FERMILAB-SLIDES-24-0067-AD

The IOTA/FAST Facility: Status, Performance, Upgrades

Aleksandr Romanov on behalf of the IOTA/FAST team

IOTA/FAST Collaboration Meeting, 12 March 2024

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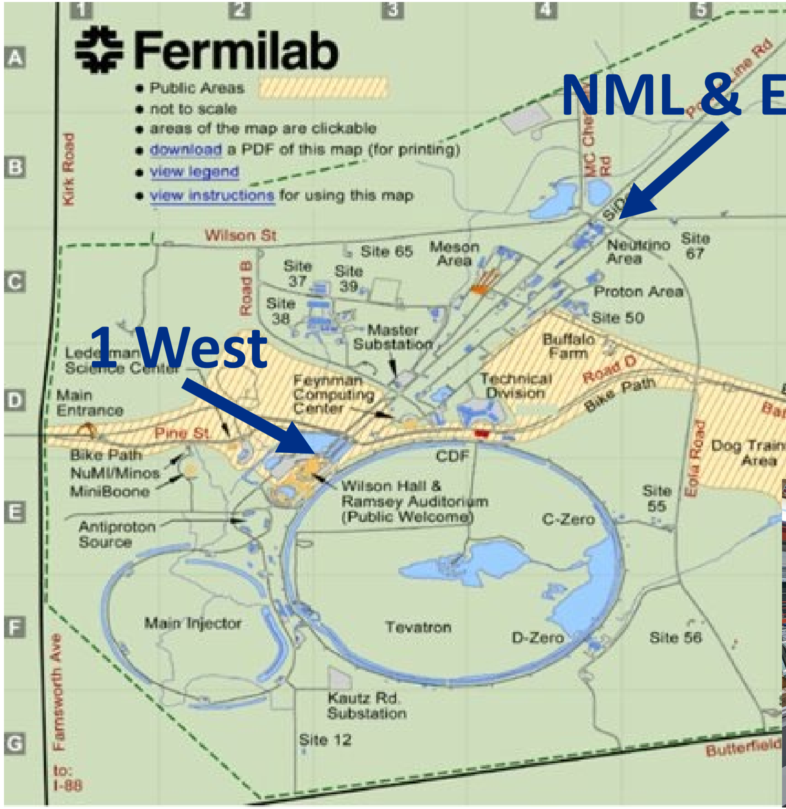
Locations



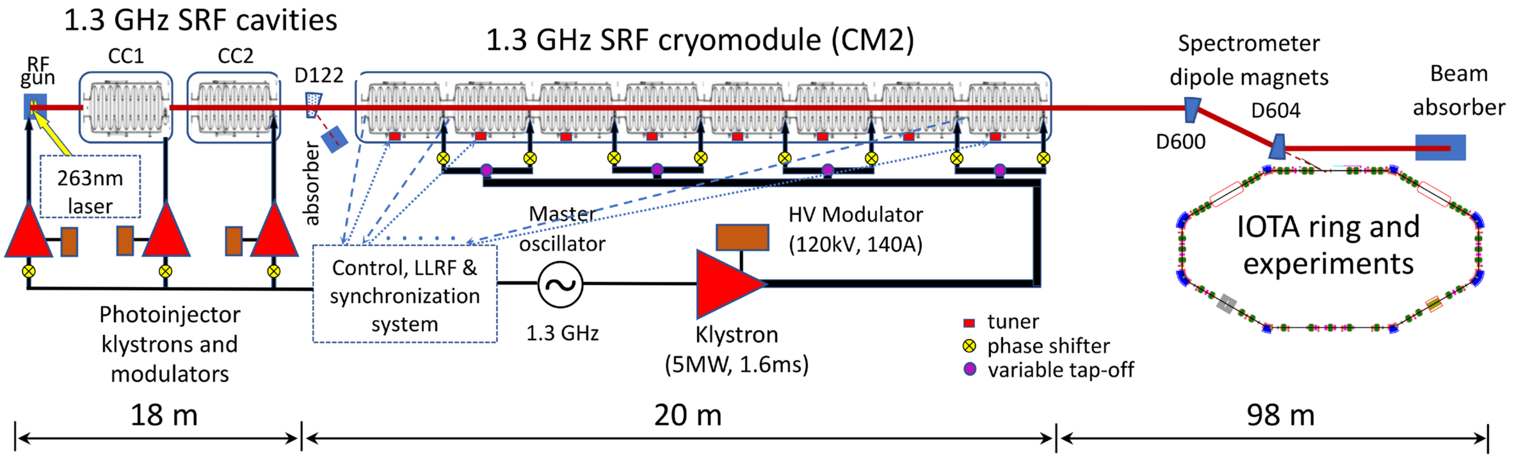
NML & ESB
Lab 7
1 West
Fermilab
Public Areas
not to scale
areas of the map are clickable
download a PDF of this map (for printing)
view legend
view instructions for using this map
NORTH
Kirk Road
Wilson St
Road B
Site 65
Meson Area
Site 37
Site 39
Site 38
Master Substation
Neutrino Area
Site 67
Proton Area
Site 50
Town Road
Fermilab Village
Lederman Science Center
Main Entrance
Feynman Computing Center
Buffalo Farm
Technical Division
Road D
Bike Path
Batavia Rd
Pine St.
Bike Path
NuMI/Minos
MiniBoone
CDF
Wilson Hall & Ramsey Auditorium (Public Welcome)
Antiproton Source
C-Zero
Eola Road
Dog Training Area
Site 55
Main Injector
Tevatron
D-Zero
Site 56
Kautz Rd. Substation
Site 12
Farnsworth Ave
to: I-88
East

NML
ESB

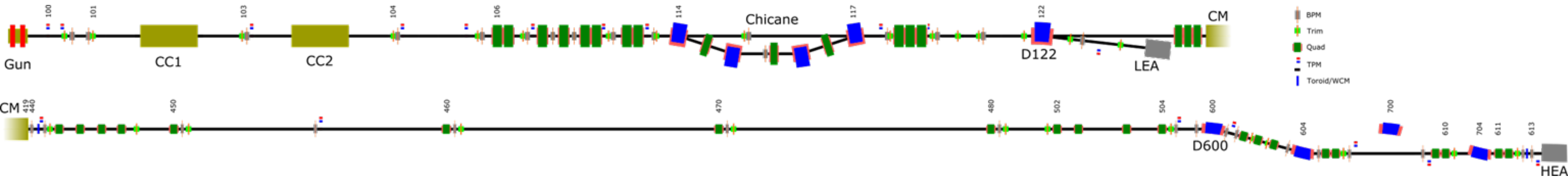
NML

IOTA/FAST accelerator complex

- FAST is a superconducting linac with photoinjector
- IOTA is a small storage ring
  - FAST can act as an injector of electrons for IOTA

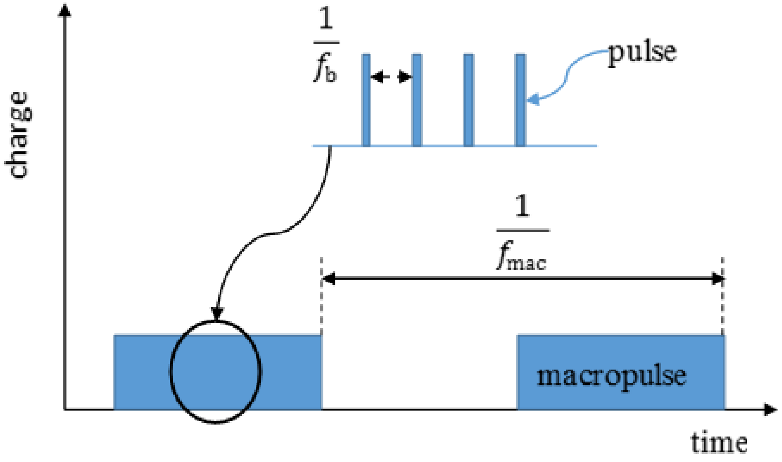


Electron Linac



The electron injector comprises a number of components, including a 5 MeV electron RF photoinjector, a 25-meter-long low energy (≤40 MeV) beamline and a ~100-meter-long high energy (≤300 MeV) beamline.

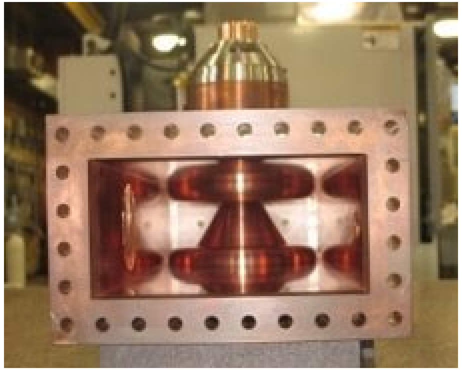
Parameter	*Value*
Beam Energy	20 MeV – 300 MeV
Bunch Charge	< 10 fC – 3.2 nC per pulse
Bunch Train (Macropulse)	0.5 – 9 MHz for up to 1 ms (3000 bunches, 3 MHz nominal)
Bunch Train Frequency	1 – 5 Hz
Bunch Length	Range: 0.9 – 70 ps (Nominal: 5 ps)
Bunch Emittance 50 MeV, 50 pC/pulse	Horz: 1.6 ± 0.2 µm Vert: 3.4 ± 0.1 µm

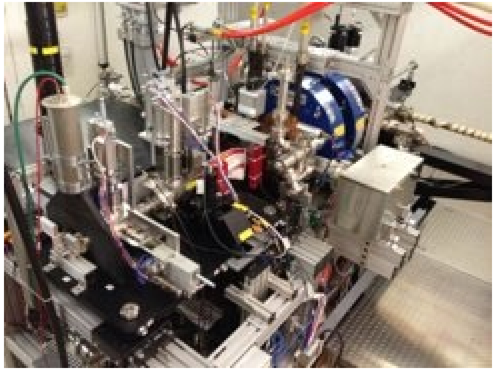


JINST 12 T03002—2017, S. Antipov, D. Broemmelsiek, D. Bruhwiler, et al

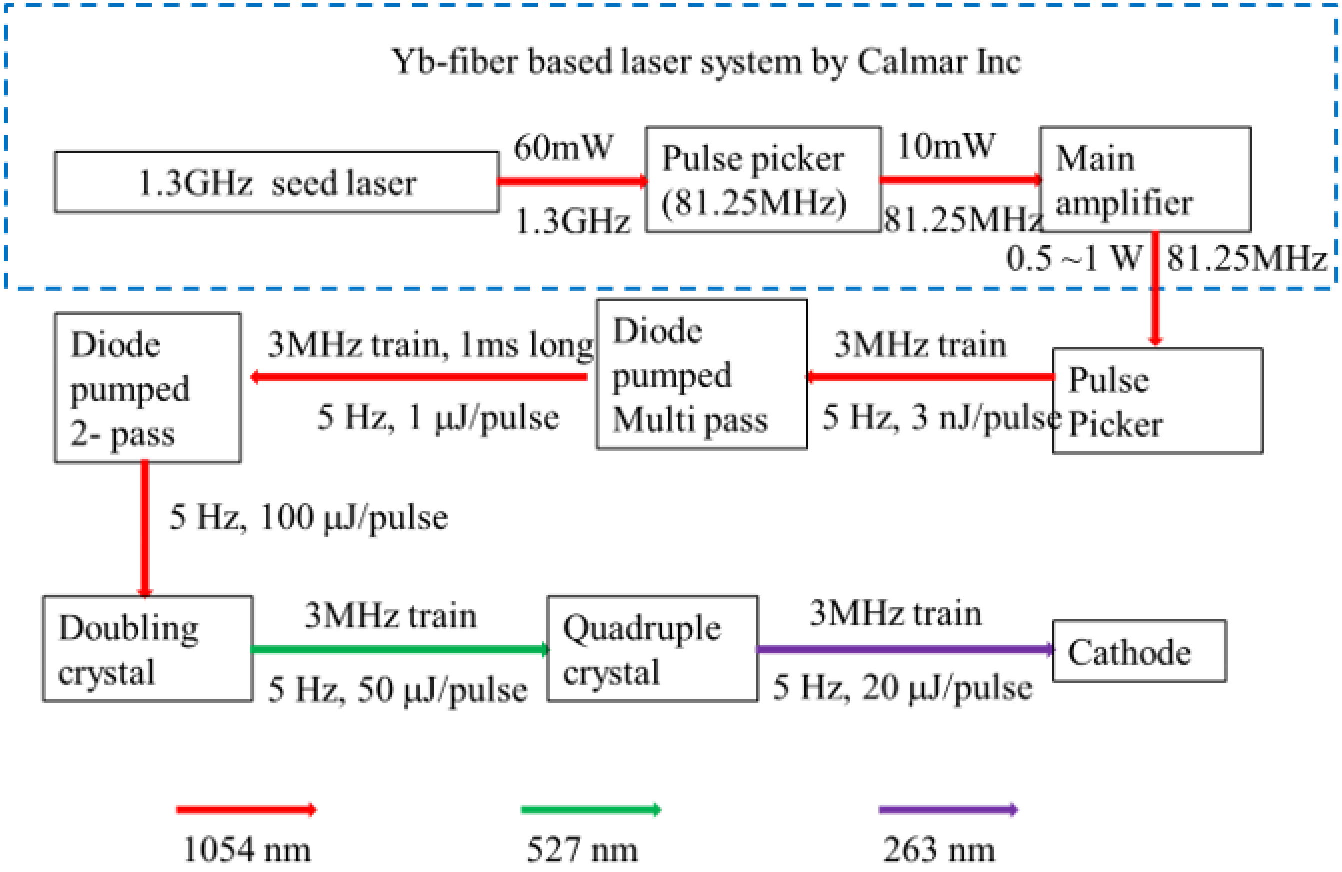
Electron Gun

- 1.3 GHz, normal conducting, 1.5 cell copper cavity (DESY/PITZ design)
- Up to 45 MV/m accelerating field at the cathode; requires 5 MW klystron; 20 KW average power at full ILC pulse length and repetition rate
- Cs2Te photocathode excited by 263 nm UV laser
- 2 identical solenoids for emittance compensation
- Coaxial RF waveguide coupler
- 3 cavities have been fabricated
  - 1 by DESY – completed and shipped to Fermilab; 1st spare
  - 3 by Fermilab – 1 shipped to KEK; 1 completed and commissioned at NML; 1 as 2nd spare





Laser

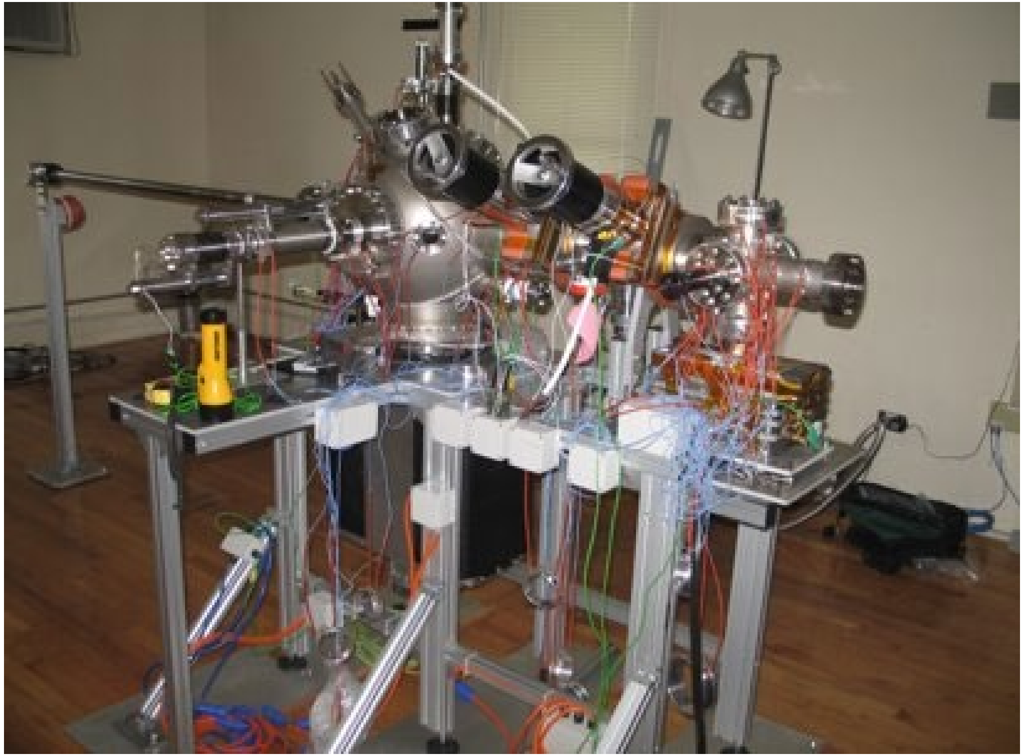


Yb-fiber based laser system by Calmar Inc
1.3GHz seed laser
60mW
1.3GHz
Pulse picker (81.25MHz)
10mW
81.25MHz
Main amplifier
0.5 ~1 W
81.25MHz
Pulse Picker
3MHz train
5 Hz, 3 nJ/pulse
Diode pumped Multi pass
3MHz train, 1ms long
5 Hz, 1 μJ/pulse
Diode pumped 2- pass
5 Hz, 100 μJ/pulse
Doubling crystal
3MHz train
5 Hz, 50 μJ/pulse
Quadruple crystal
3MHz train
5 Hz, 20 μJ/pulse
Cathode
1054 nm
527 nm
263 nm

Laser Capabilities/Upgrades

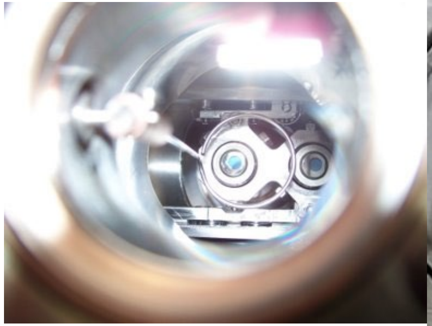
- Nominal laser bunch train is at 3MHz. 9MHz is tested inside laser room.
  - Higher frequency is also possible with the current laser configuration. However, the pulse energy is expected to drop linearly with the frequency change.
- Current laser is operated at 1Hz.
  - 5Hz operation is tested for the system as well.
- Seed laser is at 1.3GHz.
  - In principle it is possible to pick 2 bunches separated at integer number of spacing(~720ps) to do pump probe measurement.
- Have demonstrated pulse shaping (IPAC2015 MOPMA043)

Cathode Preparation

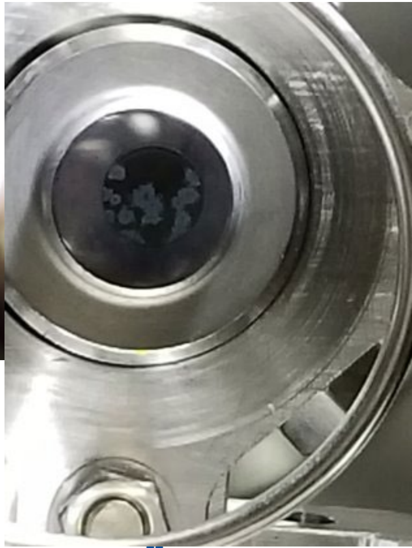


Cathode preparation chamber at Lab 7

- Cathode chambers were fabricated at INFN Milano, Daniele Sertore
  - Preparation chamber
  - Transport chamber
  - Transfer chamber



Newborn
vs.
6 year old



Capture Cavities

- Two 1.3 GHz 9-cell SRF cavities
  - CC1 at 17 MV/m (down from 27)
  - CC2 at 14 MV/m (down from 17)
- Max beam energy of up to ~ 35 MeV

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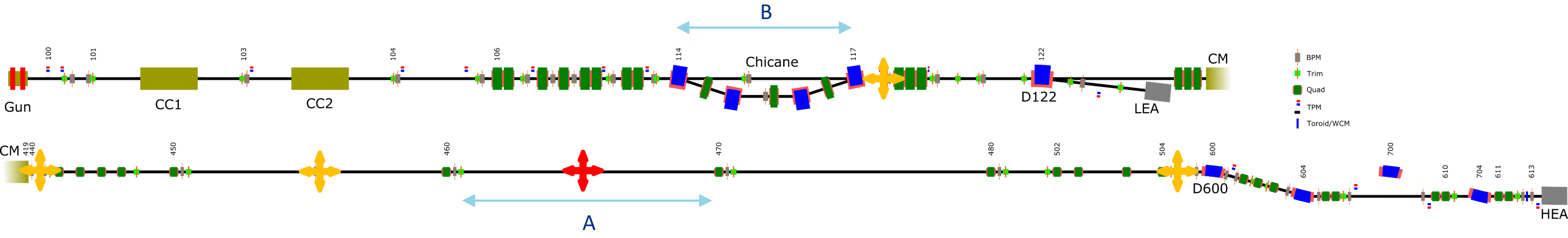
High Energy Beamline

- CM commissioned. ILC goal reached. 250 plus MeV for beam.
- Currently we did 500 bunches at 3MHz maximum.
- Several beam line locations are available for R&D.
- Possible space for more R&D.
  - Undulator
  - High energy chicane

Linac Dimensions



A – 16m in 8 x 2m vacuum segments

B – 2.8m

 – Instrumentation Crosses

 – New Instrumentation Cross for ~32m spacing after cryomodule

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FAST Linac Instrumentation

- BPMs
  - Capable of doing bunch by bunch monitoring at 3MHz
  - Can handle charge from 50pC to 3.2nC with different gain setting
- Transverse profile monitors
  - Live display
- Longitudinal profile measurement
  - Streak camera
  - Ceramic gap (non-interruptive)
- Charge measurement
  - Faraday cup, Wall current monitor
- HOM detector with Capture cavity and CM

IOTA With Electrons

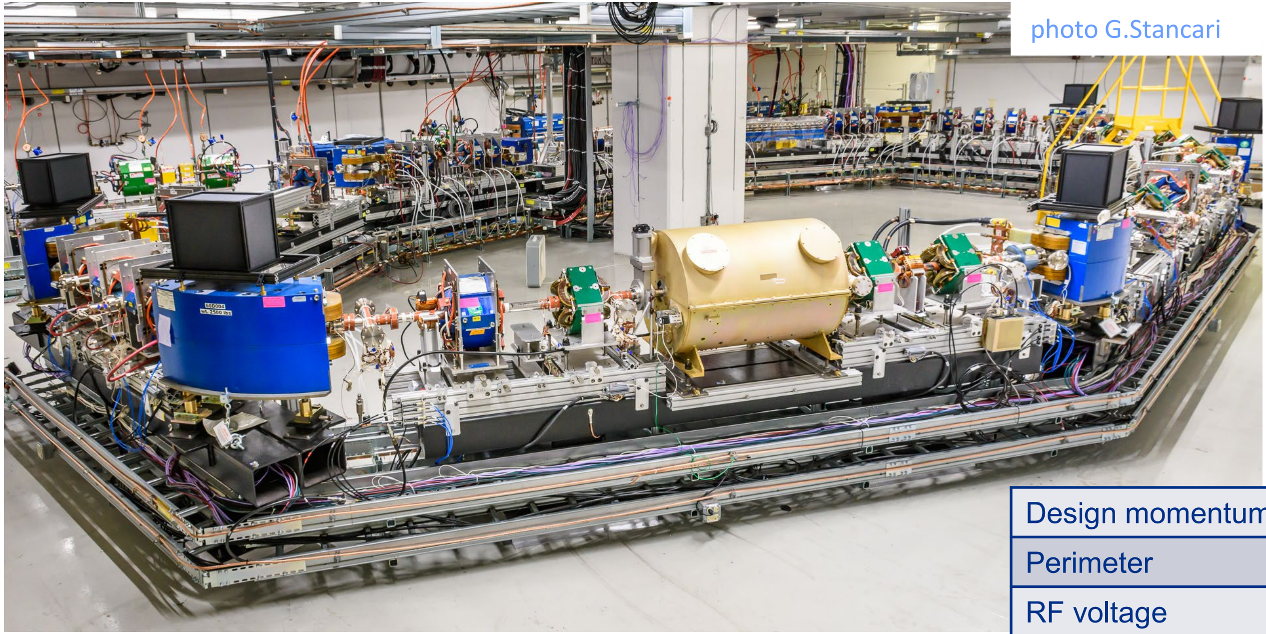
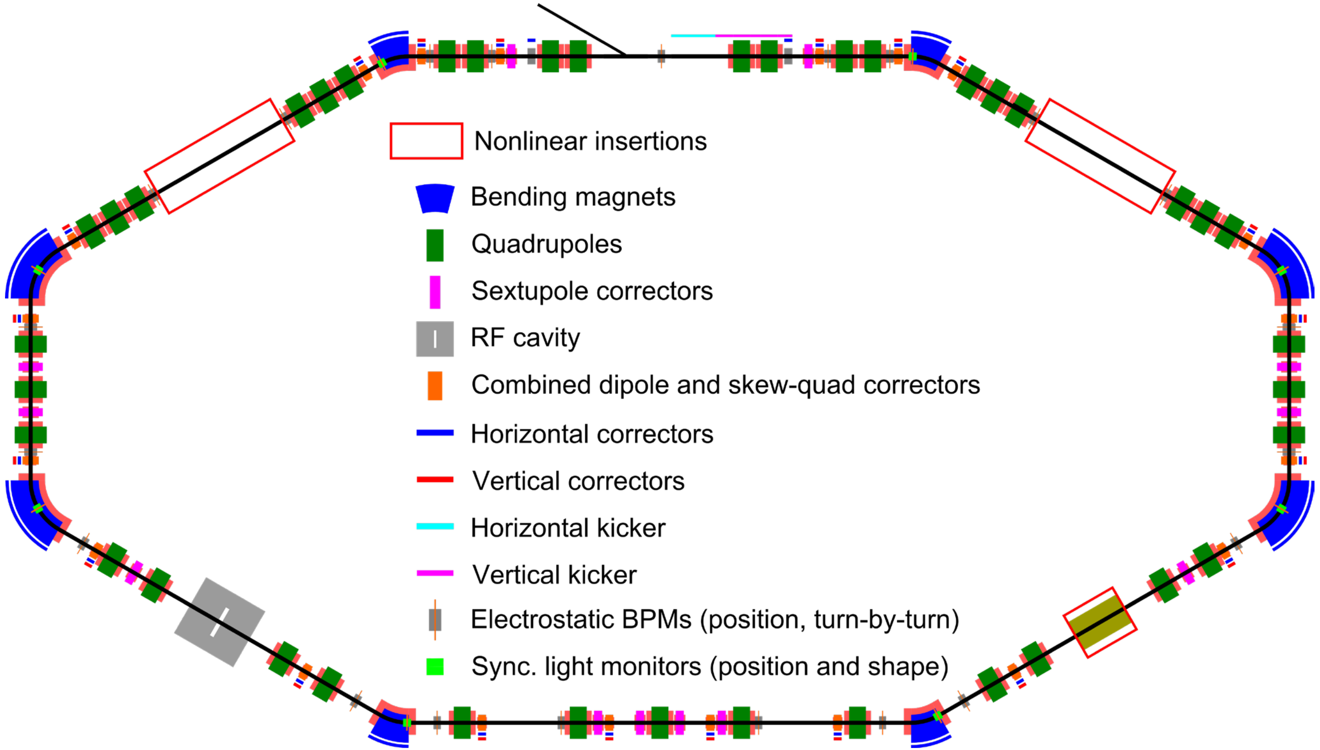


photo G.Stancari

Design momentum	50-150 MeV
Perimeter	40 m
RF voltage	300 V
RF frequency	30 MHz
3 Experimental sections	2x180 cm, 1x150 cm
Main vacuum chamber aperture (R)	25 mm
Lambertson and kickers aperture (R)	20 mm

IOTA Layout


Nonlinear insertions
Bending magnets
Quadrupoles
Sextupole correctors
RF cavity
Combined dipole and skew-quad correctors
Horizontal correctors
Vertical correctors
Horizontal kicker
Vertical kicker
Electrostatic BPMs (position, turn-by-turn)
Sync. light monitors (position and shape)

IOTA Main Components

<table>
<tr><td colspan="2">Lambertson magnet</td><td>1</td><td>Horizontal, injection in vertical plane</td></tr>
<tr><td colspan="2">Kickers</td><td>1 hor. & 1 vert.</td><td>Horizontal for studies only</td></tr>
<tr><td colspan="2">Main dipoles</td><td>4x60 deg & 4x30 deg</td><td>Powered in series with Lambertson</td></tr>
<tr><td colspan="2">Quads</td><td>39</td><td>Powered in pairs with individual shunts</td></tr>
<tr><td rowspan="4">Trims</td><td>Hor.</td><td>8</td><td>In main dipoles</td></tr>
<tr><td>Vert.</td><td>2</td><td>For injection bump</td></tr>
<tr><td>Hor.</td><td>20</td><td rowspan="3">Combined correctors</td></tr>
<tr><td>Vert.</td><td>20</td></tr>
<tr><td colspan="2">Skew-quads</td><td>20</td></tr>
<tr><td colspan="2">Pickups</td><td>21</td><td>Turn-by turn position</td></tr>
<tr><td colspan="2">Sync. light monitors</td><td>8</td><td>Shape and position</td></tr>
<tr><td colspan="2">RF</td><td>1</td><td>Dual frequency</td></tr>
<tr><td colspan="2">Solenoid</td><td>1</td><td>For electron and McMillan lenses</td></tr>
<tr><td colspan="2">Sextupoles</td><td>12</td><td>In six families</td></tr>
<tr><td colspan="2">DCCT</td><td>1</td><td>Precision calibrated DC beam current</td></tr>
<tr><td colspan="2">Wall current monitor</td><td>1</td><td>Bunch currents and longitudinal shape</td></tr>
</table>

IOTA Capabilities with Electrons

- Commissioned momentum between 50 and 150 MeV/c
- Wide range of beam currents: $1e^-$ to 4 mA
- Versatile set of diagnostics tools
- Individual control of all magnets
- Developed set of software tools for new lattice commissioning
  - Takes 3-4 shifts to fully commission a new IOTA configuration
    - Injection matching, including FAST linac tuning
    - LOCO based lattice correction (beta beating 5% or better)
    - Beam based centering in various elements (50 um in the location of interest, 500um RMS around the ring)
- Robust save/restore capabilities for quick switching between different experiments
- Good vacuum conditions
- Flexible access to the in-tunnel components

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Beam Diagnostics

- Optical diagnostics
  - Digital cameras
    - Up to 130 FPS (with ROI)
    - Single electron sensitivity (@ 500 ms exposure)
    - Software and hardware triggering
  - Streak camera
  - PMTs
  - SPADs
  - Convenient installation and commissioning of custom optical instruments
- Electrostatic BPMs
- DCCT
- Wall-current monitor
- Loss monitors

Lattice correction accuracy

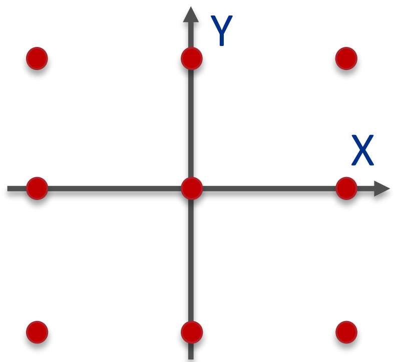
- NIO experiments are the most demanding in terms of lattice tuning precision:

Betas at the DN magnet	1%
Overall beta beating	3%
Dispersion	1 cm
Closed orbit at insertion	50 um
Phase advance errors	0.001

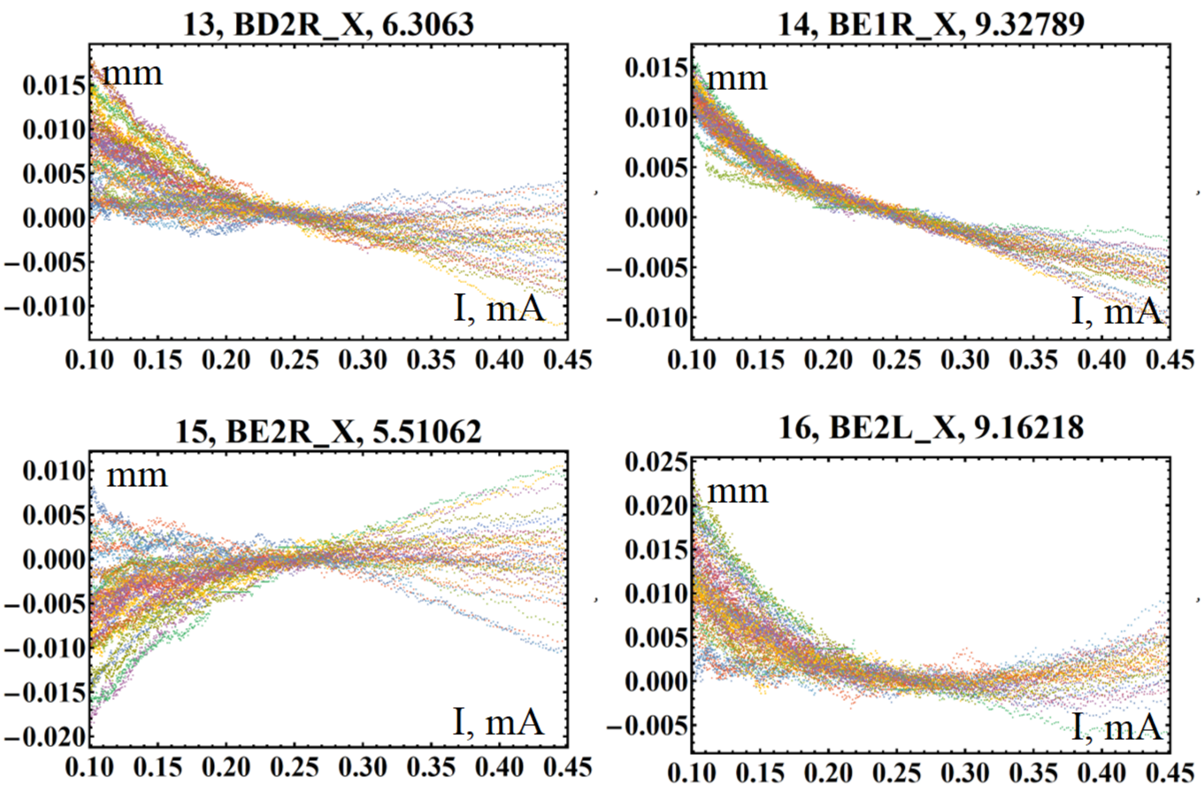
- Accuracy of the closed orbit responses must be 1 um at amplitude of 1mm as shown by modeling LOCO corrections of random lattice errors
  - Lattice was assumed to be linear, i.e. no sextupoles, fringe fields etc.

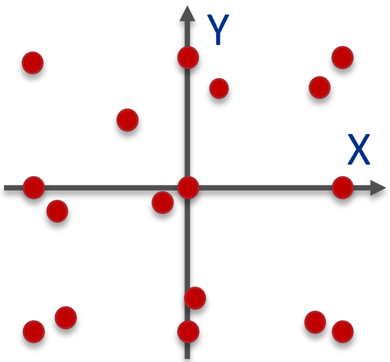
BPMs calibrations

- A set of closed orbit samples was measured with the goal to map pickups current dependance around ideal closed orbit position.
  - 2 trims for each plane were selected with ~Pi/2 phase shift to produce non-zero displacement in each BPM
  - ACNET glitches interfered significantly with data acquisition (stale readouts)
    - Partly recovered using logs
  - A total of 39 closed orbit in a current range of 0.1-0.5mA were recorded



Sample of raw data





$$Z_{fix,i}=C_{0i}+C_{1i}\ I+C_{2i}\ I^2+C_{3i}\ I^3$$

$$C_{k,i}= M_{k,i}+ N_{k,i}X+ K_{k,i}Y$$

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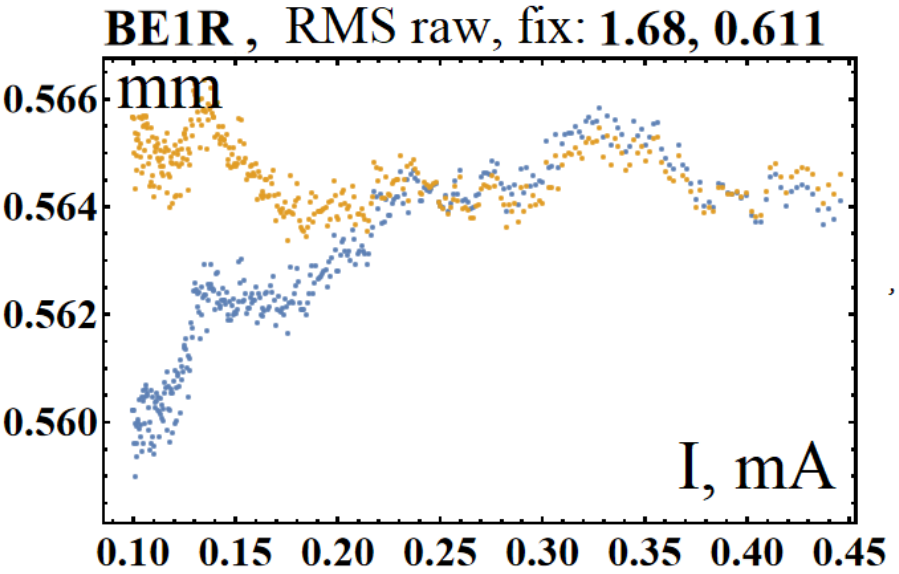
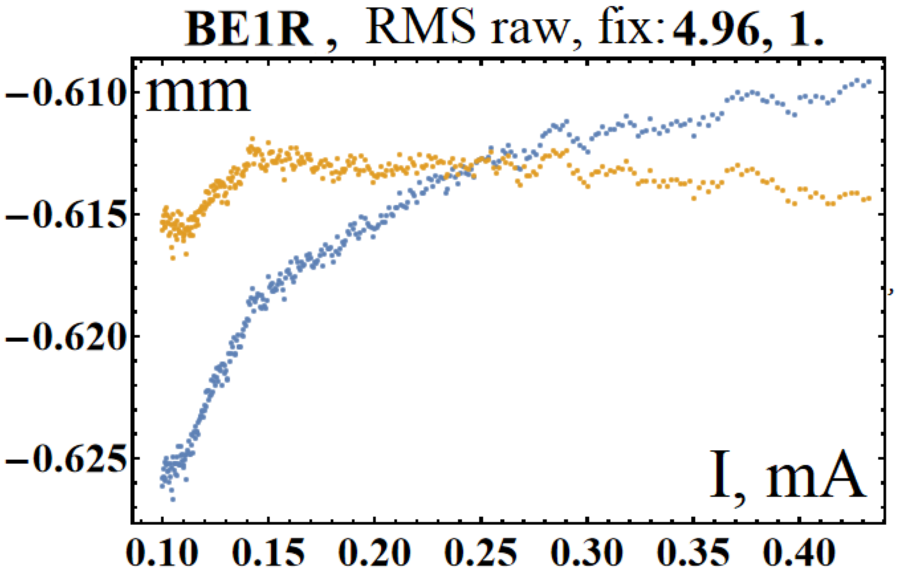
Sample of raw data with and without correction





- Current dependent calibration reduced RMS spread in the optimal current range:

from 2.75 um to 0.85 um on average

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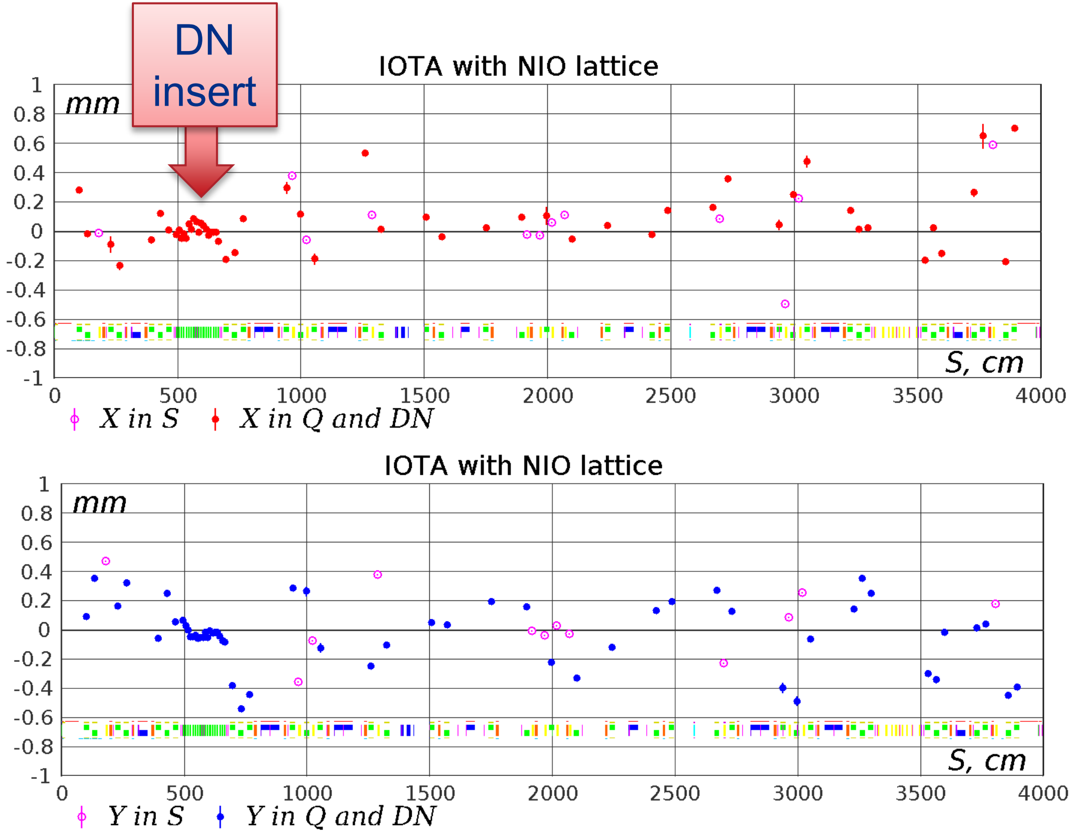
Example of closed orbit after correction

- RMS orbit deviation in DN magnets with optimal orbit correction:
  - X: 41 um
  - Y: 30 um
- RMS orbit deviation in quads and sextupoles:
  - X: 250 um
  - Y: 260 um



Lattice correction accuracy

- During Run-4 significant amount of time was dedicated to improving lattice correction accuracy.
- The resulted lattice tuning accuracy as derived from independent measurements, turn-by-turn tracking of a kicked beam:

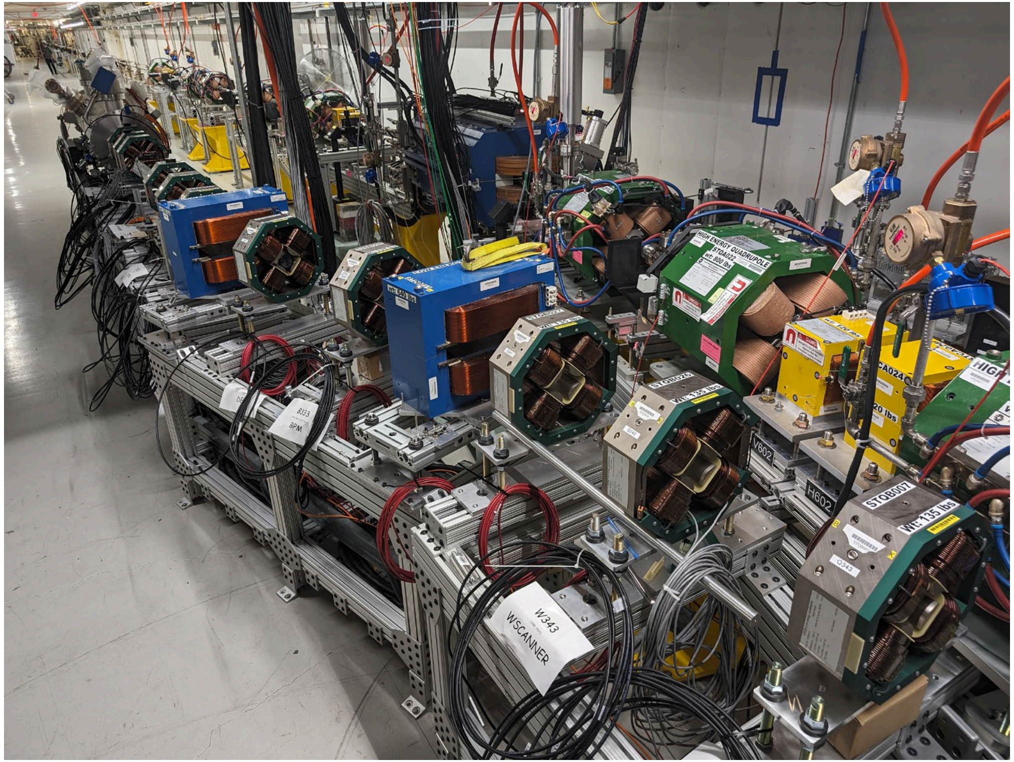
	Goal	After correction
Betas at the DN magnet	1%	2% *
Overall beta beating	3%	2%
Dispersion	1 cm	0.5(2) cm
Closed orbit at insertion	50 um	40(5) um
Phase advance errors	0.001	0.0010(5)

- A set of knobs was developed for manual tuning of all main lattice parameters orthogonal with respect to each other

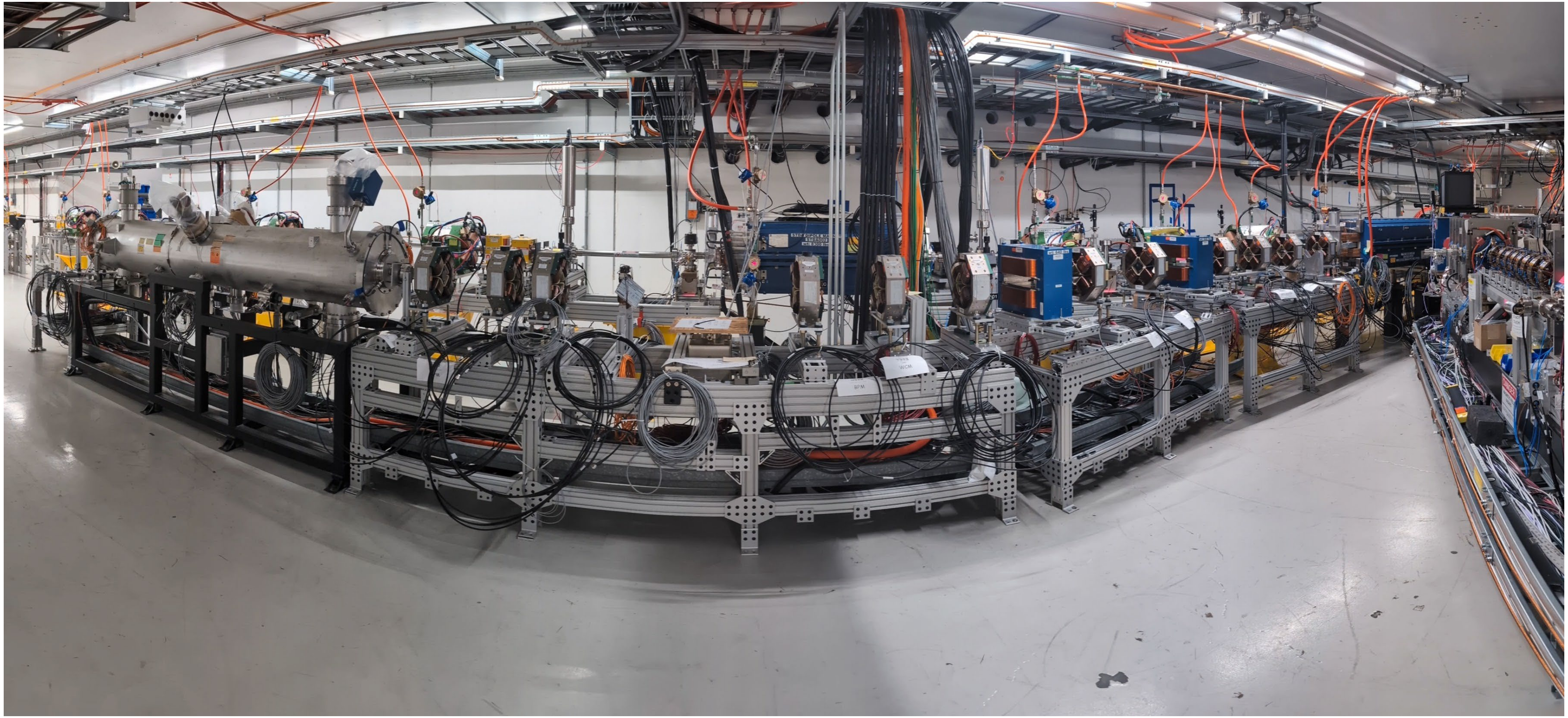
* Residual magnetization of the DN magnets have strong effect and can easily worthen lattice tuning if not degaussed properly

Proton injector construction

- LEBT
  - Proton source tests will start during the next few weeks
- RFQ and RF
  - RFQ is roughly aligned
  - RF distribution lines are nearing completion
  - High-level RF is being constructed
  - Work on low-level RF system is hindered by lack of available experts
- MEBT
  - All main magnets are installed, ready for fine alignment
  - Vacuum system assembly is underway, with completion planned for early May
  - Cables are pulled and being distributed and terminated



Proton injector construction



Next upgrades and experiments

- The FAST team is understuffed, we need
  - Electronics specialist
  - Engineering physicist (hired, waiting for US visa)
  - Technician
- Experiments
  - NIO with protons
  - Active OSC
  - GREENS
  - Electron lens
- Facility
  - Laser lab at ESB
  - Refurbishing and/or replacing power supplies
  - Collaboration with ACORN project for testing improved controls

Summary

- Recent improvements brought IOTA capabilities up and beyond the original expectations
  - Several issues found during the in-depth performance analysis and optimization will be addressed before and during the next runs
- FAST linac, especially superconducting cavities and infrastructure, shows signs of degradation, but remain functional and suitable for wide range of experiments
  - Maintenance procedures are scheduled for the current shutdown to facilitate smooth operations during the following runs
- Proton injector is actively constructed, commissioning of the first subsystems will begin shortly