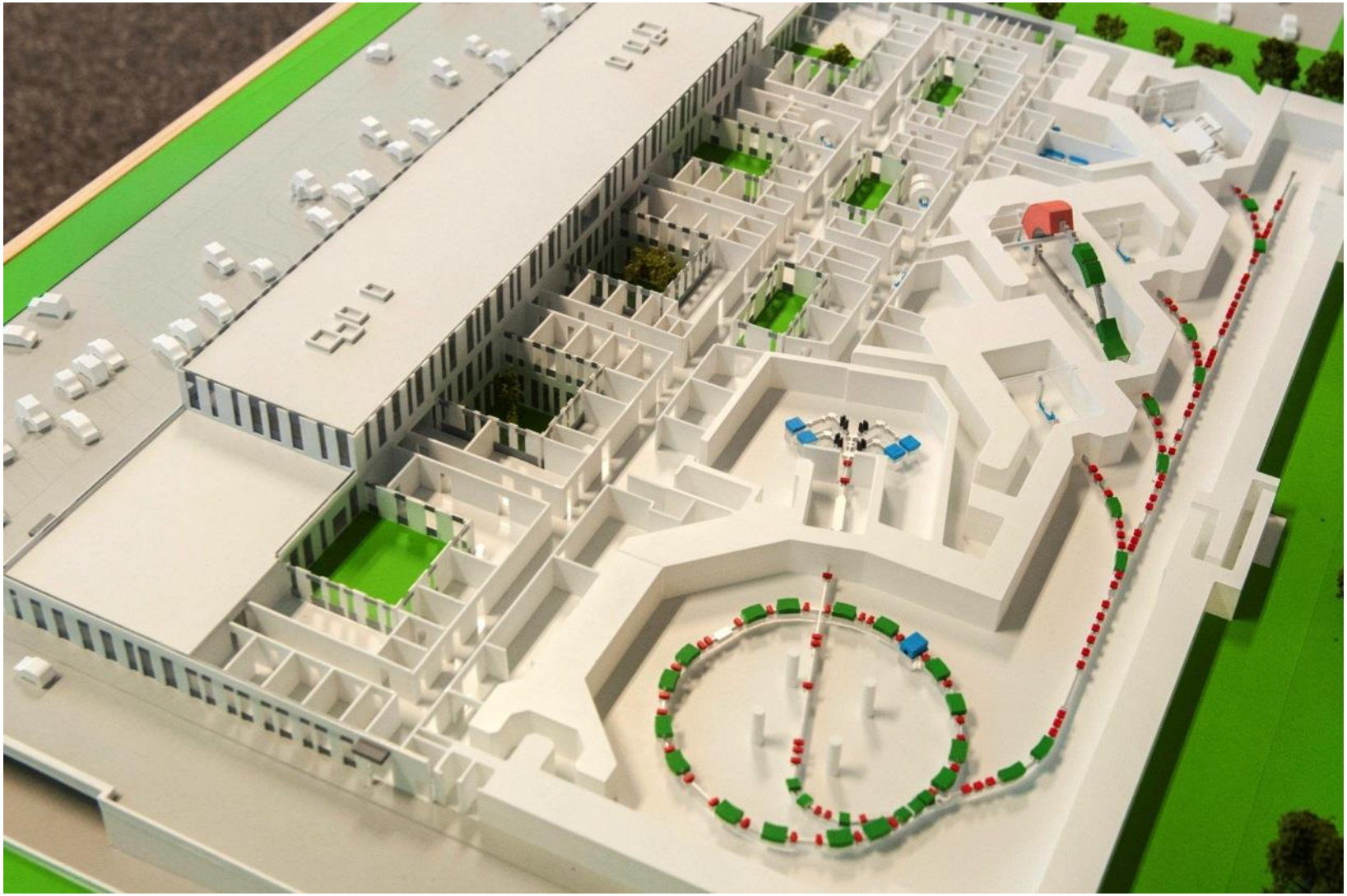
BEAM DIAGNOSTICS FOR MEDICAL ACCELERATORS

Matjaž Repovž



BEAM DIAGNOSTICS FOR MEDICAL ACCELERATORS

OUTLINE

- **What/why/what for?**
- **MedAustron monitors**
  - What do we use where
  - Structural layout and interfaces
  - Individual monitors
- **Wrap up**

WHAT IS BEAM DIAGNOSTICS
(SOME DEFINITIONS)

- Group or WP responsible for some ACC's equipment
- Equipment for measuring beam parameters
- Partially not needed after commissioning when accelerator works
- "Eyes and ears" for the operators and other equipment

BEAM DIAGNOSTICS

- **What is not BD at MA:**
  - No radiation monitors for RP
  - No diagnostics for patient (patient position, MRI…)
  - Not part of beam delivery system
  - Not medically certified devices

WHAT FOR (USE OF BD)?

There are three categories of beam diagnostic demands at any facility:

- **Regular crude checks of accelerator performance (reliable, quick, online; does not perturb the beam)**

  (Beam intensity, Beam position…)

- **Standard regular measurements (check of performance, used daily; destructive)**

  (Beam intensity, Beam position, Beam profile, Emittance, Trajectories, Tune…)

- **Sophisticated measurements e.g. during machine development sessions**

  (May require offline evaluation, May be less comfortable…)

SPLIT OF BEAM DIAGNOSTICS AT MA

- As per installed location
- Measuring parameter
- DC or AC beam
- “On-line” measurements
- Stationery, movable type
- …

MEDAUSTRON BEAM DIAGNOSTICS 1/3

- **Beam Profile**
  - Wire Scanner (LEBT)
  - Harp Grid (LEBT, MEBT)
  - Scrapers (SYNC)
  - Scintillating Fiber Hodoscope (HEBT)
  - Qualification Profile Monitor (HEBT)
- **Beam Intensity**
  - Faraday Cup (LEBT, MEBT)
  - Faraday Cup Cylindrical (LEBT)
  - Current Transformers (LEBT, MEBT, SYNC)
  - Qualification Intensity Monitor (HEBT)

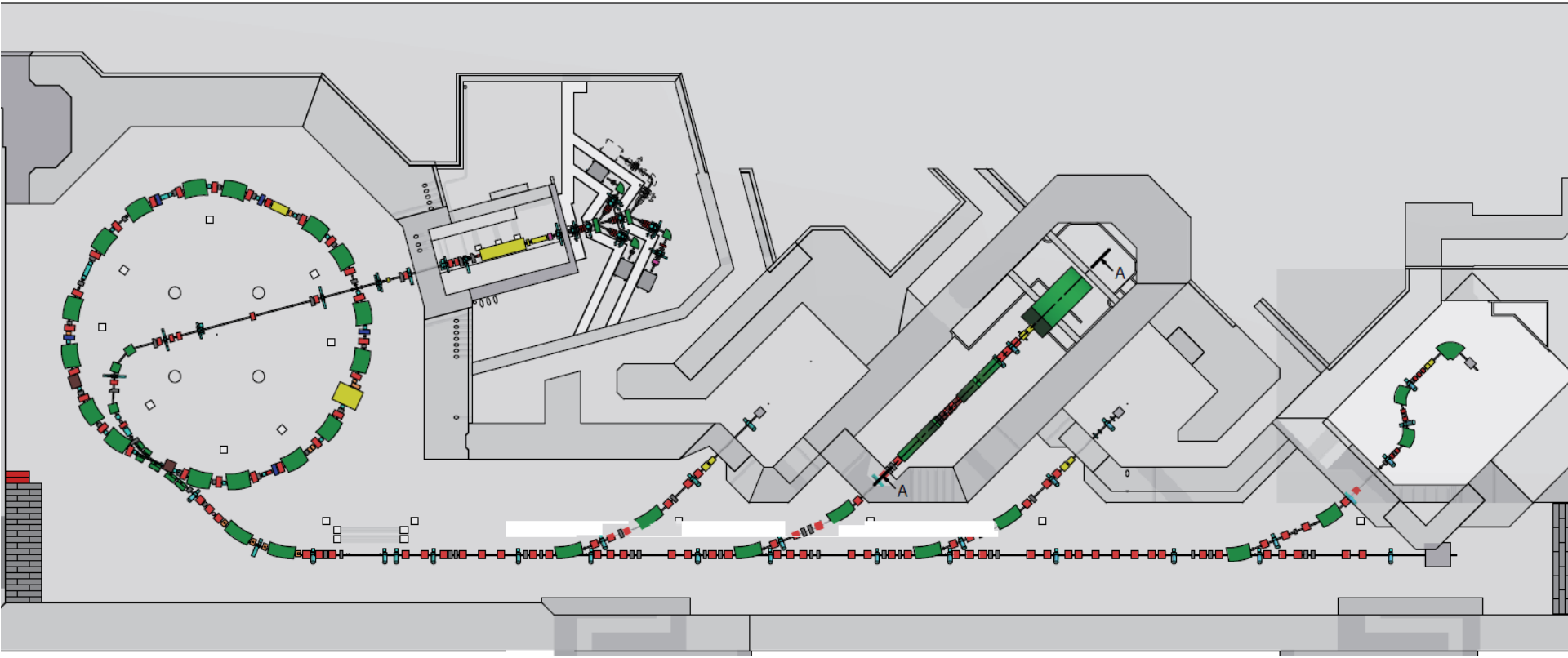
MEDAUSTRON BEAM DIAGNOSTICS 2/3

- **Beam Position**
  - Wire Scanner (LEBT)
  - Harp Grid (LEBT, MEBT)
  - Position Pick-up (MEBT, SYNC)
  - Scintillating Plates (SYNC)
  - Scintillating Fiber Hodoscope (HEBT)
  - Qualification Profile Monitor (HEBT)
- **Beam Emittance**
  - Slits + Wire Scanner (LEBT, MEBT)
  - Quadrupole scan (MEBT, HEBT)
  - Schottky Pickup (SYNC)

MEDAUSTRON BEAM DIAGNOSTICS 3/3

- **Tune**
  - Position Pickup + kicker (SYNC)
  - Schottky pickup (SYNC)
- **Beam Momentum (Δp/p):**
  - Schottky pickup (SYNC)
- **Other (more specialized) diagnostics:**
  - Degrader (MEBT)
  - Stripping foil (MEBT)
  - Silicon detector (PIN)
  - Scraper

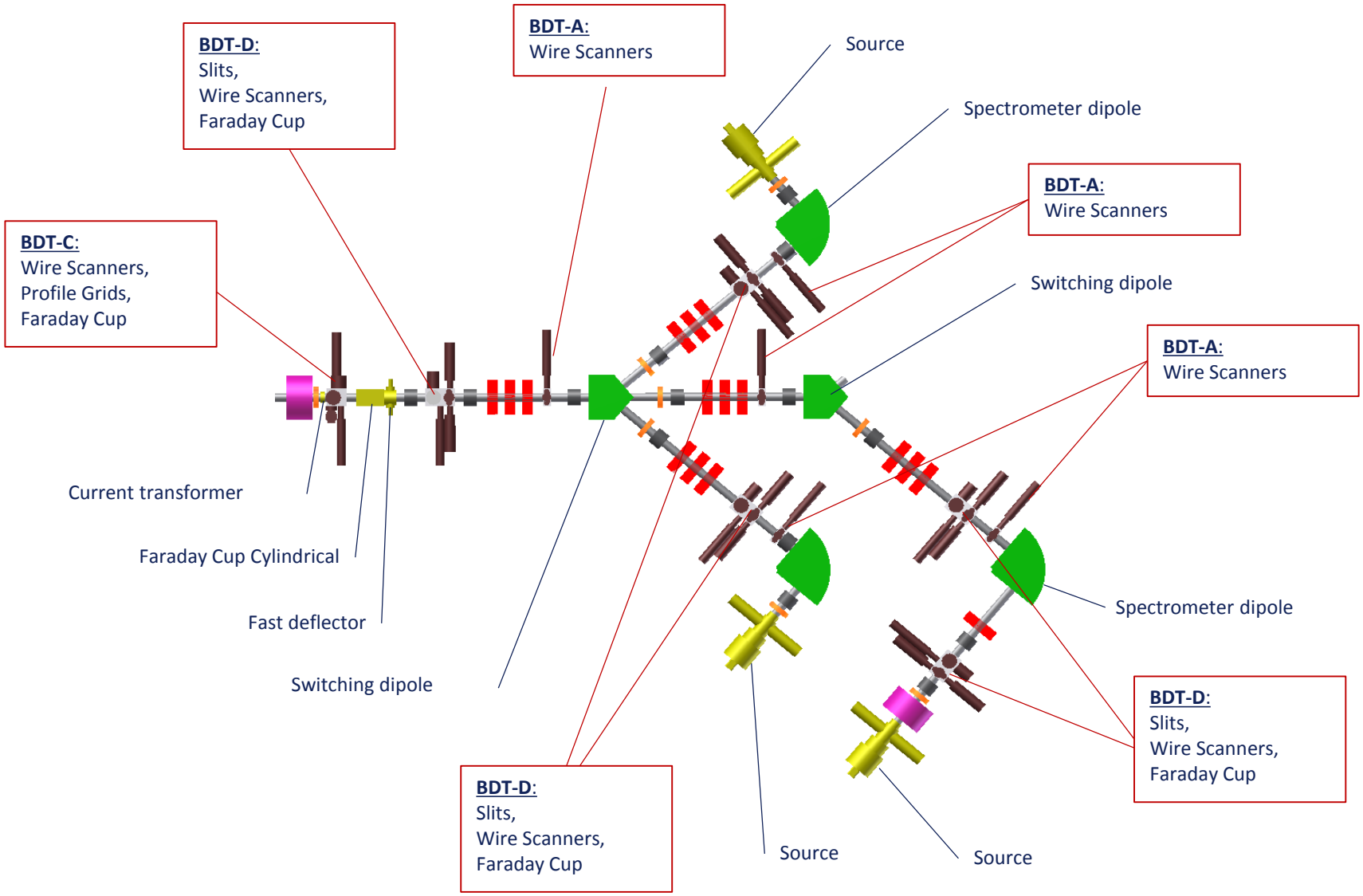
SPLIT OF BEAM DIAGNOSTICS - LOCATION



MA LEBT MONITORS

Monitor type	Number of units	Measuring	Comments
Faraday Cup (FCN-A)	6	beam intensity	stops the beam, cooled, pneumatic actuator
Slit Plates (SLX-A)	5 sets	emittance, beam halo, collimator	each set consists of 4 plates; cooled and polarized, brushless motor
Wire Scanner (WSX)	11 sets	profile, position, emittance, watch dog mode	each set consists of 2 units; brushless motor
Faraday Cup Cylindrical (FCC)	1	beam intensity	static, doesn't perturb the beam
Profile Grid Monitor (PGX-A)	1	beam profile, position, emittance	each set consists of H + V units; 64 wires, pneumatic actuator
AC Current Transformer (CTA-A)	1	beam intensity	static, doesn't perturb the beam
Total	**51**		

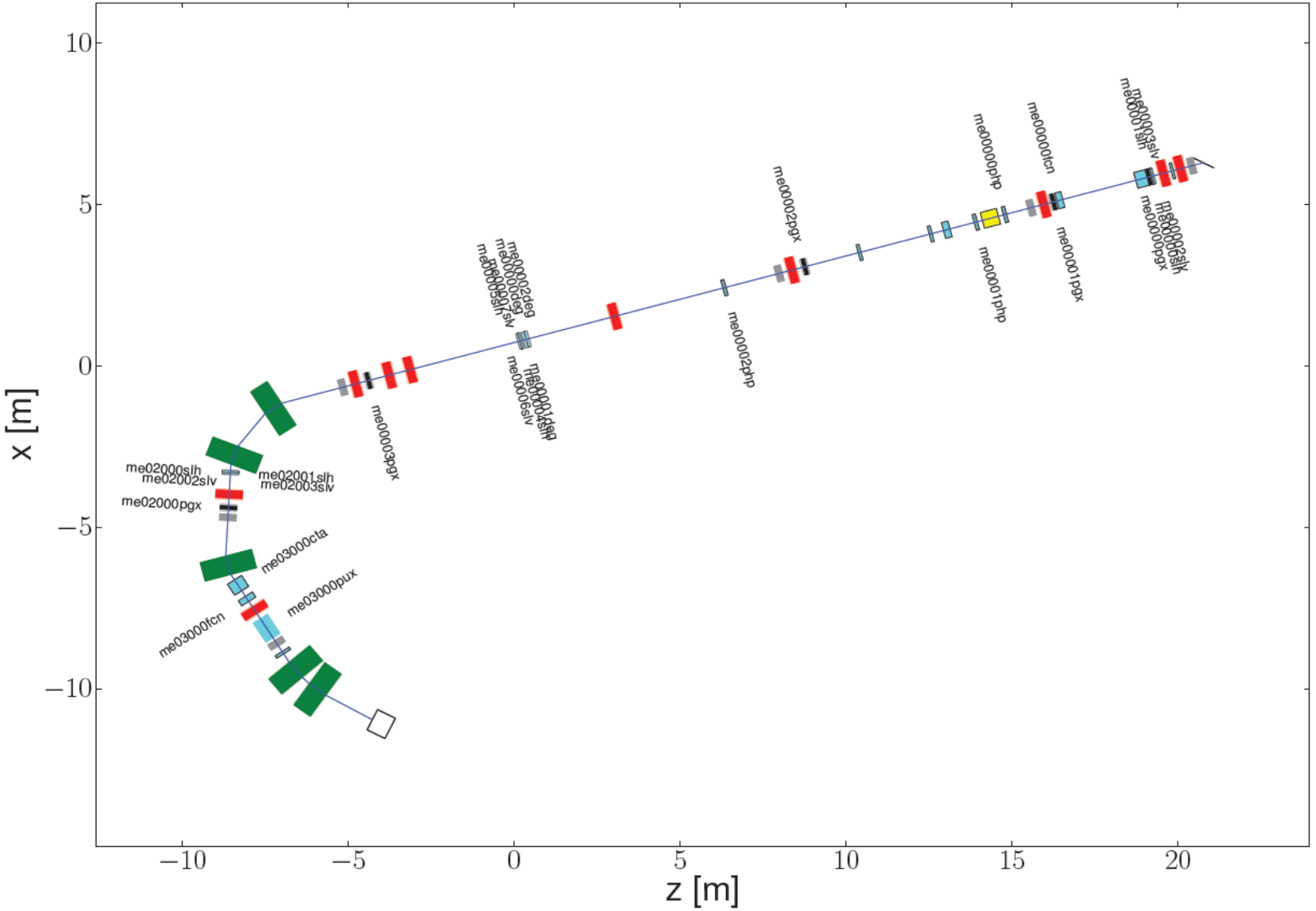
MA LEBT MONITORS



MA MEBT MONITORS

Monitor type	Number of units	Measuring	Comments
Faraday Cup (FCN-B)	4	beam intensity	stops the beam, pneumatic actuator
Slit Plates (SLX-B)	3 sets	emittance, beam profile, collimator	each set consists of 4 plates, brushless motor
Profile Grid Monitor (PGX-B)	7	beam profile, position, emittance	each set consists of H + V units; 64 wires, pneumatic actuator
AC Current Transformer (CTA-B and CTA-C)	2	beam intensity	doesn't perturb the beam
H + V position pickup	1	beam position	doesn't perturb the beam
Degrader	3	Regulates the beam intensity	pneumatic actuator
Stripping Foil (FOI)	1	$H^{3+} \rightarrow 3P^{+}$ $C^{4+} \rightarrow C^{6+}$	a ladder consists of 10 foils, brushless motor
Total	**30**		

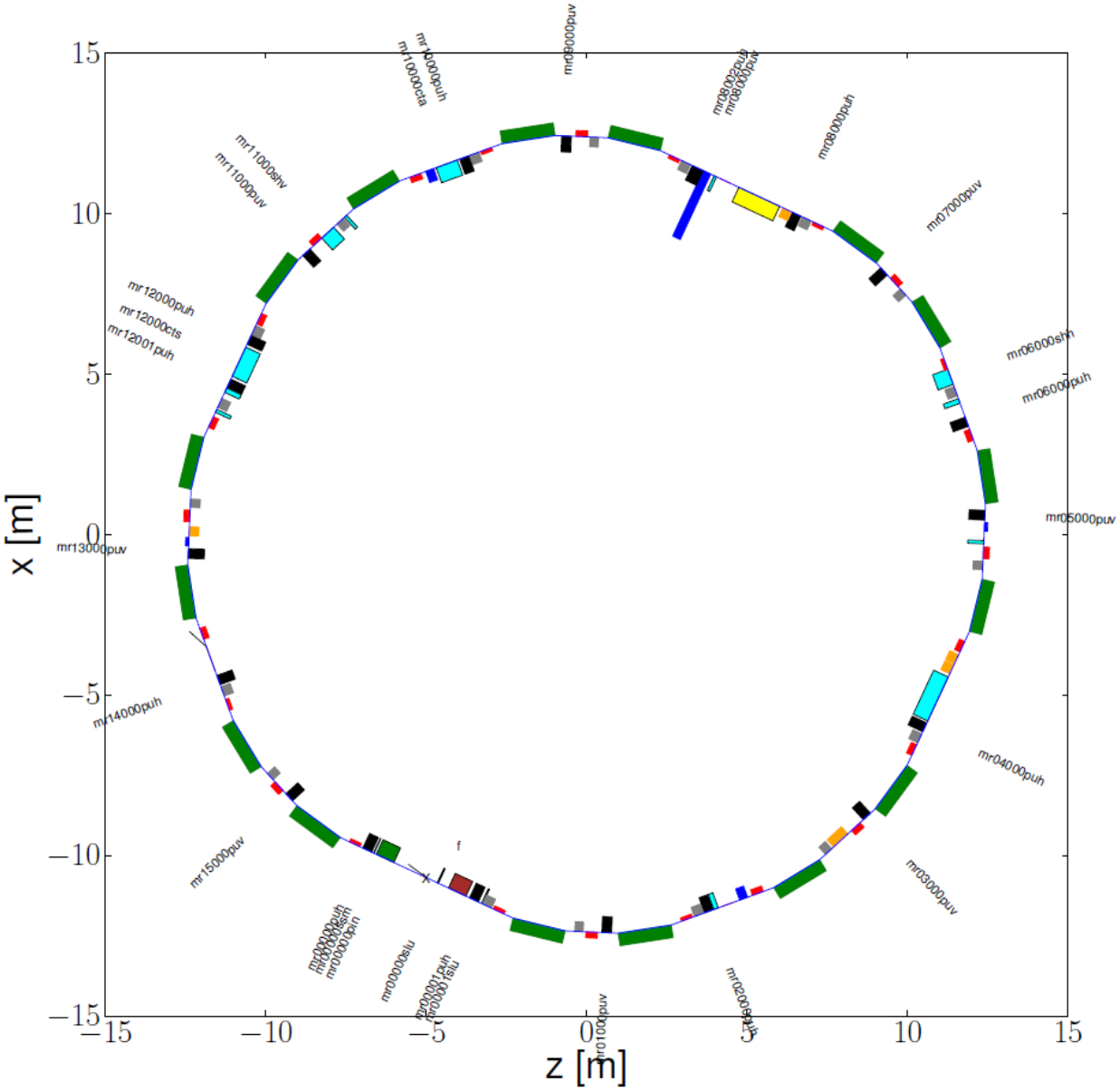
MA MEBT MONITORS



MA SYNC MONITORS

Monitor type	Number of units	Measuring	Comments
Position Pickups (PUH, PUV, PUS)	20	beam position, tune, K-modulation, RF control loop	doesn't perturb the beam
Fast Current Transformer (CTA-F)	1	beam intensity, tuning of the injection process	same as CTA-B
DC Current Transformer (CTS)	1	beam intensity	doesn't perturb the beam
Luminescent TV screens (SLU-F and SLU-S)	2	beam injection (injected beam & first-turn beam)	stops the beam
Schottky Pickups (SHH and SHV)	2	Δp/p, betatron tune Q, transverse velocity spread	doesn't perturb the beam
PIN-Diode (PIN)	1	Beam loss at extraction	Si-Diode
Total	**28**		

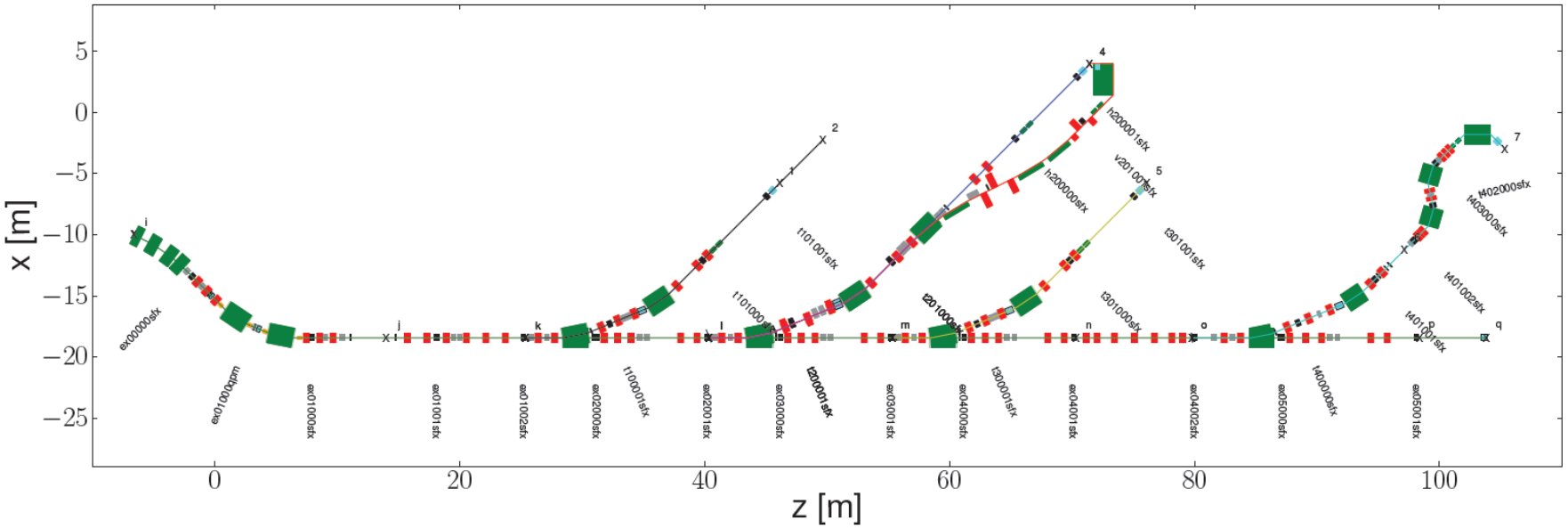
MA SYNC MONITORS



MA HEBT MONITORS

Monitor type	Number of units	Measuring	Comments
Scintillating Fiber Hodoscope (SFX)	29	beam profile, position and intensity	Pneumatic actuator, connected to the BIS
Qualification monitor (QPM)	1	beam position and intensity	Pneumatic actuator, connected to the BIS
Total	**30**		

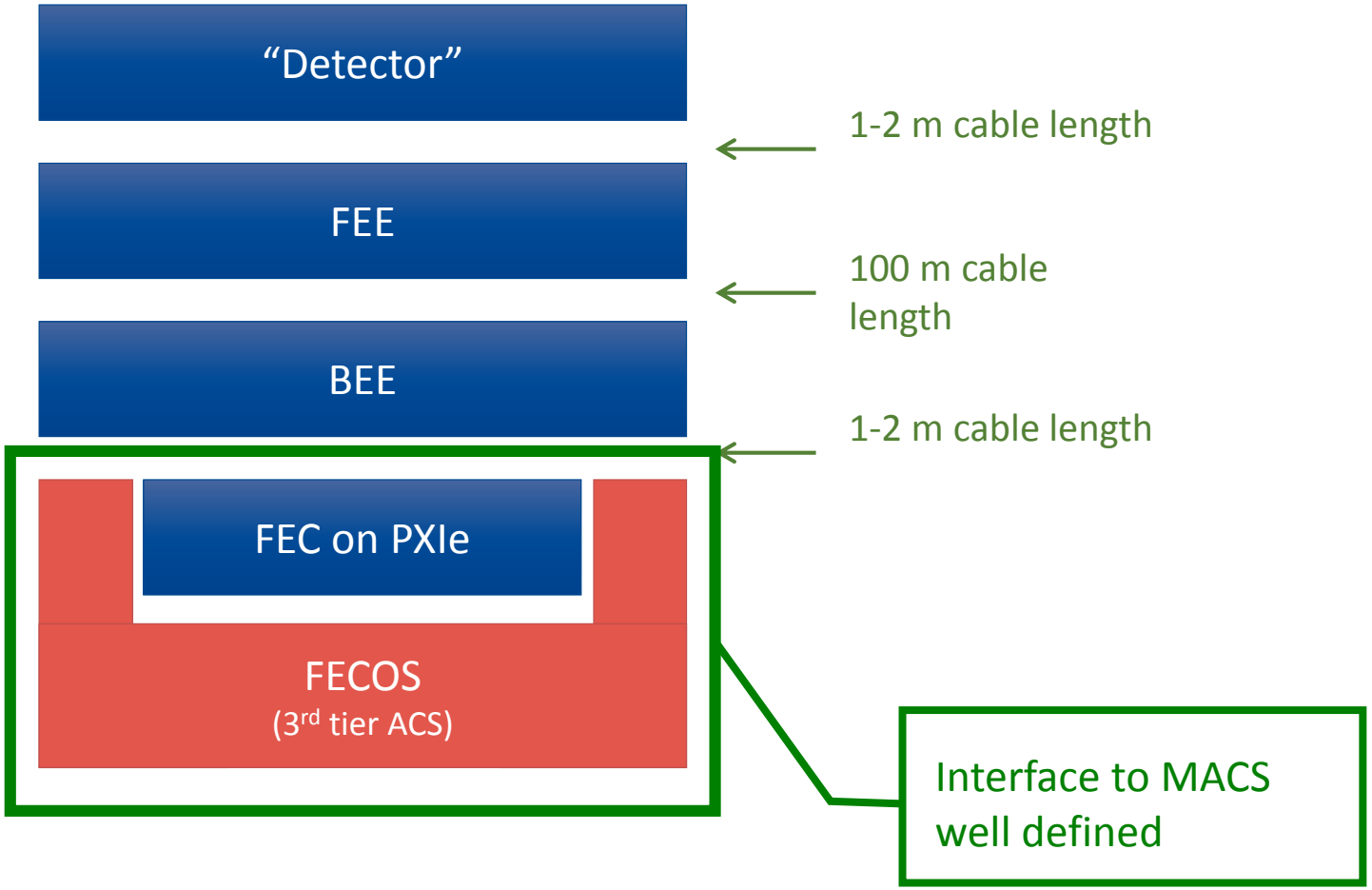
MA HEBT MONITORS



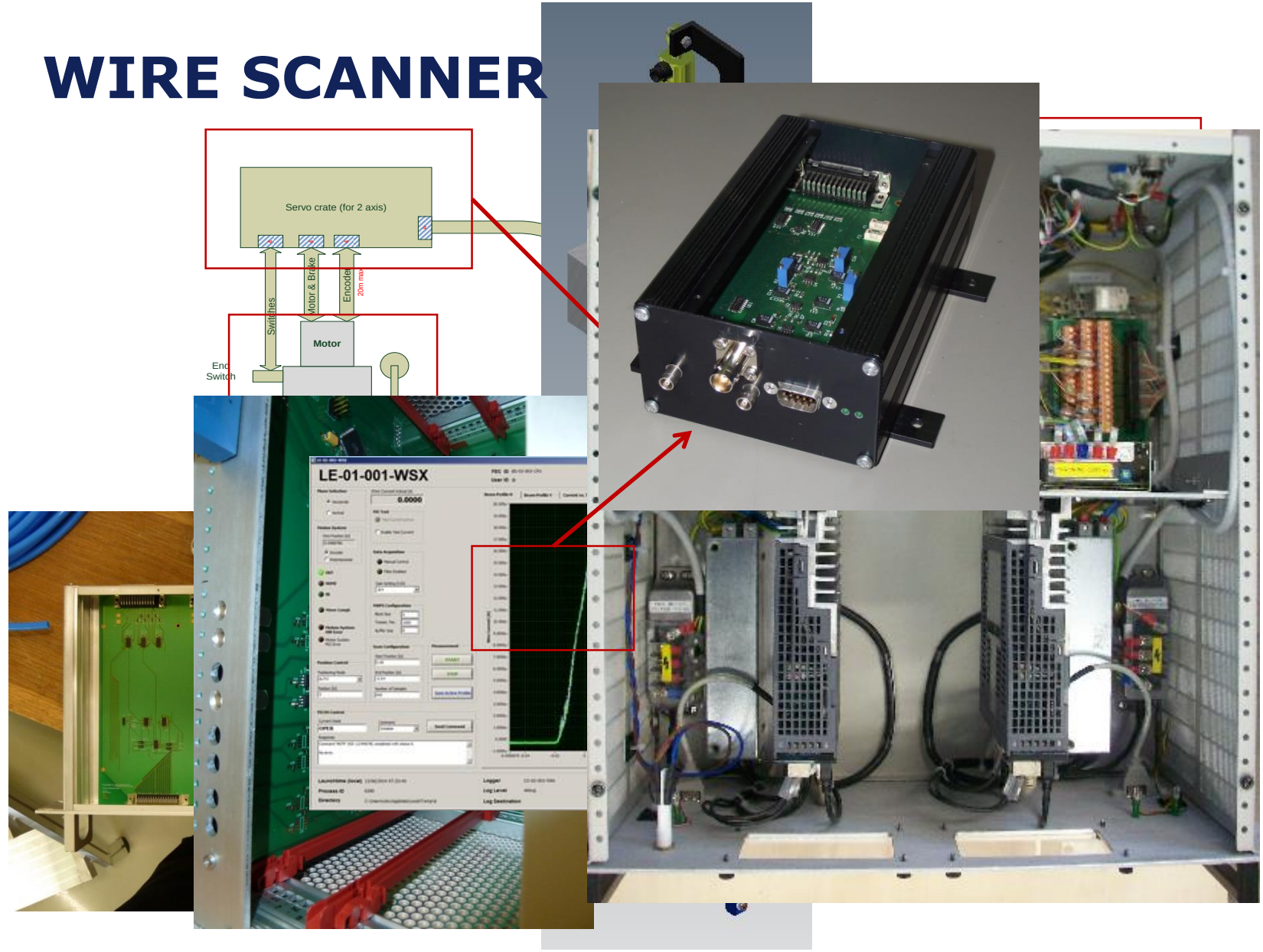
MA BD– MOVEMENT TYPES

- **Stationary – not movable**
  - Faraday Cup Cylindrical, CTs, Pickups, PIN diode
- **Movable**
  - Compressed air – Motion Pneumatic devices
    - Faraday Cups, Profile grid monitors, Degraders, Luminescence screens, Qualification monitor, Scintillating Fiber Hodoscope
  - Motors – Brushless motion system
    - Wire scanners, Slits, Foil, Scrapers

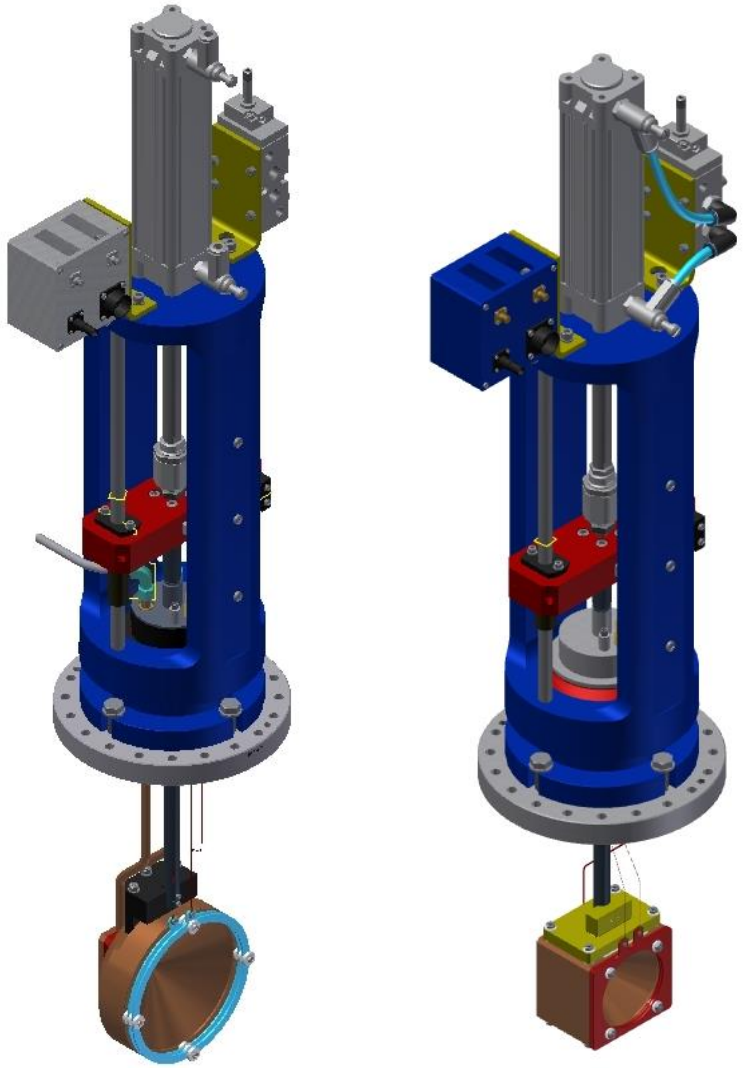
BEAM DIAGNOSTICS STRUCTURAL LAYOUT



WIRE SCANNER

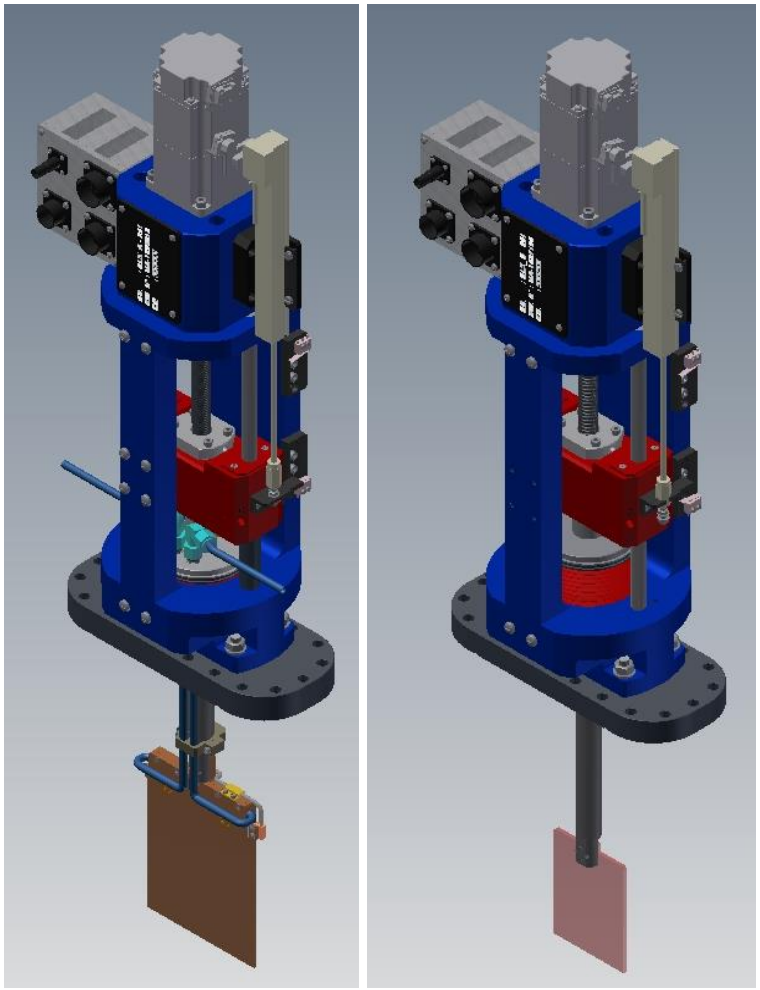


FARADAY CUP

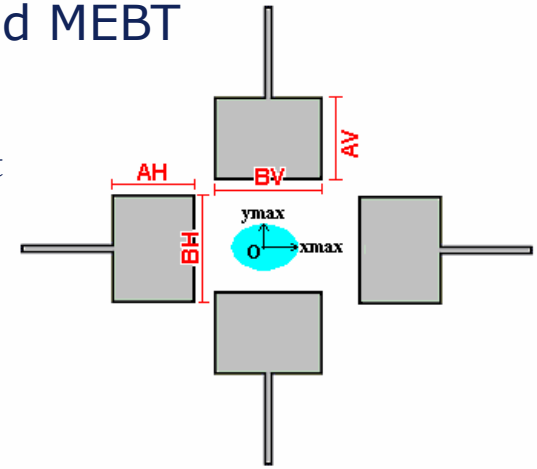


- Working principle: stops the low energy beam and measures the resulting current in the cup
- Resolution down to 1 nA (gain dependent)
- creation of secondary electrons (below 20 eV)
  - repelling electrode (up to -1kV)
- deployed in LEBT and MEBT
- LEBT type needs cooling
- Used for:
  - beam intensity measurement
  - beam profile measurement selection
  - beam stopper

SLIT PLATES

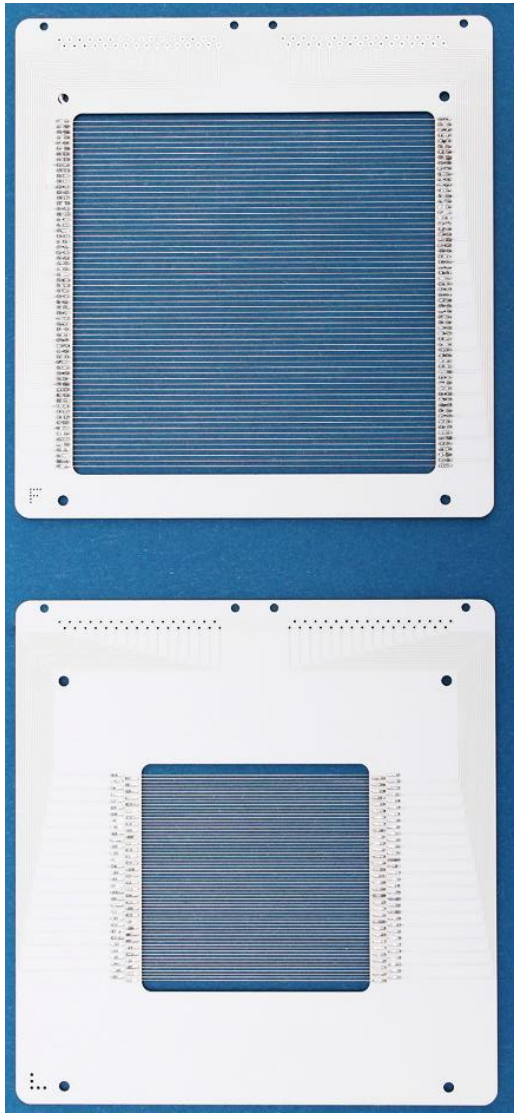


- Working principle: stops the low energy beam
- 2 horizontal and 2 vertical plates
- Plate thickness ~ 1-2 mm
- Moving speed: 100mm/s (brushless motor)
- Position measured via encoder and potentiometer
- Positioning accuracy: 0.1 mm
- Can be polarized (~ +1000V)
- Deployed in LEBT and MEBT
- Used for:
  - Emittance measurement
  - Beam scraping/shaping

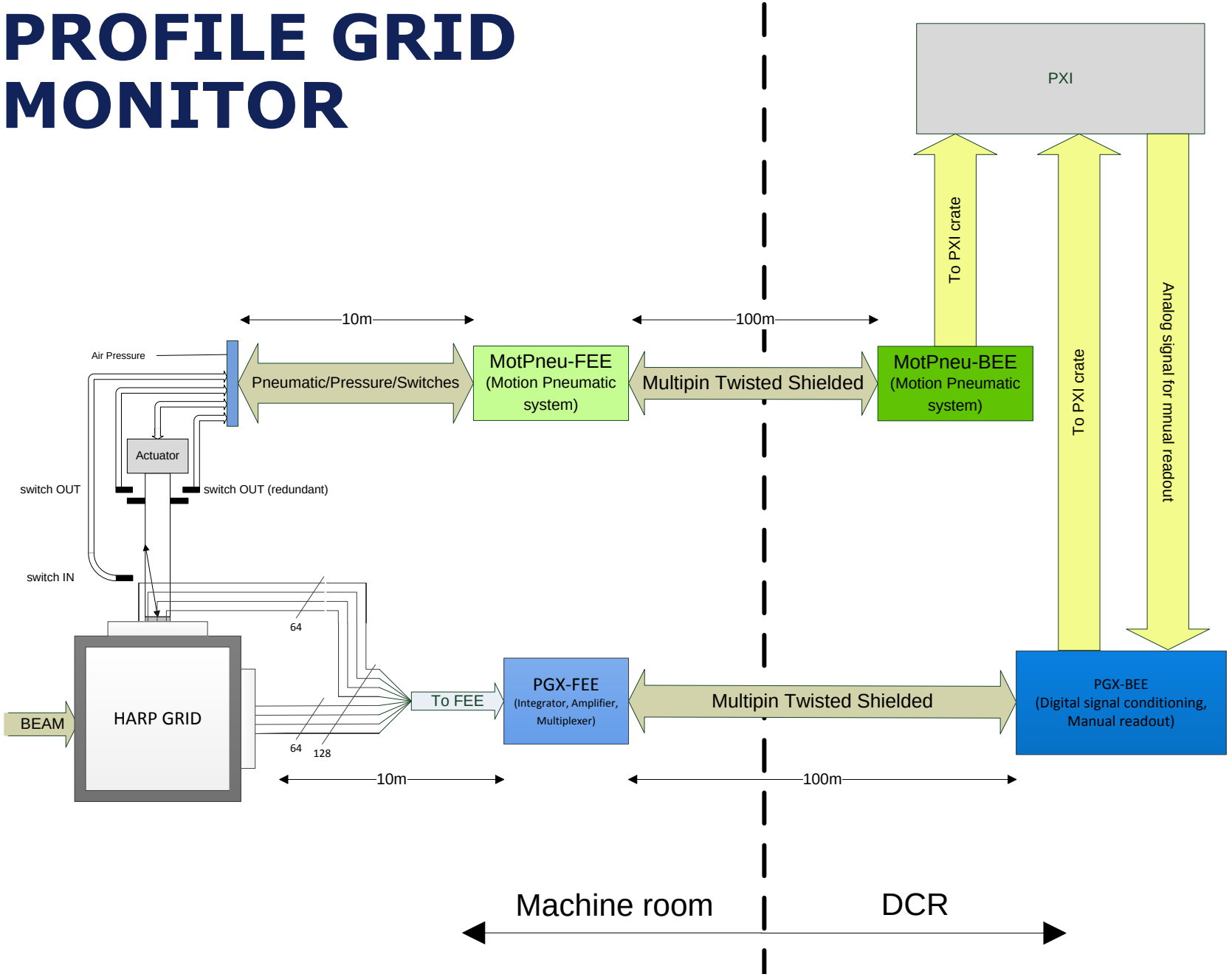


PROFILE GRID MONITOR

- Working principle:
  - like a wire scanner: grid of thin wires in horizontal and vertical direction
  - the beam induces a current in the wires, which is measured
- Wire diameter: 0.1 mm
- Wire spacing 0.8 mm – 1.2 mm
- 64 wires per plane → up to 108.8 mm covered
- All wires read in parallel
- Positioning accuracy: 0.1 mm
- Production process of the grids had to be established in many trial and error iteration steps
- Used for:
  - Beam profile
  - Beam position
  - Emittance measurement

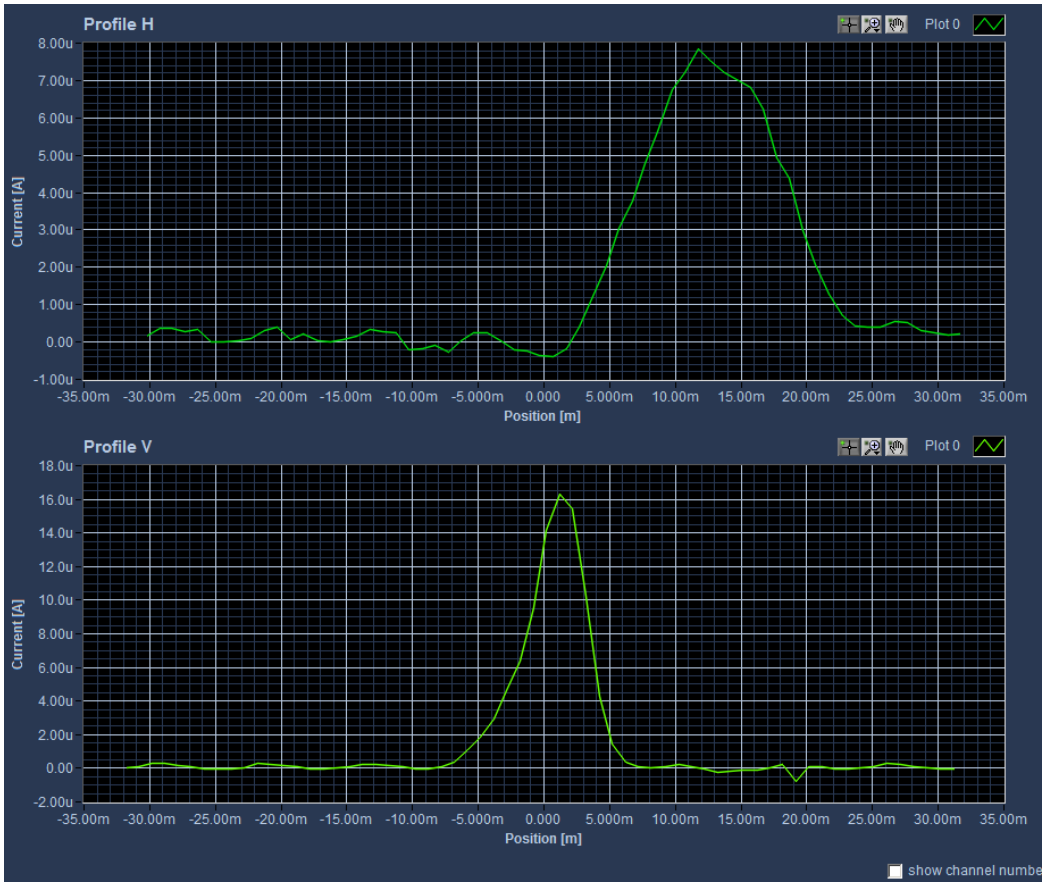


PROFILE GRID MONITOR



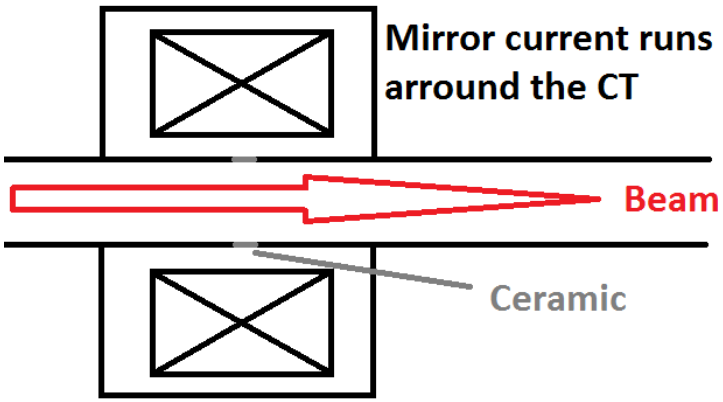
PROFILE GRID MONITOR

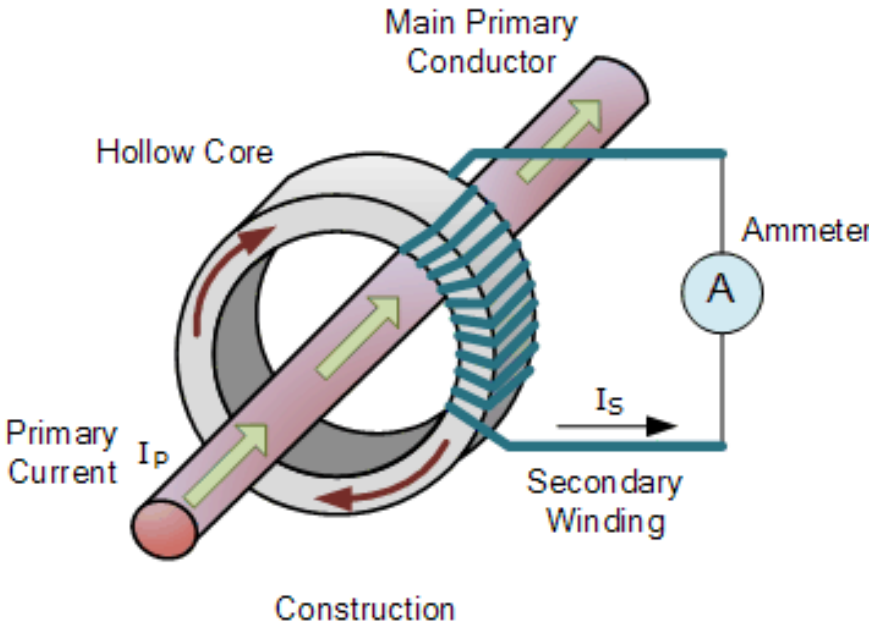
- MedAustron design
- Specially produced 32 pin coax wires cable
- Acquires wire charge of all 128 wires simultaneously
- Beam intensity dependent calibration
- At MA highest resolution used 250 pA
- Adjustable integration time



AC CURRENT TRANSFORMERS

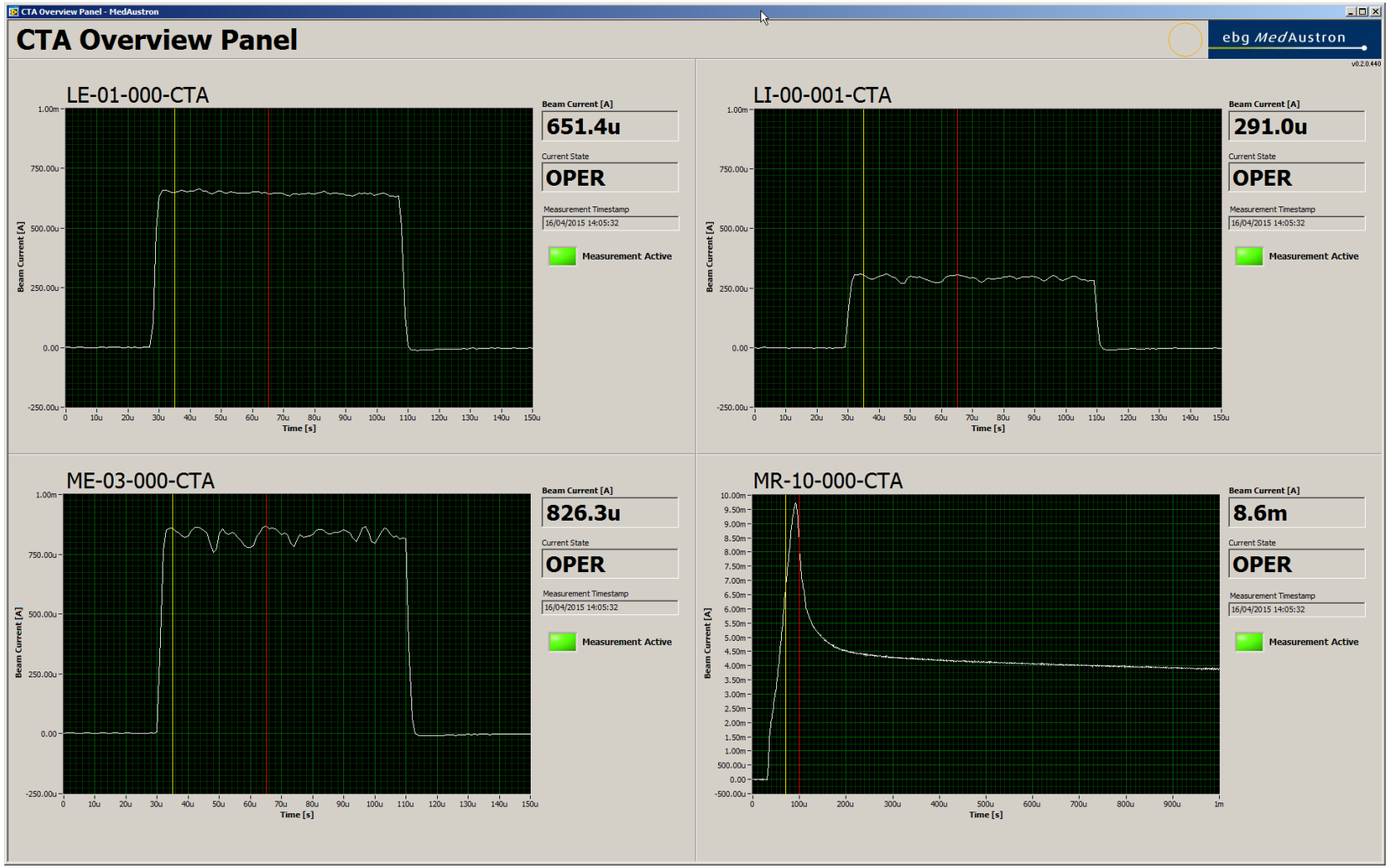
- Measures pulsed beam intensity in the LEBT, LINAC, MEBT and SYNC up to 5 mA
- Does not perturb the beam thus can measure all the time
- Test pulse (first step is ~500 uA)
- Upper limit frequency ~300 kHz
- Resolution ~ 2 uA





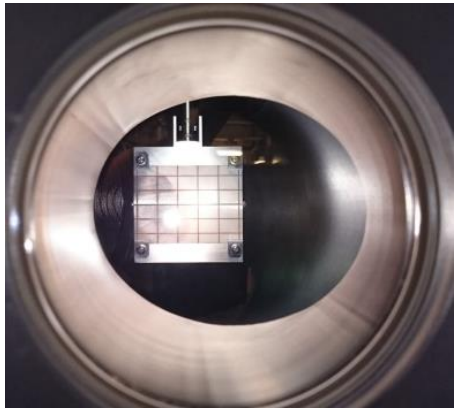
Construction

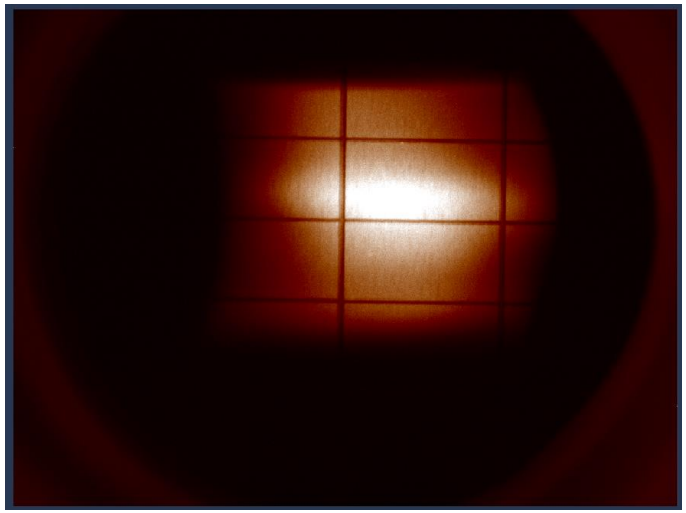
AC CURRENT TRANSFORMERS

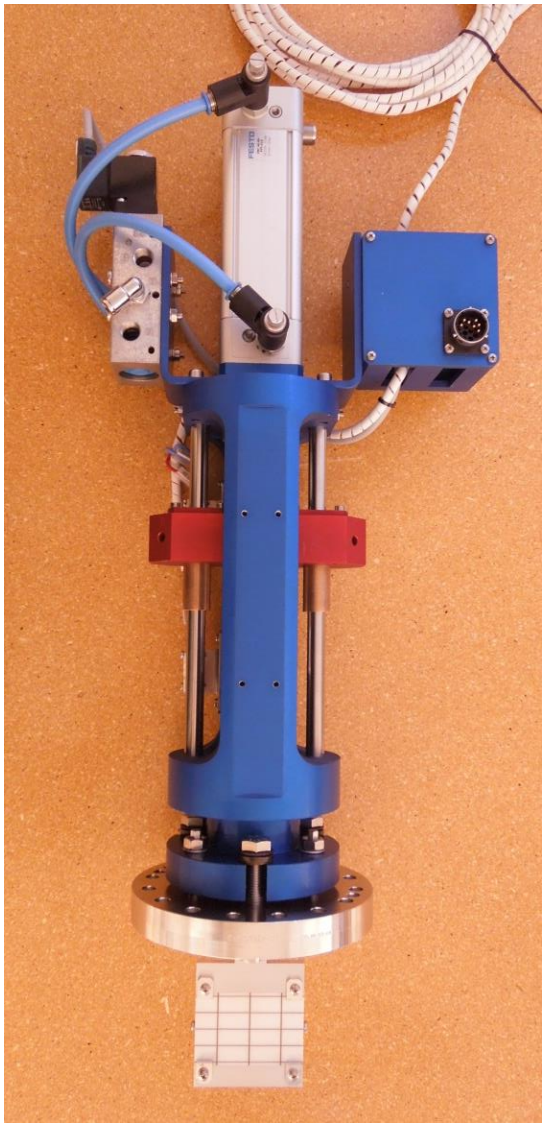


LUMINESCENCE SCREEN

- **The plate illuminates with stopping the beam. Illuminated plate is measured with a camera.**
- **45 deg (SLU-F) and 60 deg (SLU-S)**
- **Used for:**
  - Beam position of the first injected beam
  - Beam position measurement of the first turn

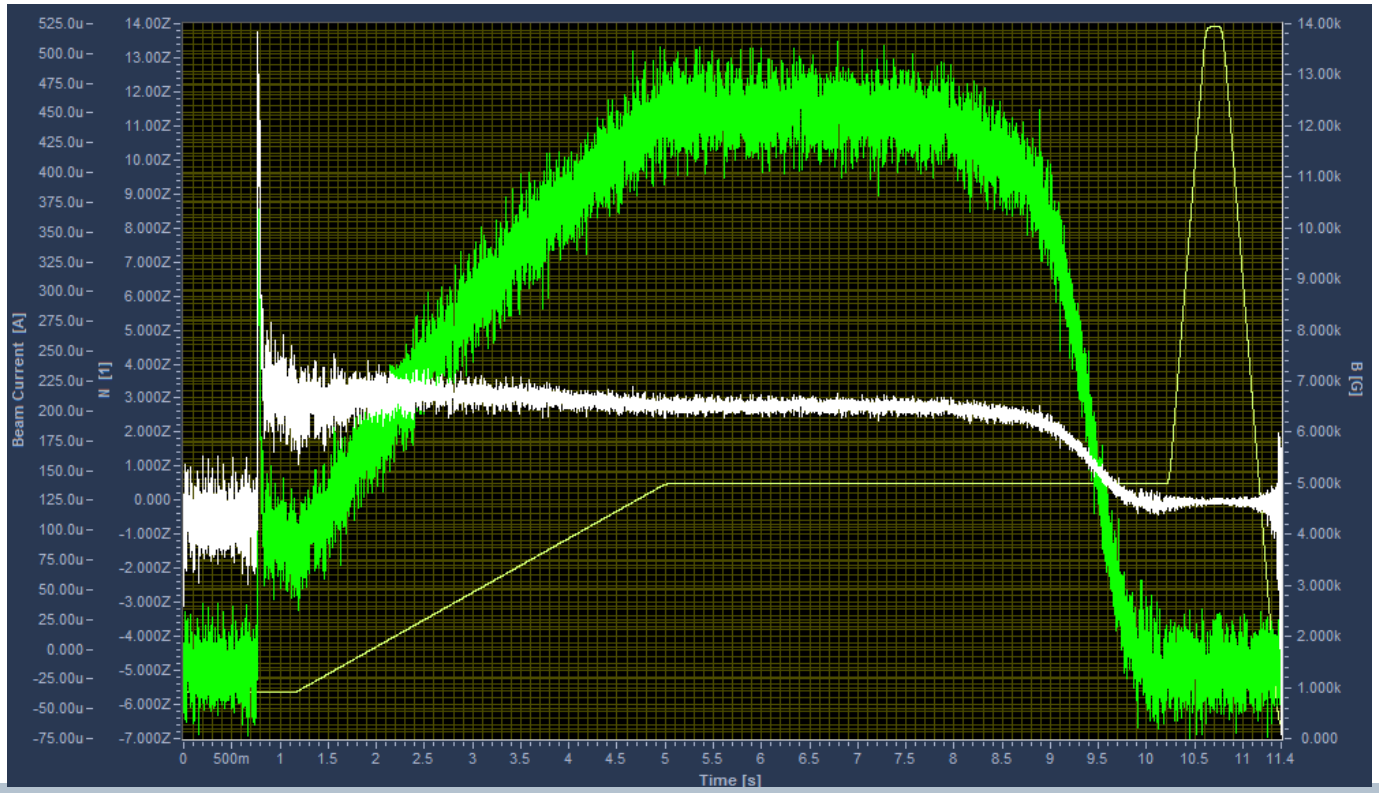






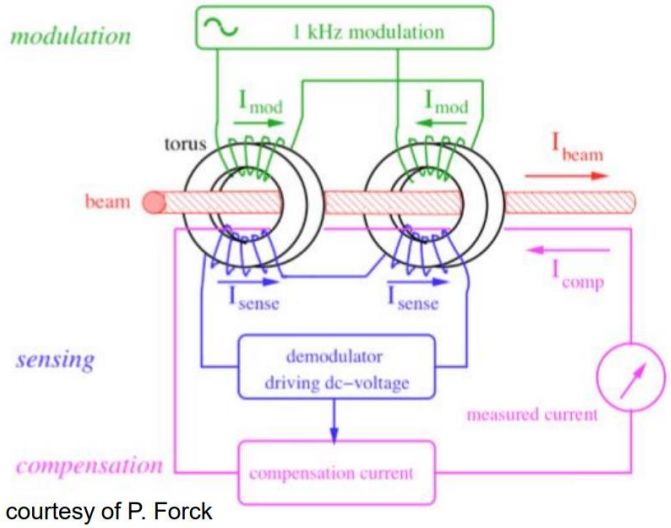
DC CURRENT TRANSFORMER

- **Measuring DC beam current in the SYNC (green line)**
- **Connection to the B-train; for calculating the number of particles in SYCN (white line)**

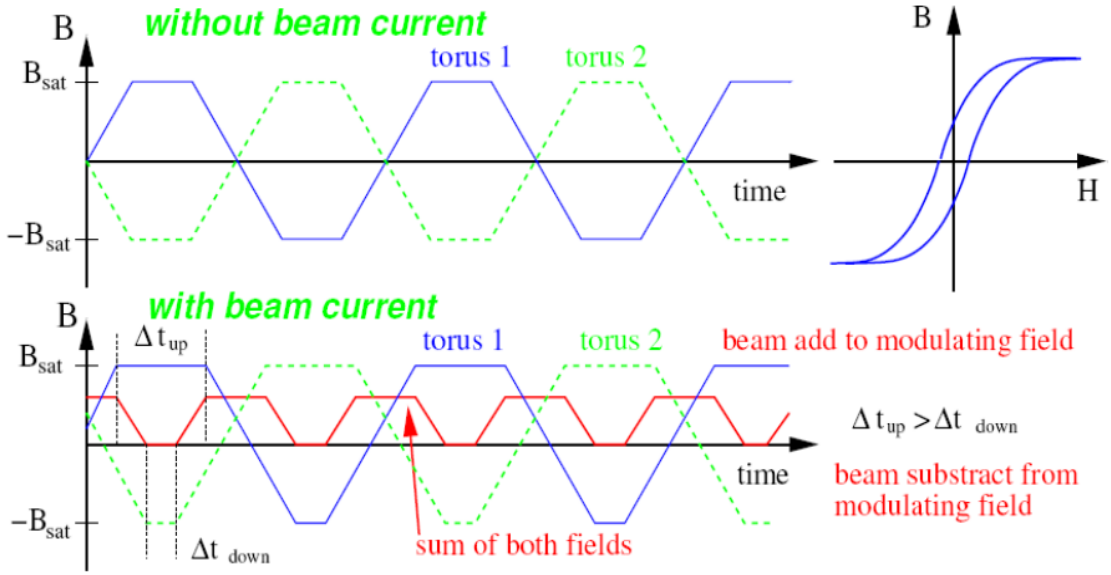


DC CURRENT TRANSFORMER

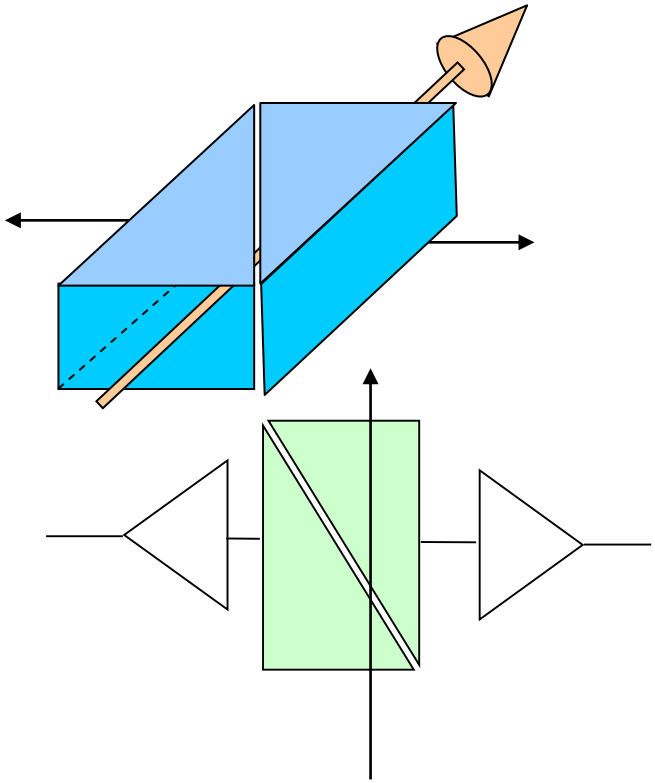
- 2 transformers are used
- Use of B/H curve
- Coils of opposite directions are exited with equal signal
- The coils are driven into saturation
- If there is no beam then there is no net magnetic field measured
- If there is beam current then one coils goes earlier in saturation then the other, thus there is measureable net signal



courtesy of P. Forck



POSITION PICK-UP



- **shoe-box pick-up**
- **Non-interceptive**
- **Deployed in MEBT and SYNC**
- **Required accuracy 0.4 mm**
- **Used for:**
  - beam position measurement
  - tune measurement (2 pickups – one per plane)
  - k-modulation
  - sRF LLRF-system
  - orbit correction
- **In MedAustron 21 PUs**

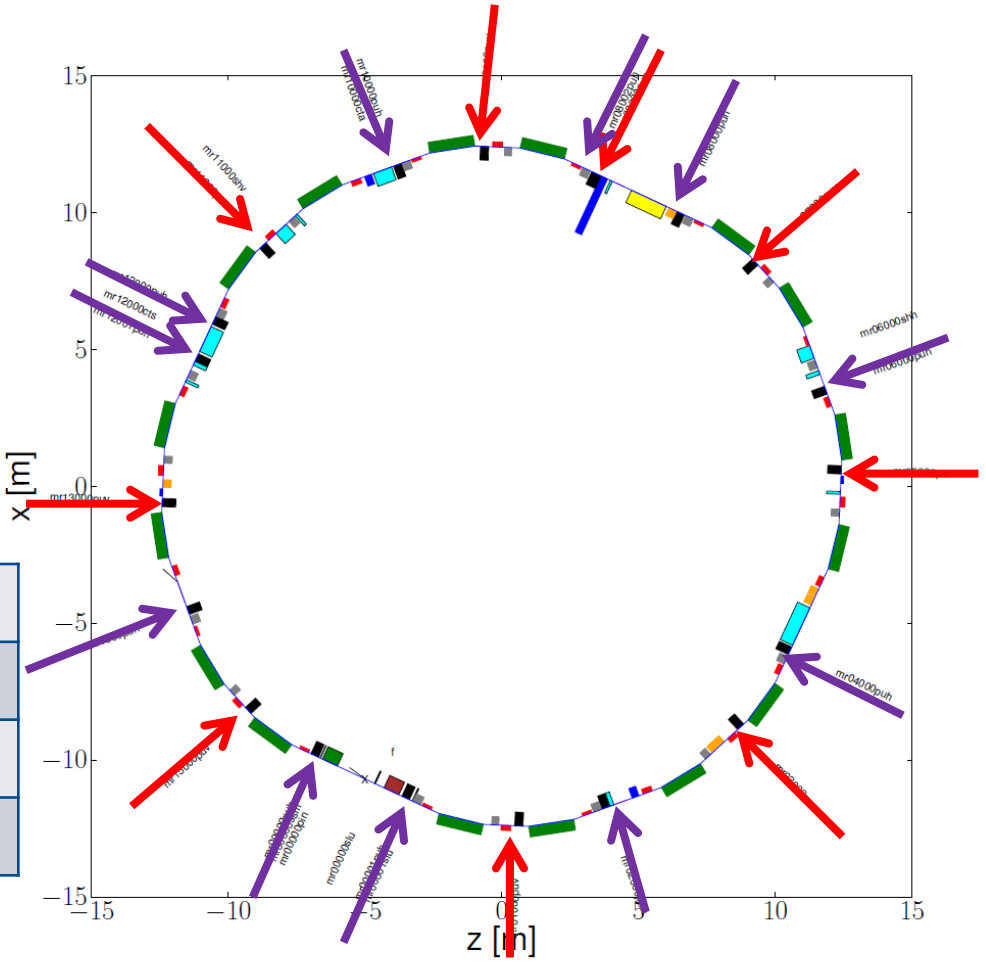
$$x \propto \frac{U_L - U_R}{U_L + U_R} = \frac{\Delta}{\Sigma}$$

The difference signal (Δ) is proportional to the beam position and the intensity while the sum (Σ) is only proportional to the beam intensity. The ratio of the two signals (Δ/Σ) is only proportional to the beam position.

POSITION PICK-UP - LAYOUT

Position Pickup Hor

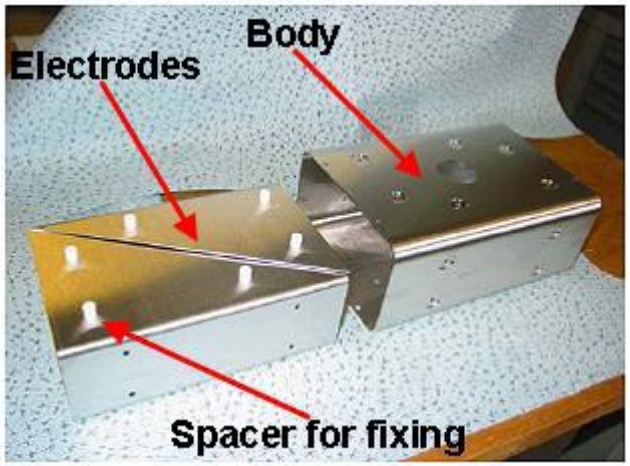
Position Pickup Ver

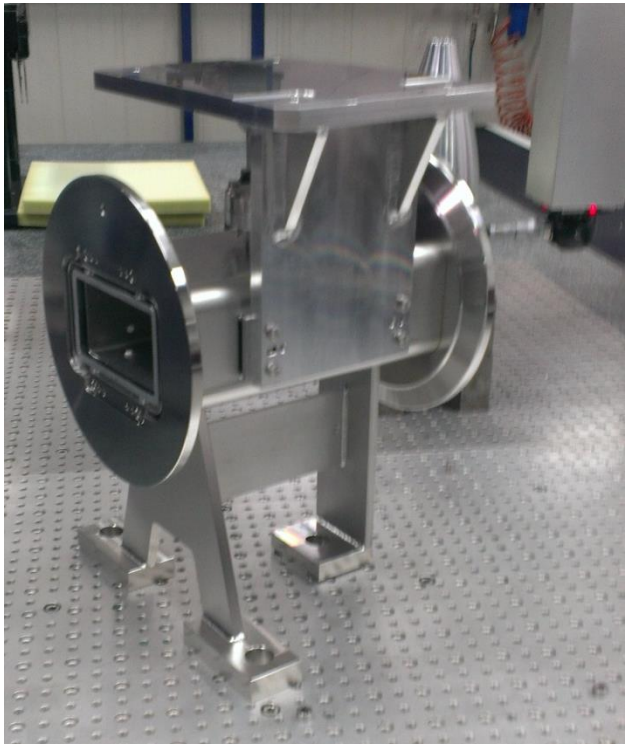


General MA synchrotron parameters

Circumference [m]	77.65
Hor/Ver tune (extr)	1.666 / 1.789
Hor/Ver Chromaticity	-3.655 / -1.1580
Gamma transition	1.97

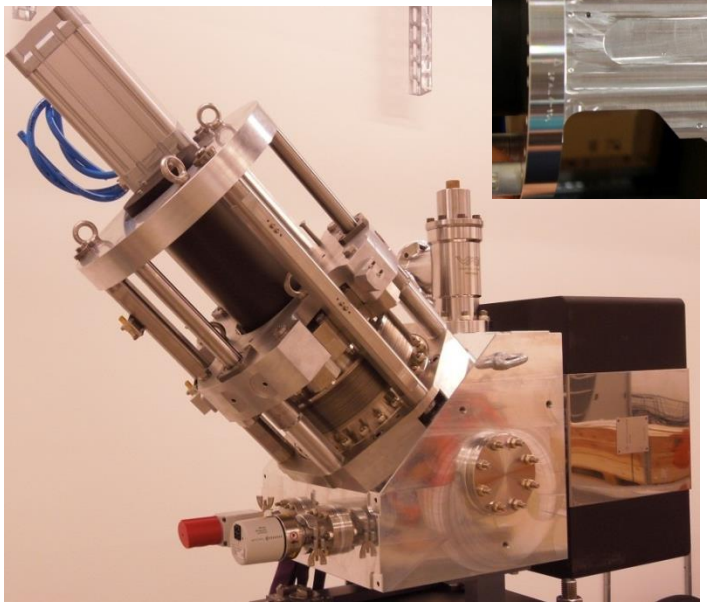
POSITION PICK-UP

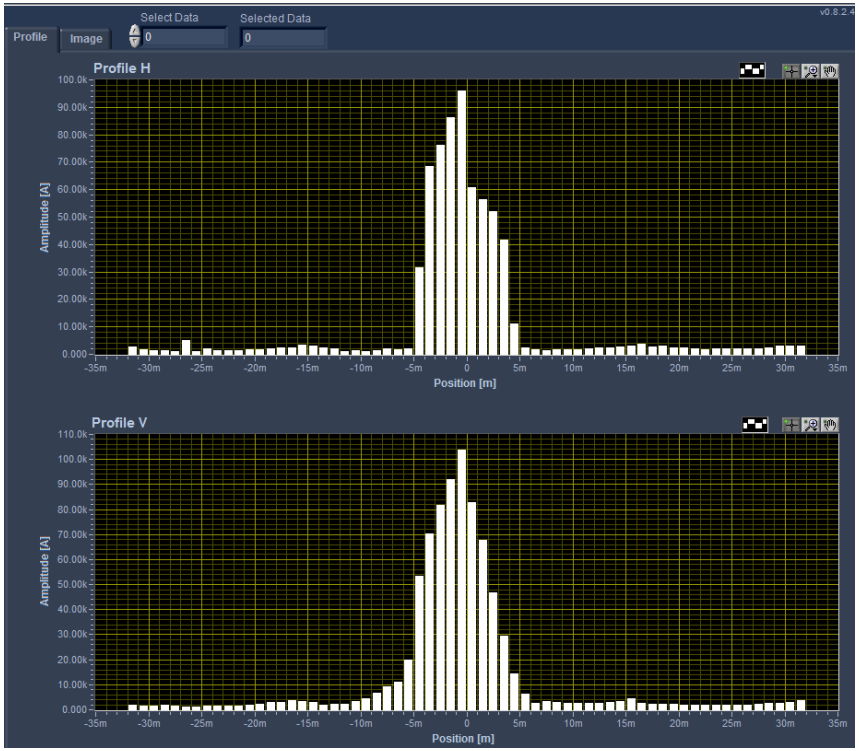




SCINTILLATING FIBER

- **Optical fibers produce photons when hit with beam. The fibers are routed to a glass port for acquisition.**
- **64 x 64 fibers (width of fiber is 1 mm)**
- **Used for:**
  - Measuring the beam profile and position of the beam with energy above 15 MeV/u
  - Measuring the beam along HEBT line





QUALIFICATION MONITOR

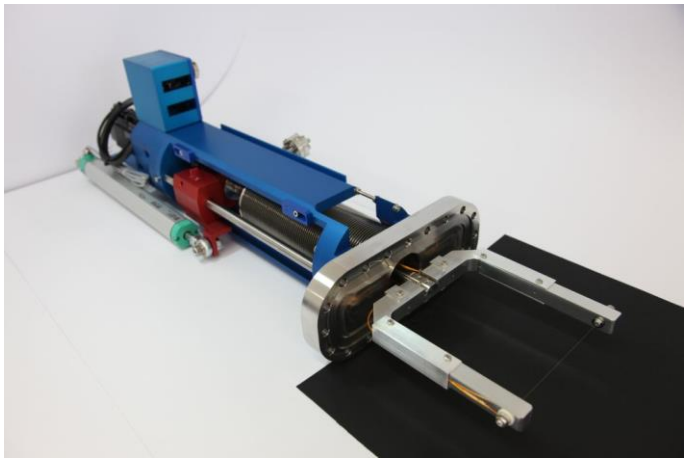
- **In addition to beam profile and position (similar to SFX) it is also an intensity monitor**
- **34x45 fibers**
- **Used for:**
  - Measuring the beam profile and position of the beam with energy above 15 MeV/u
  - Measuring beam intensity

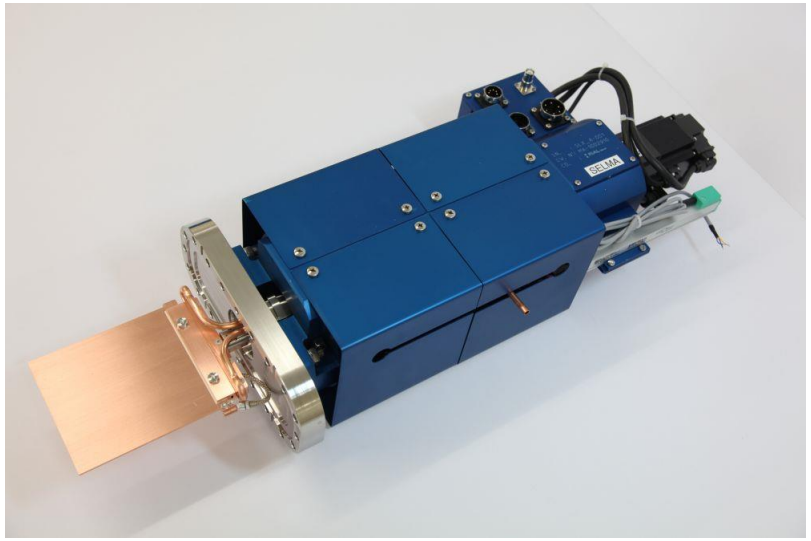
WHAT IS IMPORTANT FOR BD OF MEDICAL ACCELERATOR

- **High uptime → low failure rate**
  - Reliable components
  - Keep it simple (do not over-engineer)
- **Fast recovery if failure occurs**
  - Modular system with same components
  - Simple replacements
- **Low number of different components**
  - Less knowledge needed to be transferred
- **Enough diagnostics for fast machine debugging**
- **Certified components**

MEDAUSTRON BEAM DIAGNOSTICS

- Design partly based on CNAO BD
- Full in-house development
- 153 beam monitors
- 26 different beam monitors
- 16 different beam monitor types
- 2 test benches





Questions?

Thank you for your attention!

FITCH
BD
RULZ