring sections 5-8 starts on 10th of July.
- There is a significant offset between input and output values for dipoles in the ring.
- Half of the ring steerers power supplies are not operational.
- Electrostatic quadrupoles will be rotated 45° this week
- Hardware commissioning is ongoing

Conclusions: Life is not easy, but we are optimistic

Commissioning is ongoing

Спасибо за внимание!

Mystery


X Position / mm
Y Position / mm
Show Marker
Center
FAIR.SELECTOR.ALL
2017-05-24 15:48:43.844
1276554
Pos. X: 3.4 mm
3.2 mm
12.2 mm
Pos. Y: 4.4 mm
2.8 mm
6.8 mm
Brightness