Development of a direct sampling µTCA LLRF system for the MedAustron Injector Regulation and Beam Instrumentation

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Libera Workshop
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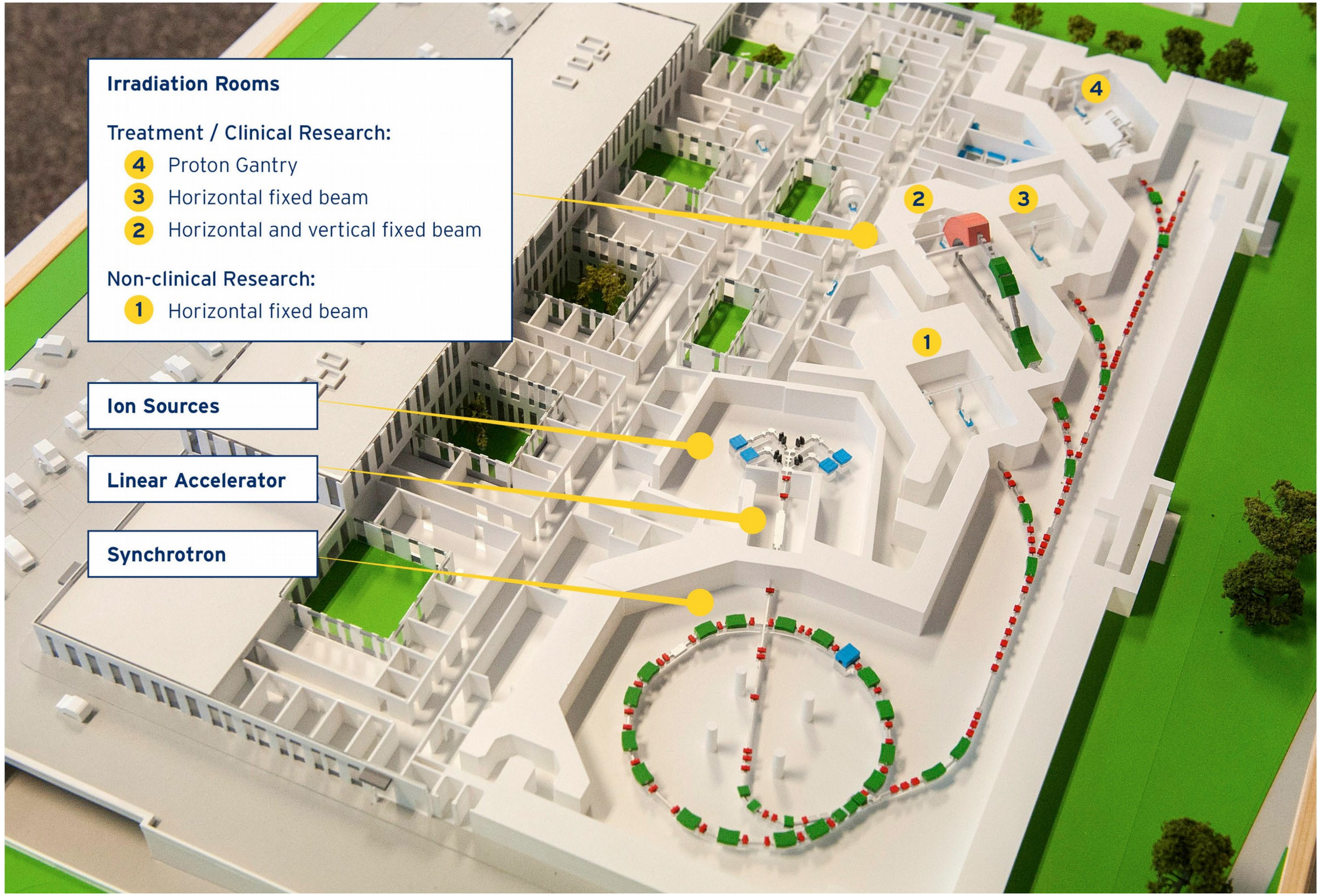
What is Medaustron

- Synchrotron based particle therapy center for cancer therapy
- Particles for treatment are protons and carbon ions
- Machine:
  - Injector (LINAC) at 216.816MHz (7MeV/u)
  - Synchrotron at 400kHz – 10MHz
    - Proton (62 - 252MeV)
    - Carbon (120 - 400MeV)
- Installation started 2012
- Treatment started 2016
- 550 Patients planned for 2022



Reasons for the upgrade

- Components are EOL
  - Hardware not produced any more (Spare Parts!)
  - Software on Windows XP
- Limited support and internal knowledge
  - No official support by the supplier any more
  - Source code not available for internal support
- Different systems for the Injector and the Synchrotron
  - No synergies for developments done in the old systems
- Missing data access
  - e.g. regulation error, root cause for stopped operation not available
  - Limited pulse shaping options

Project Setup

- Collaboration between Instrumentation Technologies and MedAustron
- Common project management tools and code repository
- Weekly progress meetings with both teams
- Regular integration testing at Instrumentation Technologies

Requirements and Selected Hardware

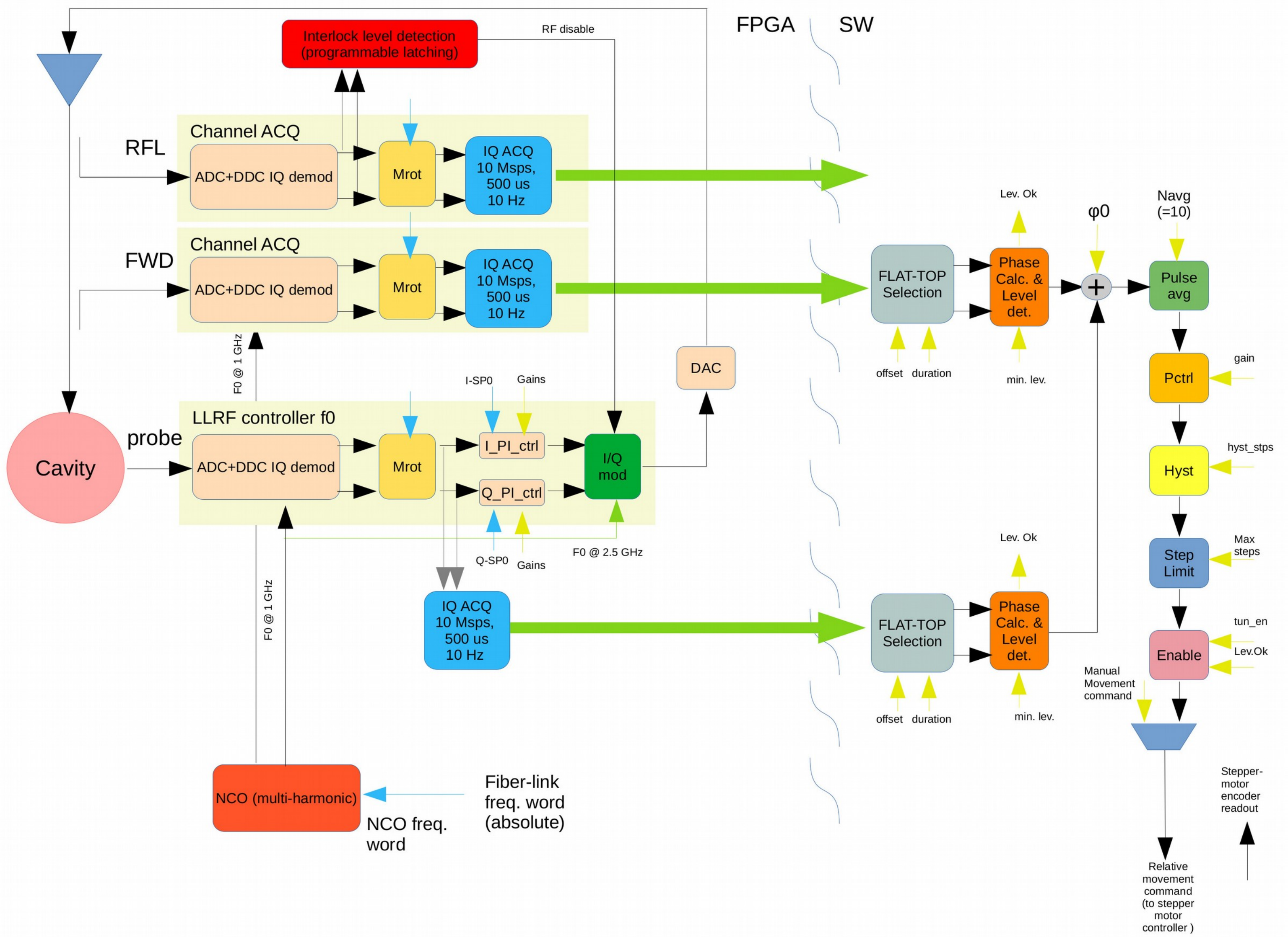
Requirements

- CotS Hardware – we do not have resources for hardware development
- Technical Requirements
  - Frequency range 400kHz – 220MHz for Injector and Synchrotron compatibility
  - Stability (Amplitude 0.05% RMS, Phase 0.1° RMS)
  - Real Time „Pulse“ Control
  - Cavity tuning (iLLRF)
  - Frequency ramping (sLLRF)
  - Multiple Harmonics (sLLRF)

Selected Components

- µTCA Hardware from Vadatech
  - 2U Chassis with 6-8 AMC slots (VT812/VT814)
    - Reference clock distribution
    - Chassis management, Ethernet distribution, …
  - AMC 560 FPGA cards
    - 2x FMC slots
    - Xilinx Zynq Ultrascale+
    - Clock distribution
  - FMC 231 Analog Frontend Cards
    - 4x 16bit ADC @ 1GSps
    - 4x 16bit DAC @ 2.5GSps
  - FMC 105
    - 4x SFP+
  - FMC 155
    - 8x RS485
    - GPIO

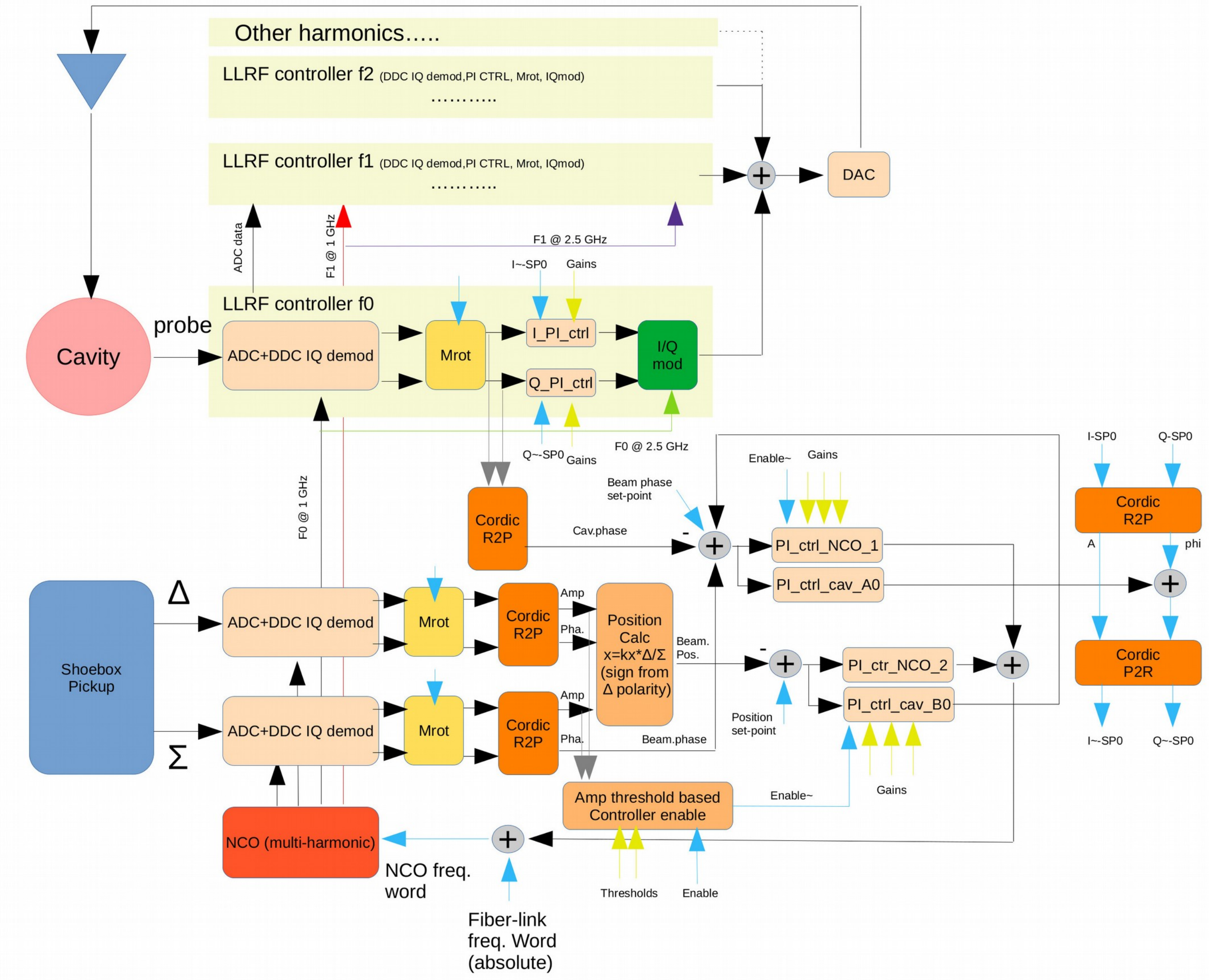
Firmware Architecture



INSTRUMENTATION TECHNOLOGIES

MedAustron Ionentherapiezentrum

Firmware Architecture



Injector Beam Diagnostics – Energy Measurement

- 4 phase probes at different downstream positions
- Measure phase of probes and calculate time of flight for the particles
- Energy reproducible
  - Commissioning helium, IH cavity amplitude scan
- Energy fluctuations over the „Spill“
  - Old iLLRF introduces noise

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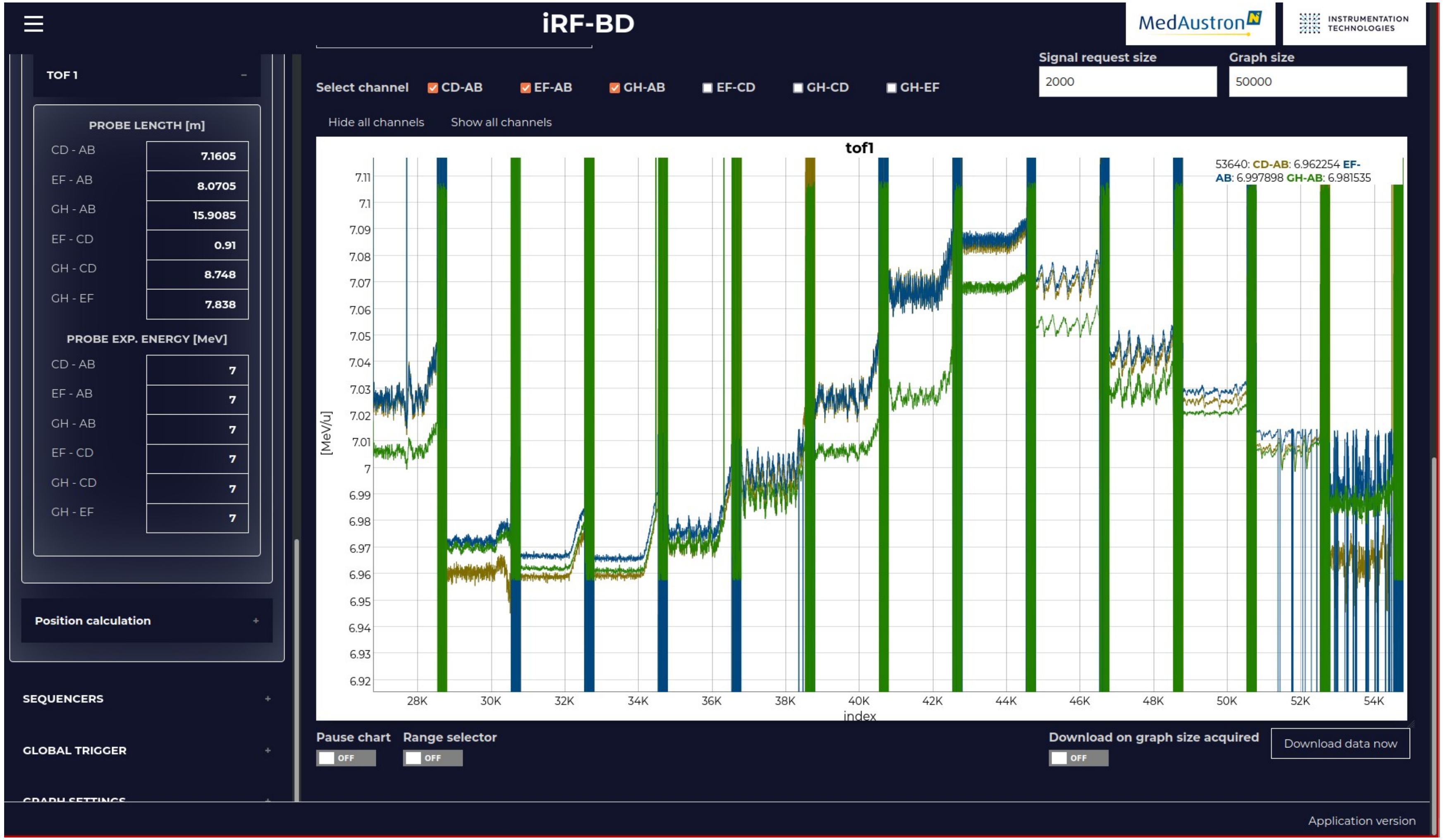

RF Pulse Generation

- Test Setup without a cavity (Our Linac is in use and cavity tuning is not ready)
  - DAC output (max 0dBm) → 30dB Attenuation → 40dB low noise Amplifier → ADC input (max 10dBm)
- Frequency dependent phase correction (Matrix rotation) to compensate for static cable delays
- Frequency sweep from 2MHz to 302MHz in 33MHz steps
- Phase sweep from -90 to +90° in 20° steps
- Steps every 100µs, 1ms total pulse length
- Preliminary PI coefficient setup

RF Pulse Generation

- PI setup not ideal yet, might not be possible for this frequency range
- 0.3° Phase noise (peak to peak) at 202MHz (0.1° @2MHz)
- 0.1% Amplitude noise (peak to peak) at 202 and 2MHz

Conclusion

- Effective collaboration even with remote work
- Measurement results fulfill or exceed our requirements
- Linac Cavity Control and Beam Instrumentation are implemented and ready to use
- Synchrotron regulation (regulation on beam feedback) partially implemented
- Knockout extraction planned but not implemented yet

Thank you

Questions?