VARIAN

medical systems

Commissioning and Testing of Varian's 250 MeV Superconducting ProBeam™ Cyclotrons for Proton Therapy

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OUTLINE

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- Conclusion

VARIAN ProBeam™ SC Cyclotron Key Data
(Engineering Goals)

➢ **Beam**	- Energy and particles	250 MeV protons
	- Extracted current (max)	800 nA
	- Emittance of extracted beam	< 3 / 5 π mm mrad (2σ)
	- Momentum spread Δp/p	±0.04% (i.e. 200keV @ 250MeV)
	- Number of turns	650
	- Extraction efficiency (multi-turn extraction mode)	~80%
	- Dynamic range for intensity modulation	1:800
	- Fast intensity modulation	via electrostatic deflector, >10% in 100 μs
➢ **Iron Yoke**	- Outer diameter	3.1 m
	- Height	1.6 m
	- Weight	<90 t
➢ **SC Magnet**	- Stored energy	2.5 MJ
	- Central field	2.4 T
	- Max. field at the coil	<4 T
	- Operating current	160 A
	- Rated power of cryocoolers	40 kW
➢ **RF System**	- Frequency	72.8 MHz (2nd harmonic)
	- Voltage source to puller / @ extraction radius	80 kV / 105 kV
	- RF power	≤115 kW

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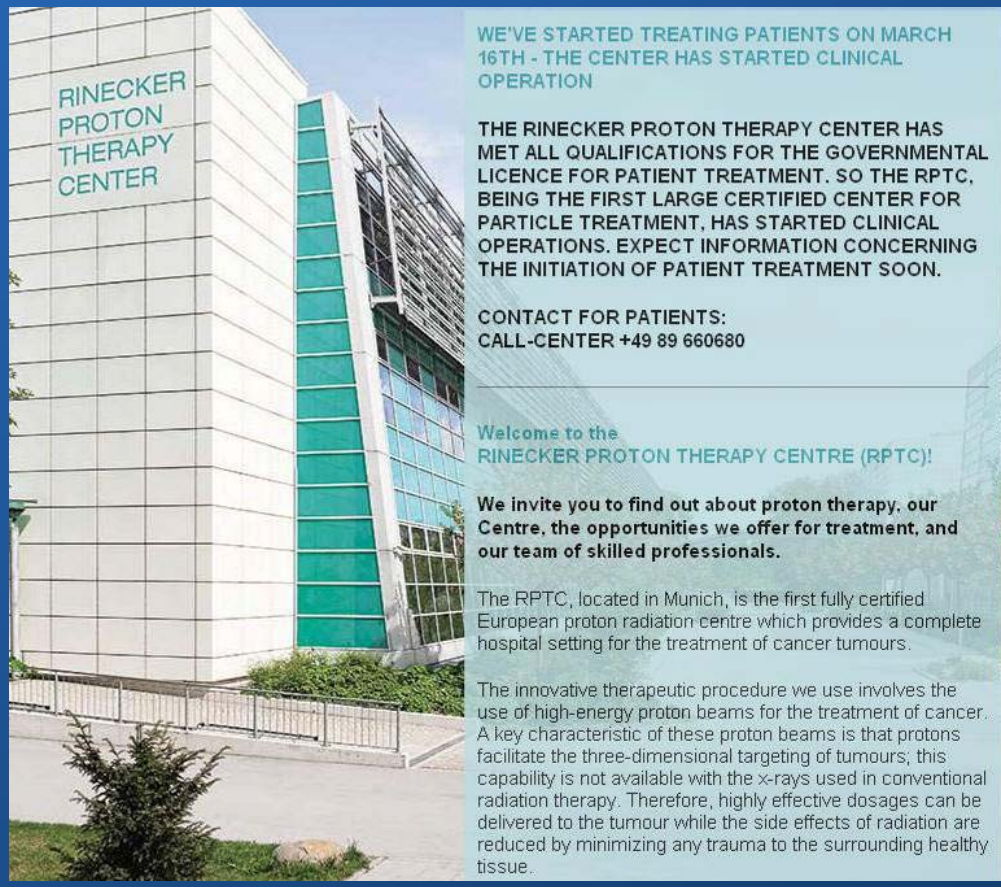
- Patient treatment started at RPTC Munich, all scanning proton therapy treatment equipment provided by Varian



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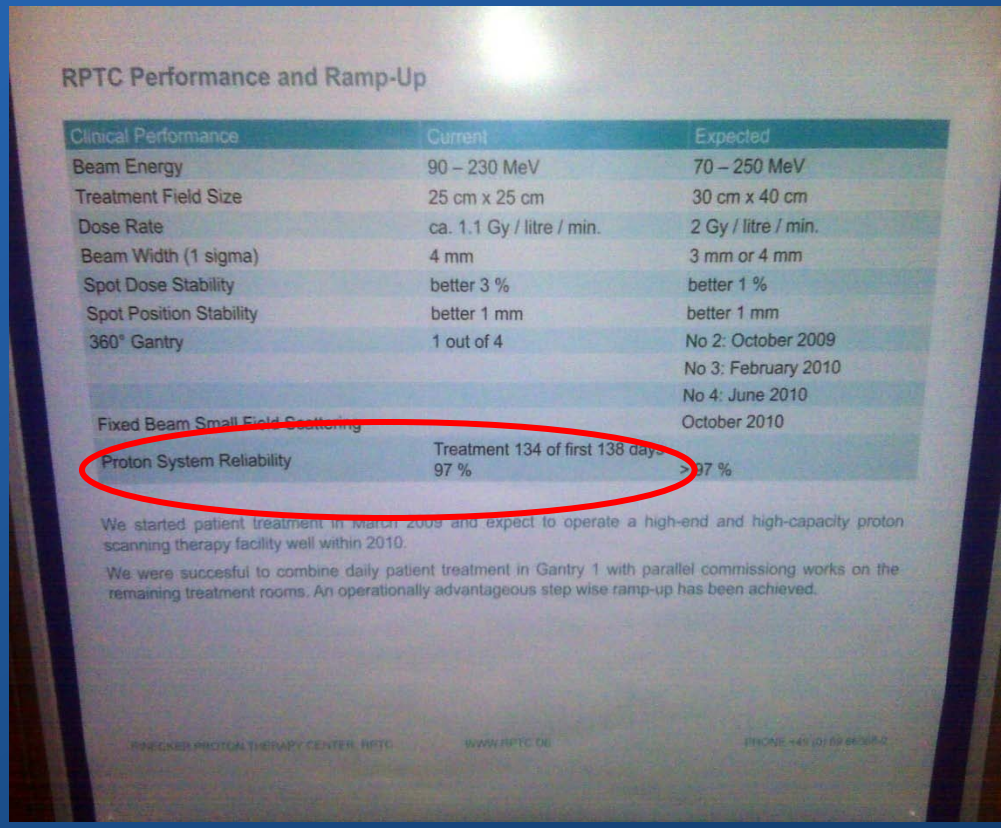

RPTC Performance and Ramp-Up

Clinical Performance	Current	Expected
Beam Energy	90 – 230 MeV	70 – 250 MeV
Treatment Field Size	25 cm x 25 cm	30 cm x 40 cm
Dose Rate	ca. 1.1 Gy / litre / min.	2 Gy / litre / min.
Beam Width (1 sigma)	4 mm	3 mm or 4 mm
Spot Dose Stability	better 3 %	better 1 %
Spot Position Stability	better 1 mm	better 1 mm
360° Gantry	1 out of 4	No 2: October 2009
		No 3: February 2010
		No 4: June 2010
Fixed Beam Small Field Scattering		October 2010
Proton System Reliability	Treatment 134 of first 138 days: 97 %	> 97 %

We started patient treatment in March 2009 and expect to operate a high-end and high-capacity proton scanning therapy facility well within 2010.

We were succesful to combine daily patient treatment in Gantry 1 with parallel commissiong works on the remaining treatment rooms. An operationally advantageous step wise ramp-up has been achieved.

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Supplied by Cryoelectra GmbH

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- ProBeam™ Cyclotron #3 was being assembled

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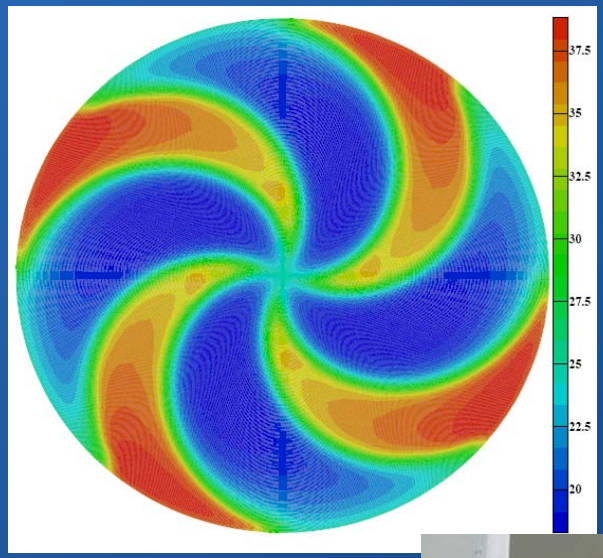

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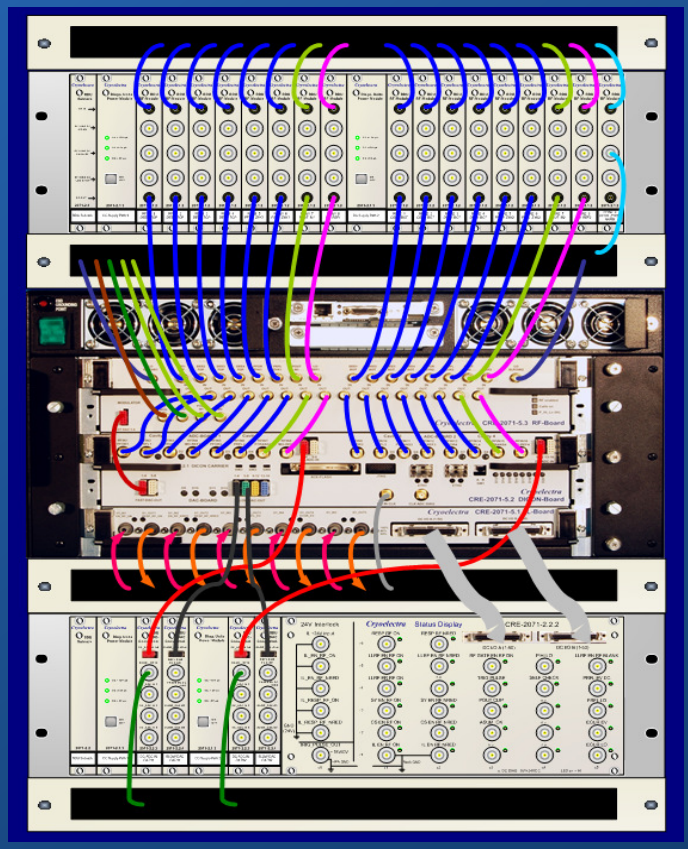

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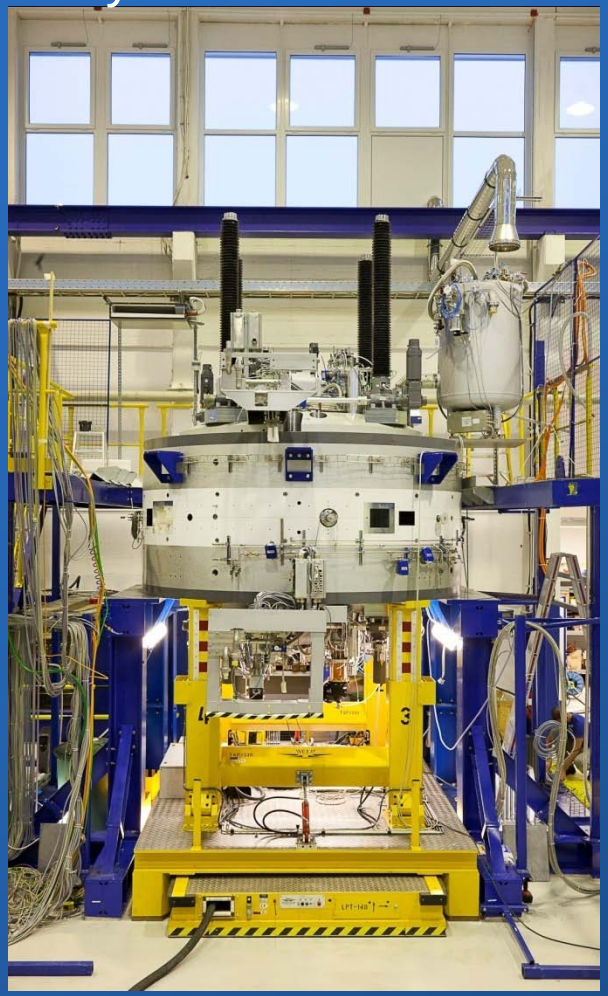
- Factory Test Cell was ready for operation

Current Status of Varian's ProBeam™ Systems

- RPTC Munich: All 4 gantries are clinical
  >1000 patients have been treated with a scanned proton pencil beam
  functionality is continuously being upgraded
  cyclotron is in continuous operation
- Cyclotron #3 RF conditioning is performed very efficiently
  using transistor amplifier and digital LLRF
- Cyclotron #3 was beam tested in the factory test cell
- Cyclotron and all other ProBeam™ PT equipment is shipped
  and installed at Scripps PTC in San Diego / USA
- First beam in April!
- Cyclotron #4 is under assembly
  coil is ready
  cryostat is ready and passed LN cold test
  complete machine will go into test cell in summer
- Cyclotron #5 coil is ready and electrically tested
  cryostat has to be completed

Factory Testing of Cyclotron #3

- Cyclotron #3 was moved into factory test cell



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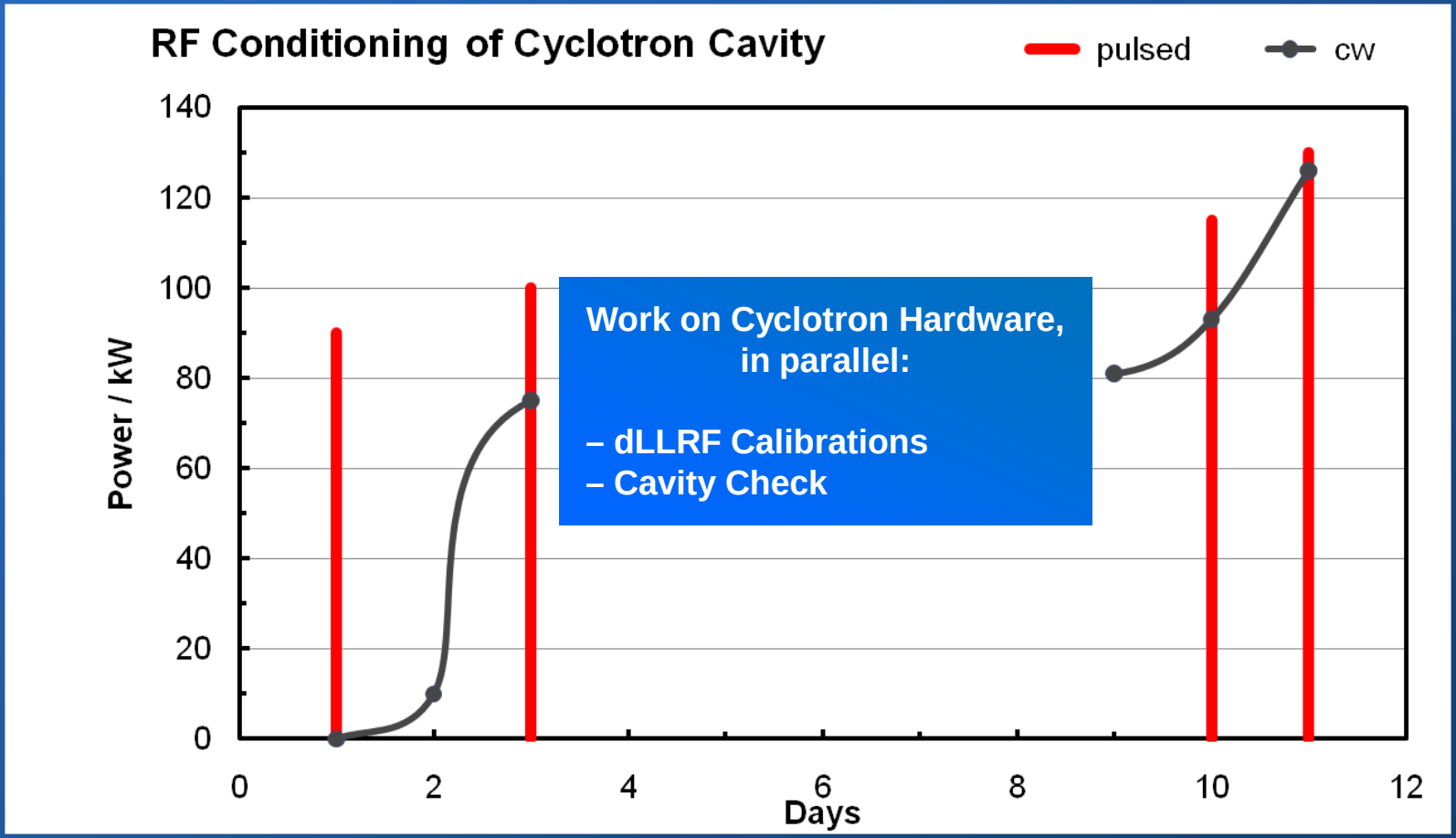
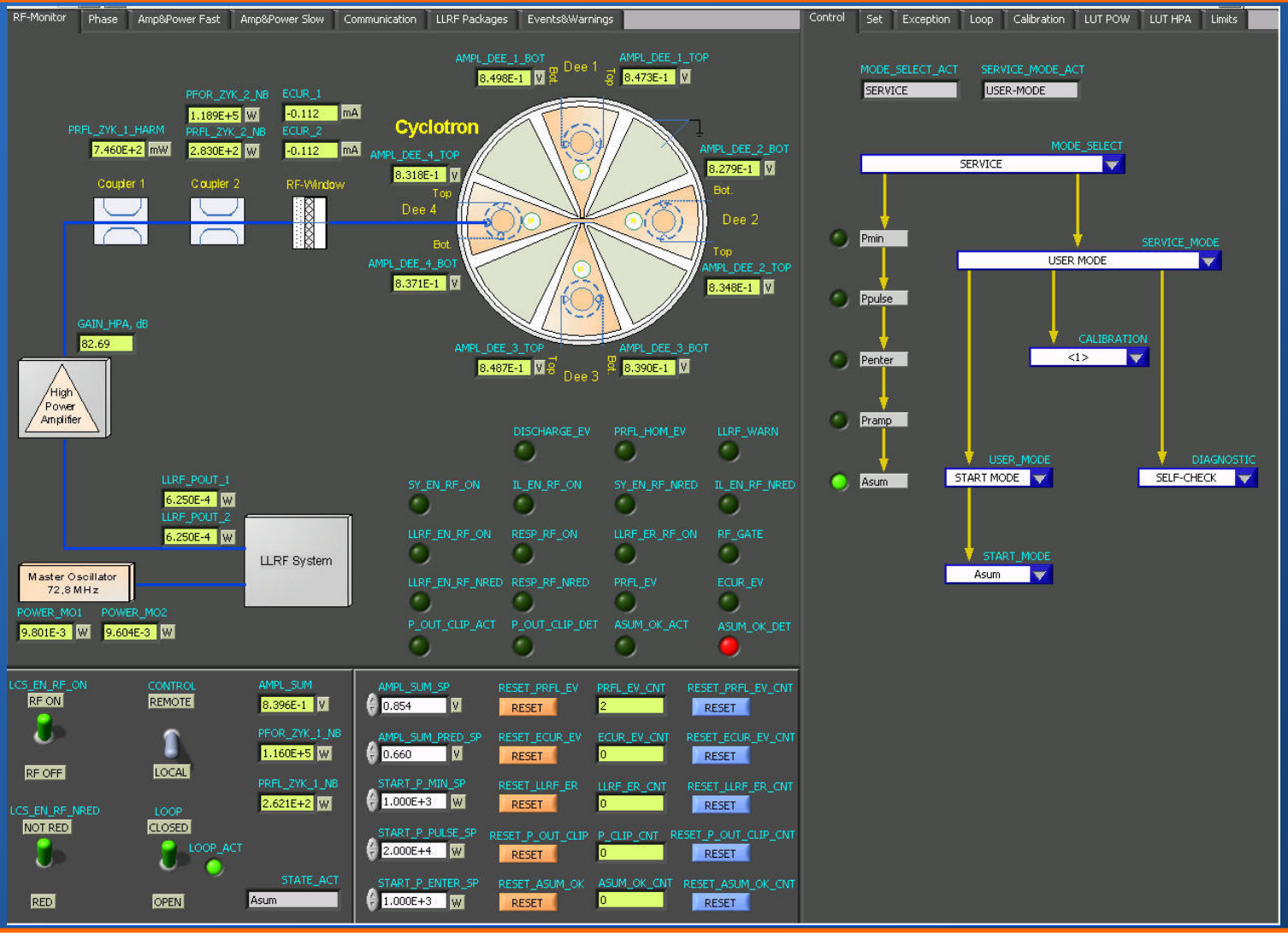
RF Commissioning Results

Solid State Amplifier & Digital LLRF → Very Fast RF Conditioning in Pulsed Mode (5% - 20% duty cycle)



Digital LLRF Control System



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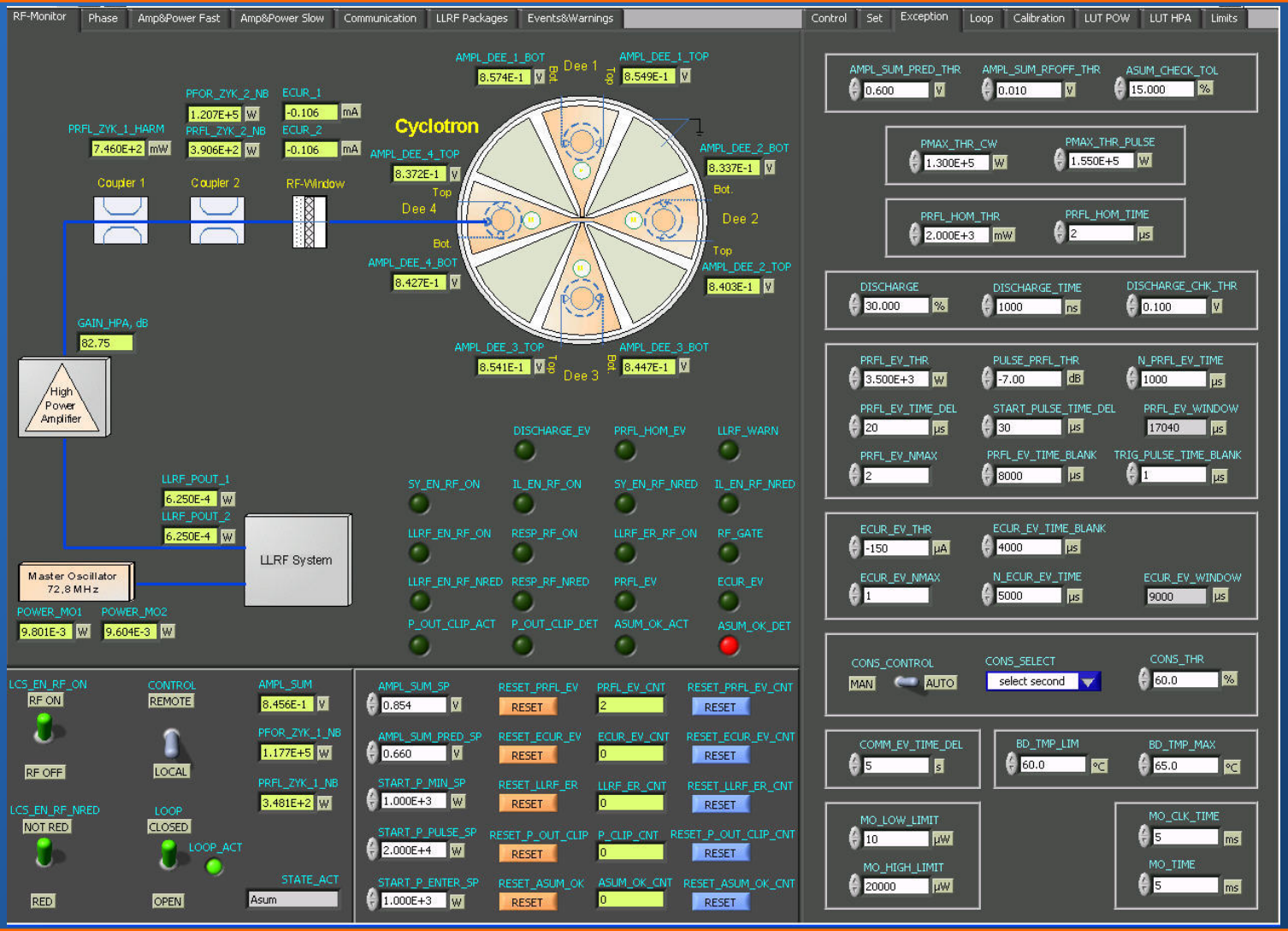

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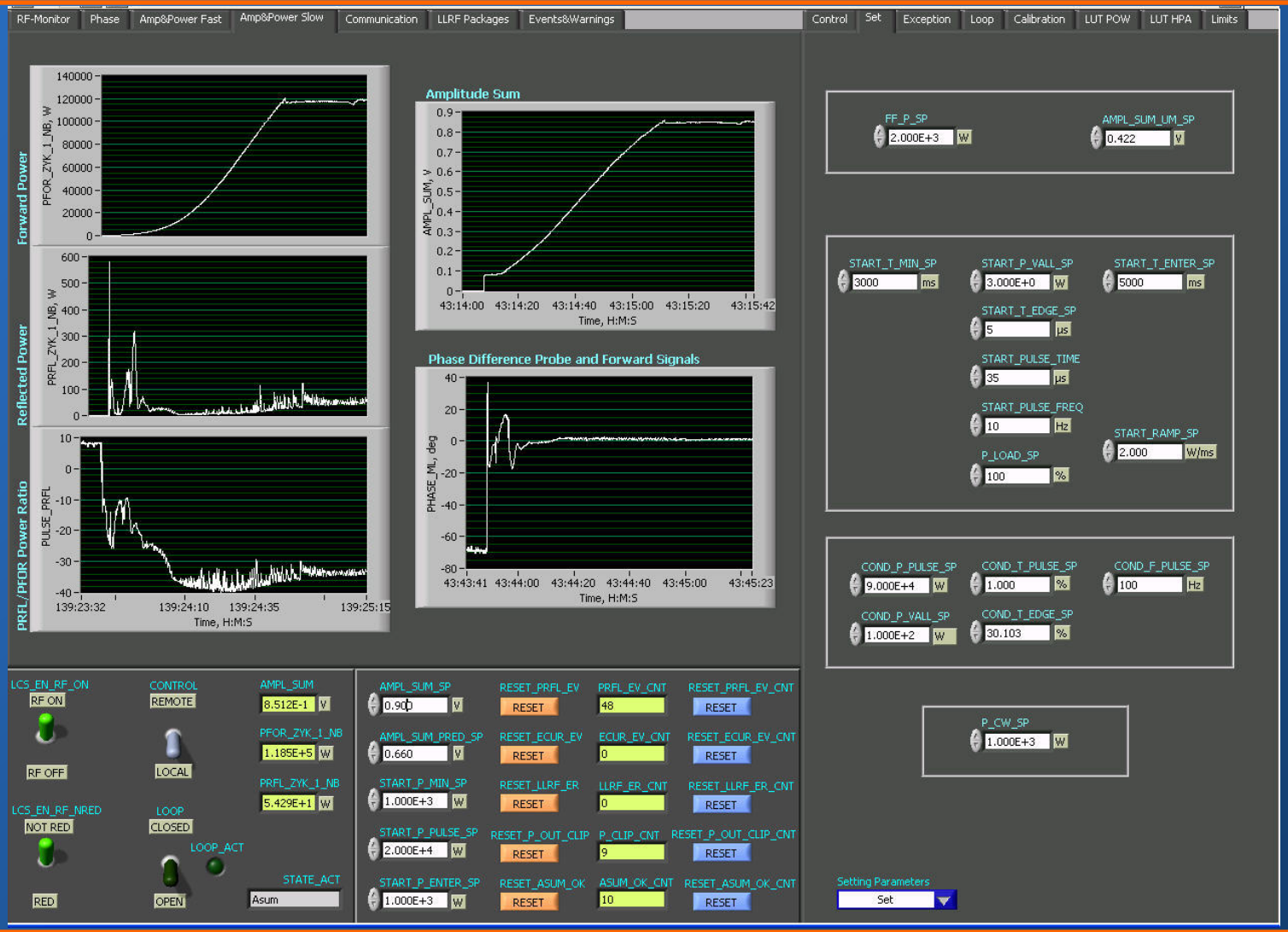
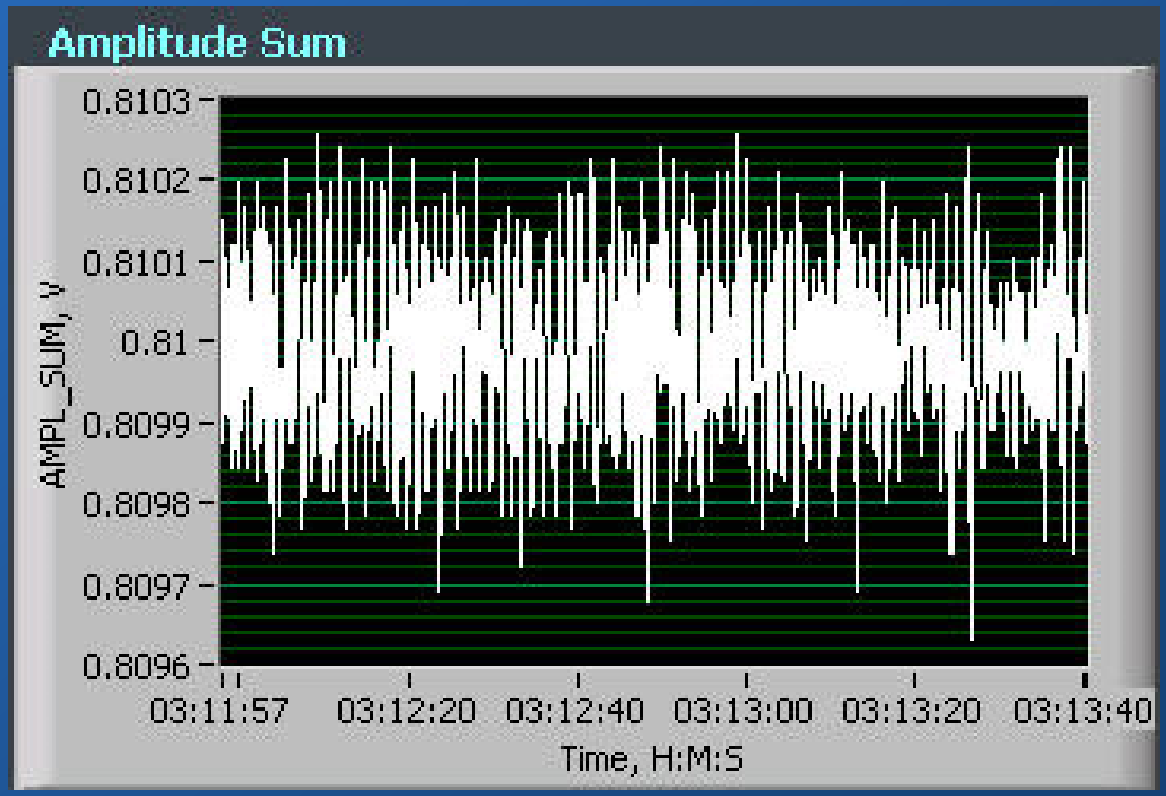


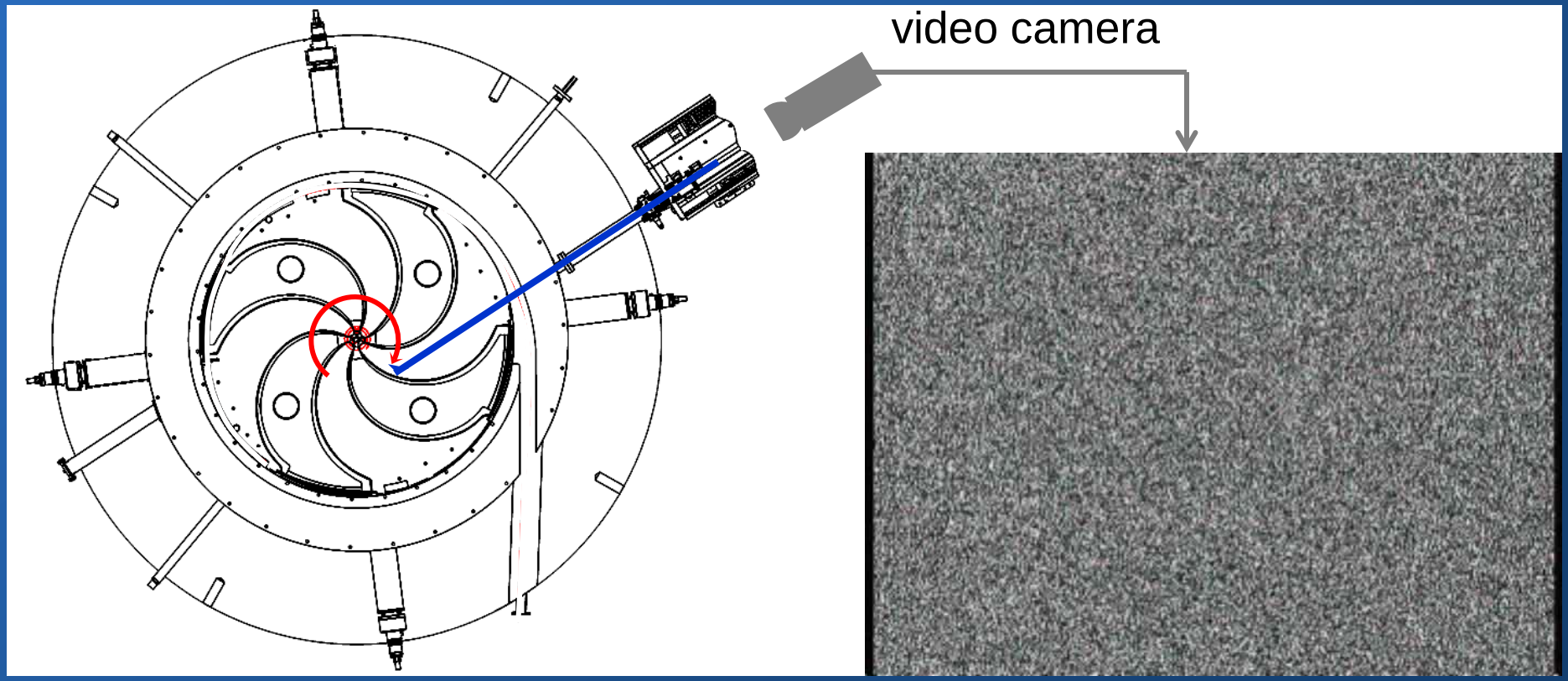
RF Amplitude Stability

$\Delta V/V \approx 2\times10^{-4}$ (1σ)
$\Delta V/V \approx 6\times10^{-4}$ (pp)



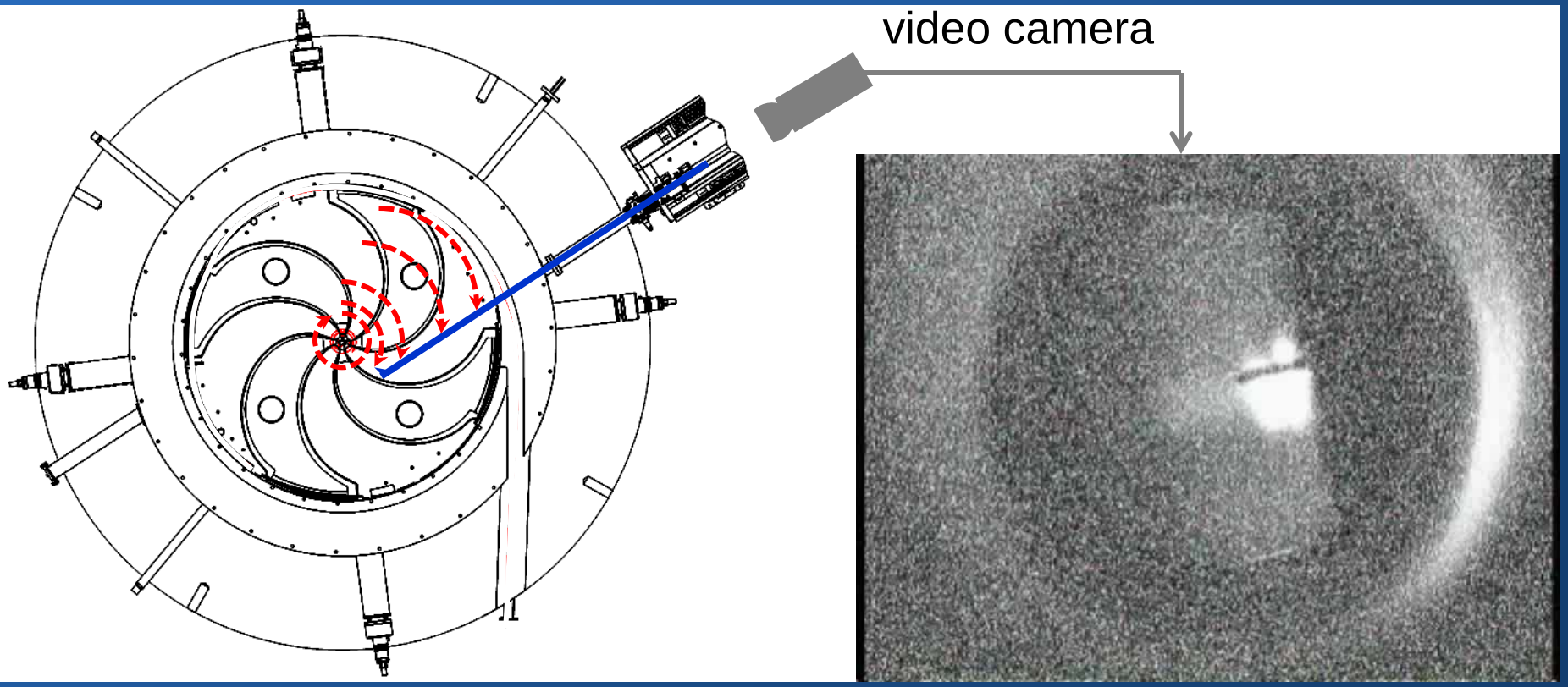
First Internal Beam, June 8, 2011

- System prepared (magnet & RF ramped up, viewer probe with video camera installed near cyclotron center)
- First switch-on of ion source



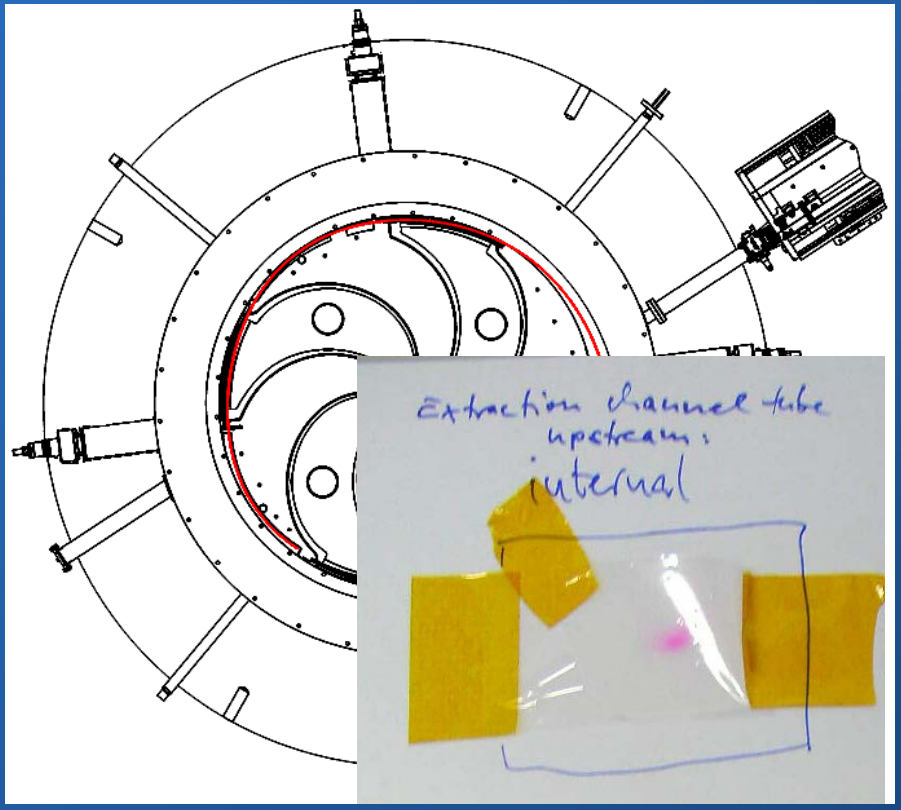
Beam Development, June 9, 2011

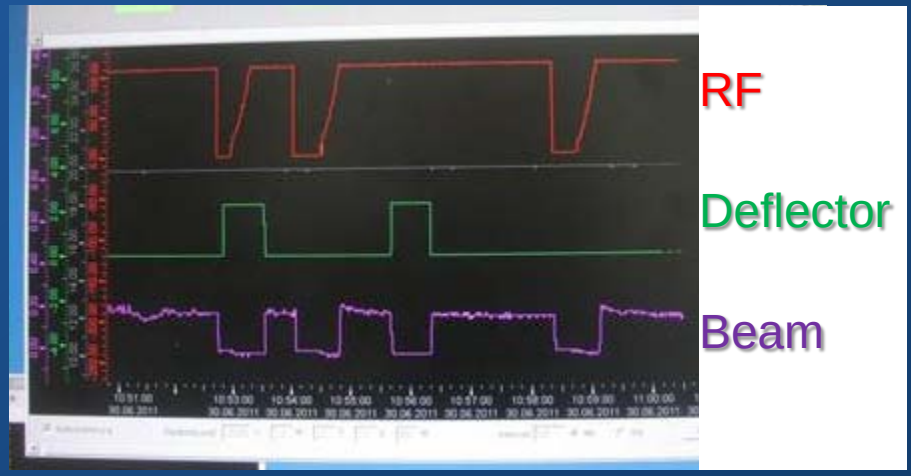
- Already on the next day it was possible to bring the beam close to extraction radius



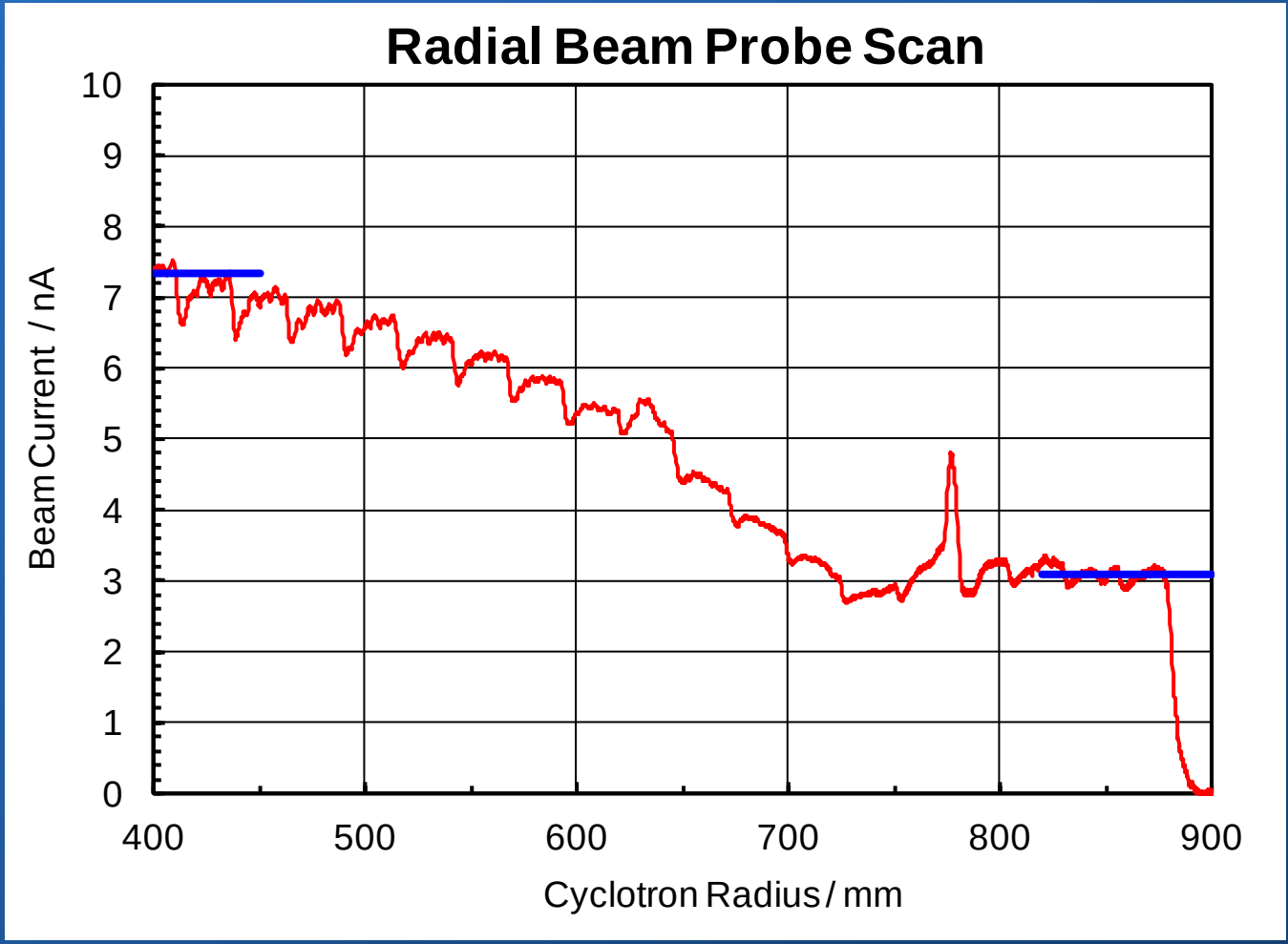
First Extracted Beam, June 29, 2011

- 1st extracted beam:





Extraction Efficiency ~40%, July 15, 2011



Transport to the USA, 2011

- Disassembly and packaging end of July

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- Shipping August to September

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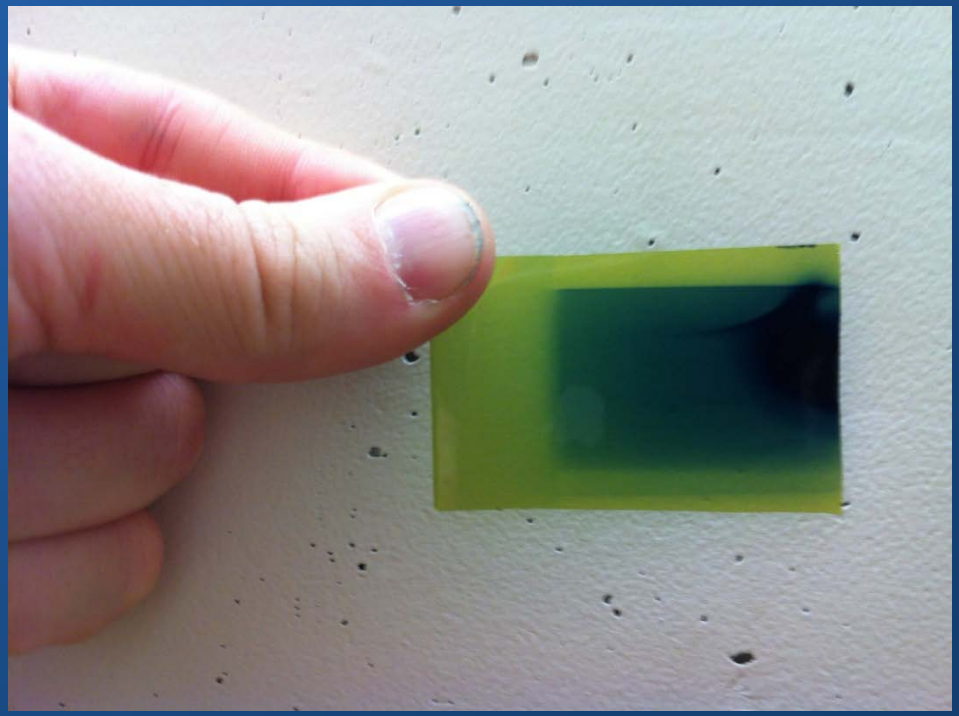
First Beam On Site, 2012

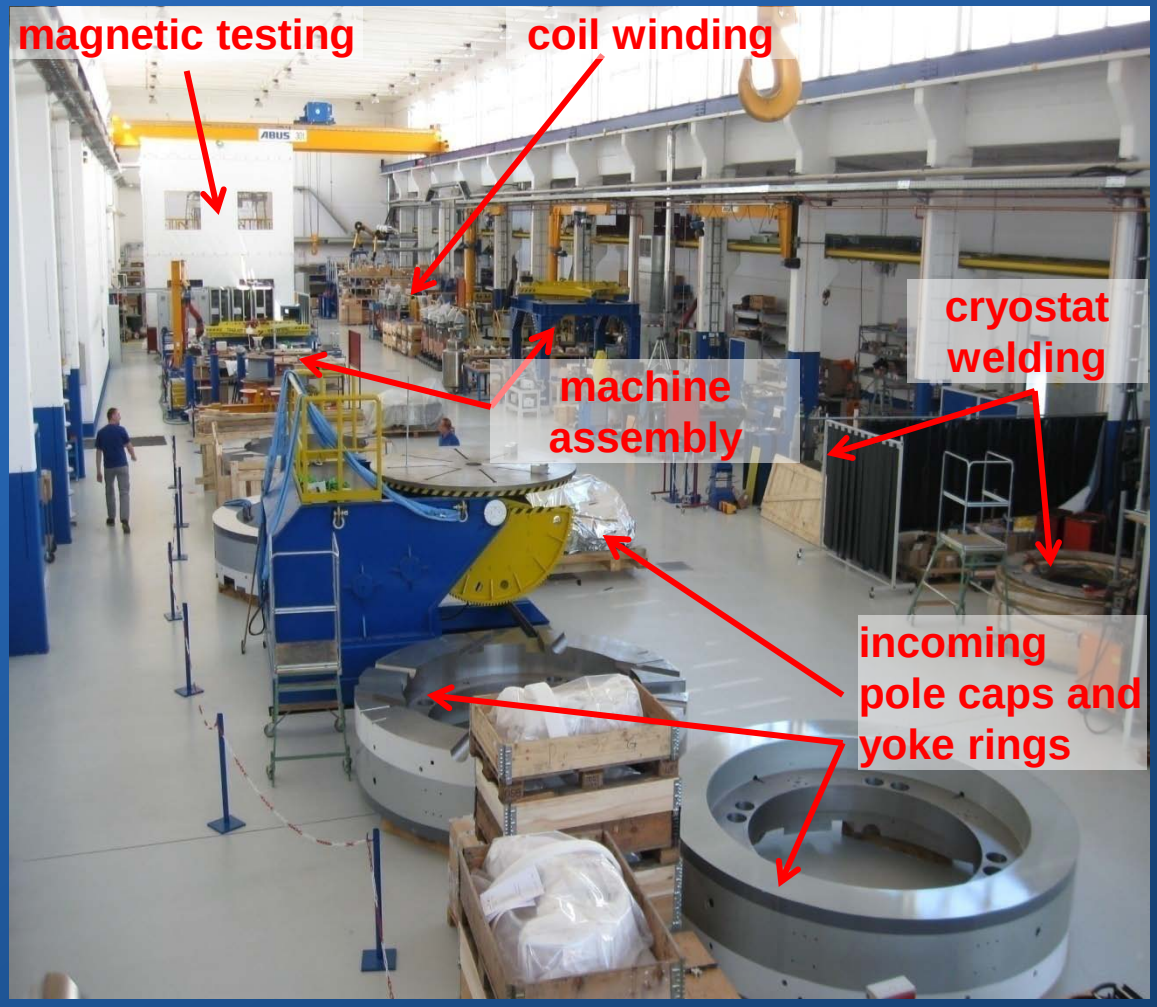
- November to December 2011: Cabling, installation of beamline
- January 2012: Cyclotron powered and cooled down
- February: On site magnetic field verification after transport
- March: RF re-conditioning
- April 18: First beam on site!

Without any re-tuning,
all parameters known from
the factory testing.



Production of Further ProBeam™ Systems

- Cyclotron Production Hall



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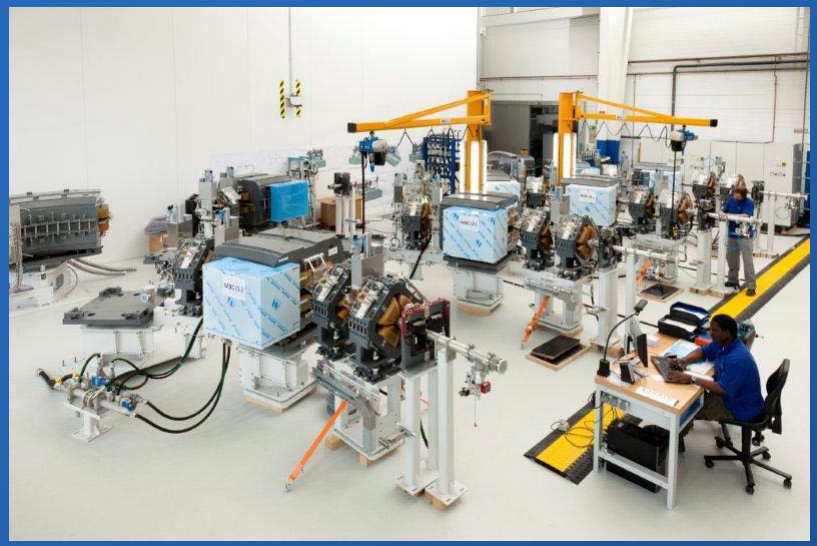
Production of Further ProBeam™ Systems

- Other production areas:
  - Beamline modules



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- Other production areas:
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  - Scanning nozzles

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- Other production areas:
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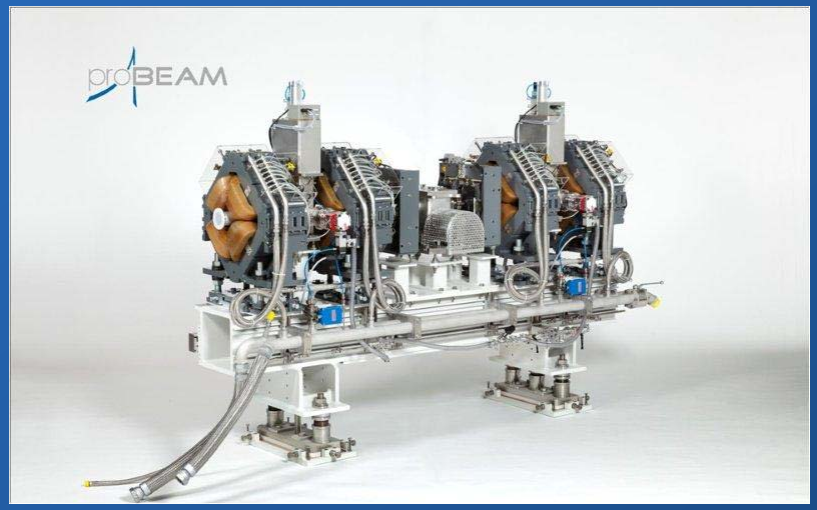
  - SW test center

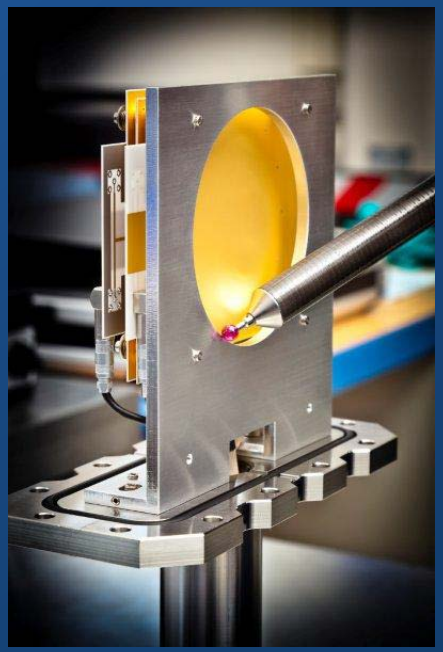


Status of ProBeam™ Cyclotrons #4 & #5

- Cyclotron #4
  - Pole caps and yoke rings are being equipped with components
  - All media get connected
  - Cryostat is completed and passed electrical and LN2 tests

Status of ProBeam™ Cyclotrons #4 & #5

- Cyclotron #5
  - Coil is completed and passed electrical tests, cryostat welding will start soon
  - Yoke rings and pole caps passed factory incoming inspection
  - Assembly will continue in parallel to #4 testing



Conclusion

- The VARIAN ProBeam™ Superconducting Compact Proton Cyclotrons feature superior properties that make them turn-key operational machines and predestine them for use in pencil beam scanning proton therapy.
- 2 of such cyclotrons are already in clinical use.
- #3 is currently being commissioned at customer's site, first beam was extracted in April 2012.
- Several more machines are in production.
- All cyclotrons will be factory tested with beam.
- VARIAN is continuously developing its technology further and introducing new features.
- Recent product enhancements include Transistor RF Power Amplifiers and Digital Low Level RF electronics.

- cw proton beam
- high energy
- high current
- stable beam position
- small footprint
- high extraction efficiency
- low activation
- fast and easy access for maintenance
- high uptime
- operator-free operation
- low power consumption

THANK YOU!