# Indiana University Cyclotron Operation for Proton Therapy

**1. Introduction:**

- Brief History of IUCF Accelerator Facilities
- Cyclotron Conversion to Proton Therapy

**2. Accelerator system components**

- 750 MeV Pre-Injector
- K15 Injector Cyclotron
- K220 Main Cyclotron
- Beam Distribution to Treatment Room

**3. IUCF Operation experience through 2007**


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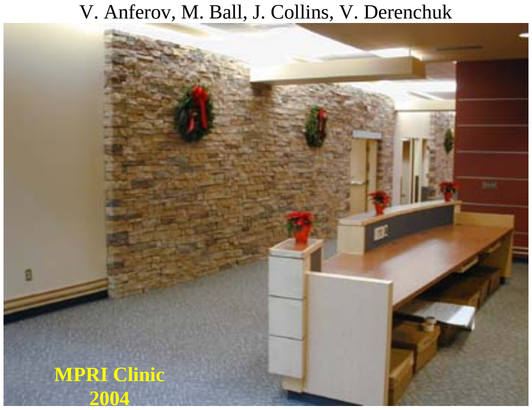
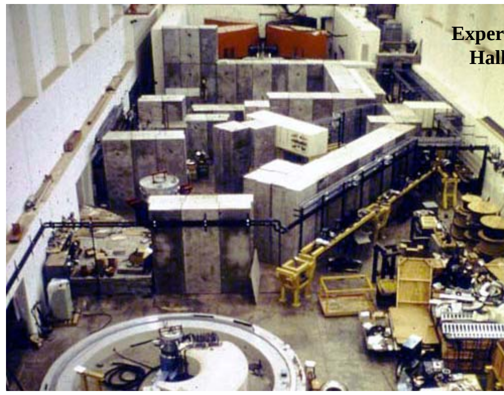


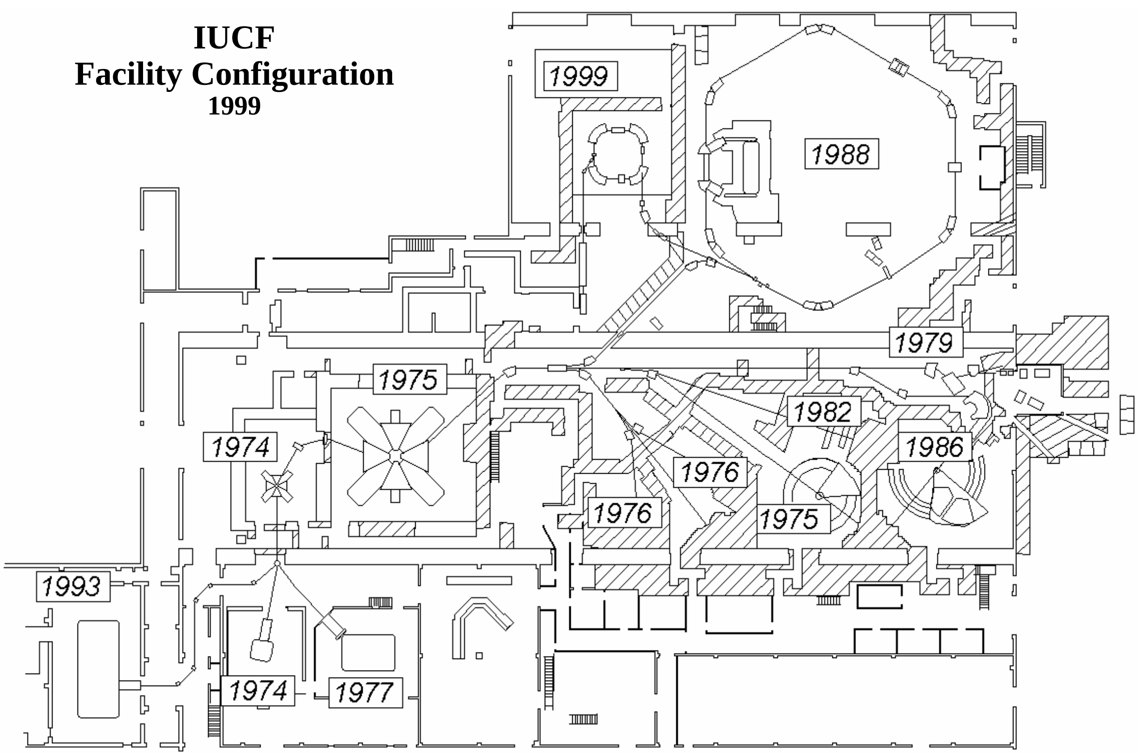



Experimental Hall 1975



# *History of IUCF Accelerator Facilities 1974-1999*

**IUCF**
**Facility Configuration**
**1999**



# IUCF Cyclotron Conversion to Proton Therapy

- IUCF Cyclotron ceased delivering beams for nuclear physics research in 1999.
- In 2000 IU released Sate and Federal Funds for conversion to a Proton Therapy Facility.
- Reliability Review of Cyclotron operation at the peak production years (1983-93) concluded:

**Major Sources of Cyclotron Down time**
1983-1993

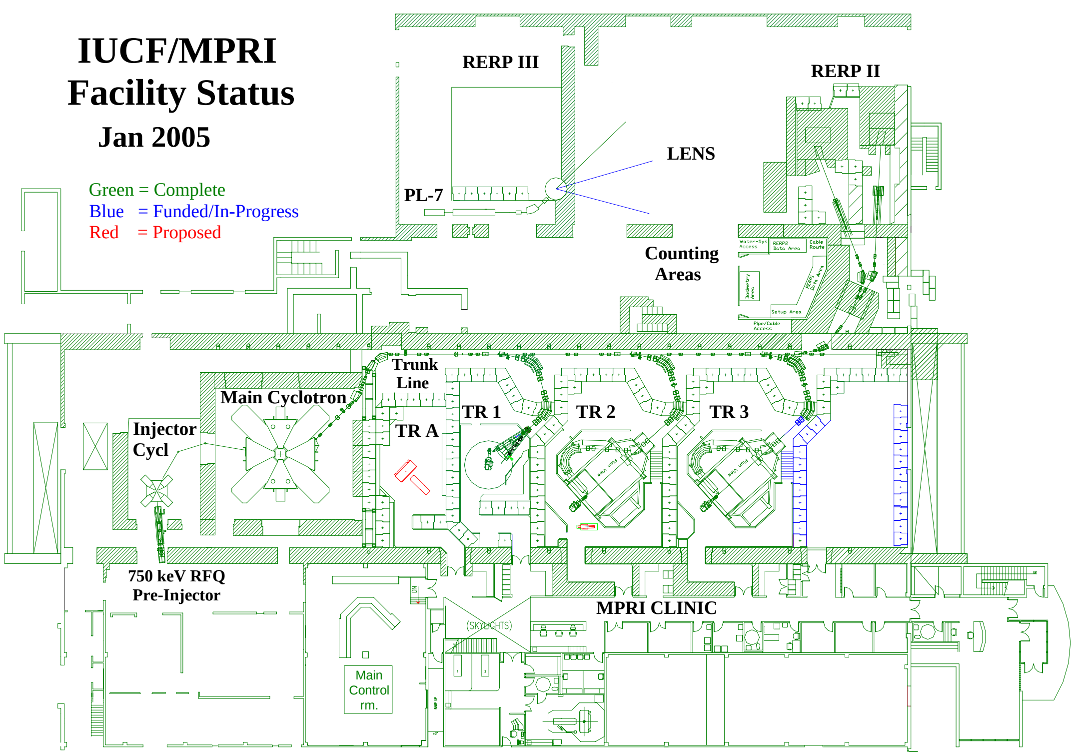
- Variable energy operation (extended tuning, hardware stress)
- Cockroft-Walton pre-accelerator and polarized ion source together accounted for 50% of down time in some years
- Remainder of accelerator systems had 95% reliability record

**Proposed Upgrades:**

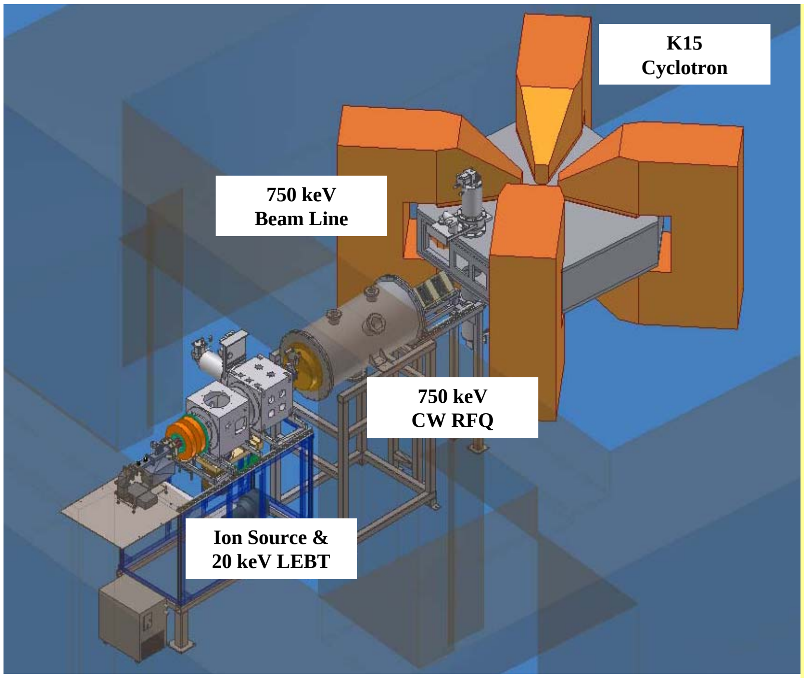
- Constant energy operation (with optimized subsystem performance)
- Commercial 750keV RFQ instead of 600keV pre-accelerator
- Conversion to new control system
- Upgrades to trim coil power supplies and to de-ionized cooling water system.



# MPRI Construction 2000-2005



# 750 keV Pre Injector




**750keV RFQ replaced 600keV Cockroft-Walton high voltage terminal.**

**Microwave Ion Source:**

- Operates CW ~5mA extracted current
- Beam is collimated to 1mA
- Maintenance interval is 6 month

**20keV LEBT:**

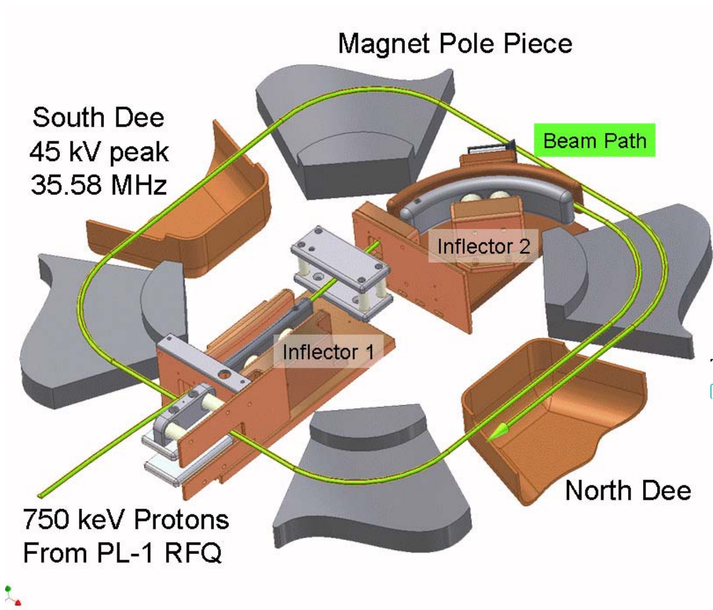
- 3 solenoid lenses to focus beam into RFQ
- Electrostatic chopper @ 17.79MHz=Frf/2
- Chopper provides intensity control
- Dynamic range is from 0.5nA to 200nA

**750keV CW RFQ:**

- Operates at 12.Frf = 213.48MHz
- Nominal Power 12.5kW (run at 12.3kW)
- Phase and frequency locked to Cyclotron



# 750 keV Beam Transport and Inflection

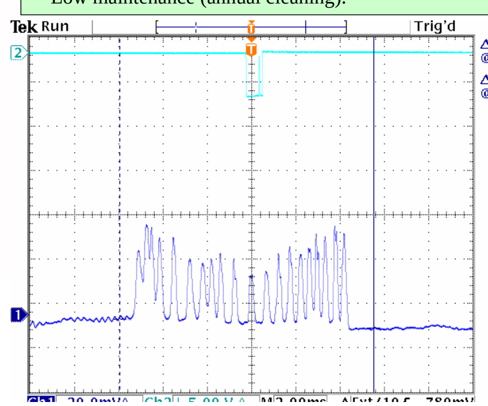



**Redesign of the Injector Cyclotron Central Region for optimal inflection onto the first orbit.**

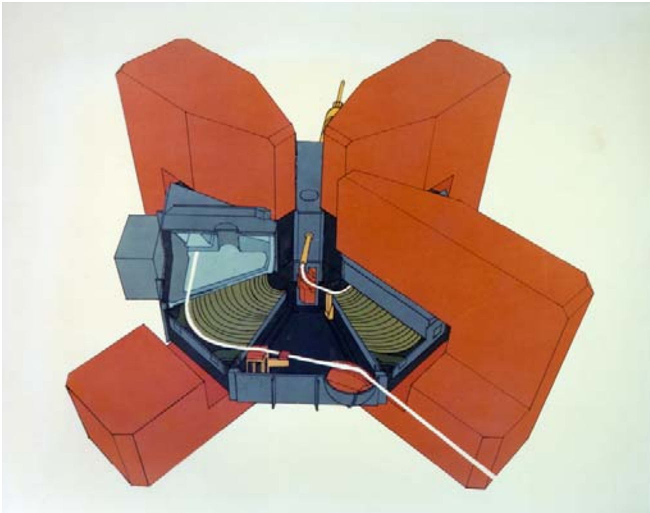
- Magnetic map of the injection valley
- RFQ is on 5.6 deg line to help inflectors
- Inflector 1: -25kV across 0.385” gap
- Inflector 2: +65kV across 0.185” gap
- Phase slit was added at the radius of the 4th turn

**RESULT:**

- Clean injection, good turn structure, easy tuning.
- Low maintenance (annual cleaning).



# IUCF K220 Cyclotron



## Operating Parameters

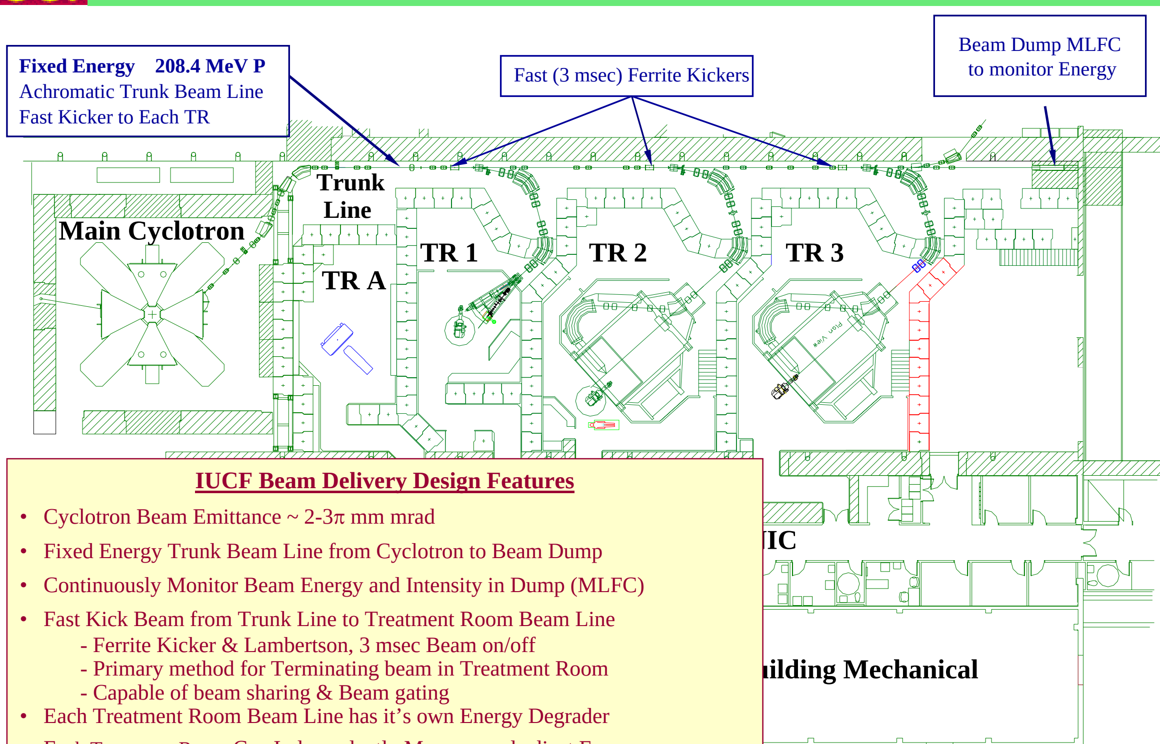
- 208.40 ± 0.1 MeV Protons
- 0.1 nA to 200 nA beam to the user
- 35.58 MHz RF Frequency
- 200 kV max energy gain per turn
- ±0.5 mm extracted beam position stability
- Vacuum = $10^{-6}$ Torr
- Control system upgraded in March 2001
- Beam Transmission up to 75%

**Electrostatic Inflector :**

- Improved vacuum caused excessive glow discharge and sparking.
- Per advice from David Poe from NSCL, added controlled $O_2$ leak, which completely solved the problem



# IUCF Beam Delivery to the Clinic

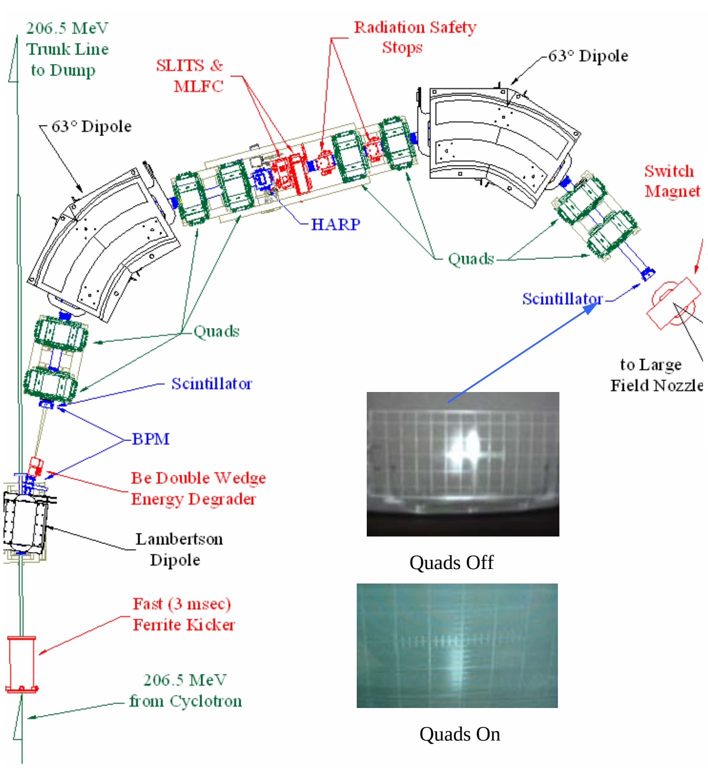


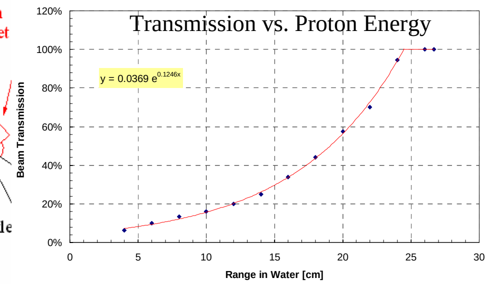

**IUCF Beam Delivery Design Features**

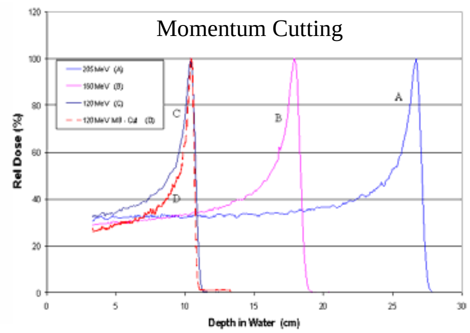
- Cyclotron Beam Emittance ~ 2-3π mm mrad
- Fixed Energy Trunk Beam Line from Cyclotron to Beam Dump
- Continuously Monitor Beam Energy and Intensity in Dump (MLFC)
- Fast Kick Beam from Trunk Line to Treatment Room Beam Line
  - Ferrite Kicker & Lambertson, 3 msec Beam on/off
  - Primary method for Terminating beam in Treatment Room
  - Capable of beam sharing & Beam gating
- Each Treatment Room Beam Line has it's own Energy Degrader
- Each Treatment Room Can Independently Measure and adjust Energy, Energy Spread and Intensity

# Energy Selection Line for each TR

**Energy Selection Beam Line:**
- Double Spectrometer Design
- Double Achromat Entrance & Exit
- Treatment Beam Start/Stop (Kicker)
- Energy Degradation
- Energy Selection (momentum Analysis)
- Energy Verification
- Intensity Verification



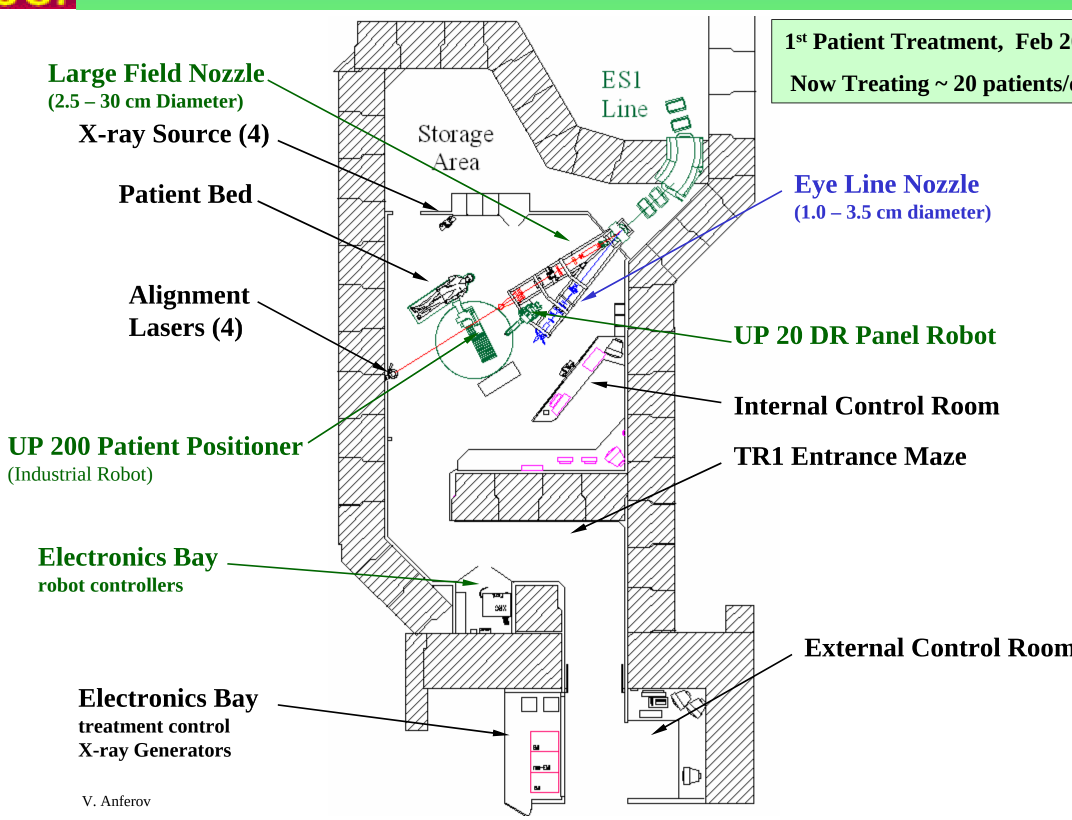






# Layout of Treatment Room 1 (Fixed Beamline)

**1st Patient Treatment, Feb 2004**

**Now Treating ~ 20 patients/day**



# Layout of the Gantry Treatment Room

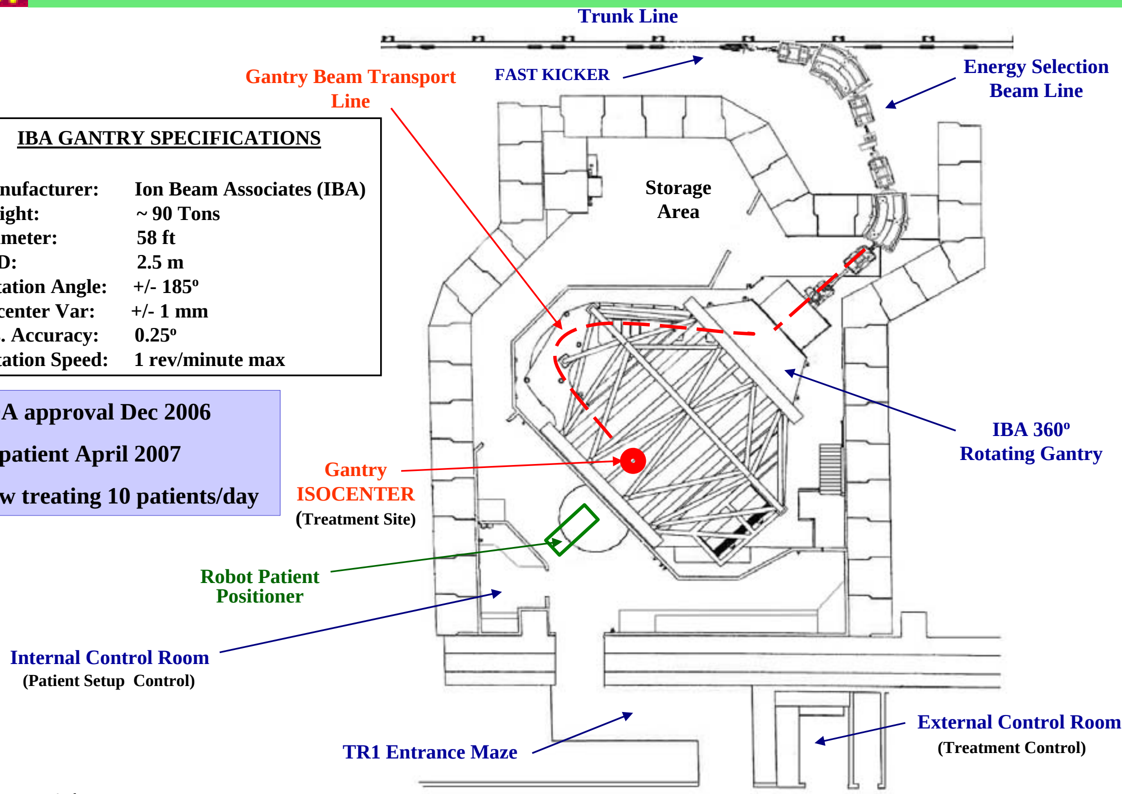
**IBA GANTRY SPECIFICATIONS**

| | |
|---|---|
| **Manufacturer:** | **Ion Beam Associates (IBA)** |
| **Weight:** | **~ 90 Tons** |
| **Diameter:** | **58 ft** |
| **SAD:** | **2.5 m** |
| **Rotation Angle:** | **+/- 185º** |
| **Isocenter Var:** | **+/- 1 mm** |
| **Pos. Accuracy:** | **0.25º** |
| **Rotation Speed:** | **1 rev/minute max** |

**FDA approval Dec 2006**

**1st patient April 2007**

**Now treating 10 patients/day**





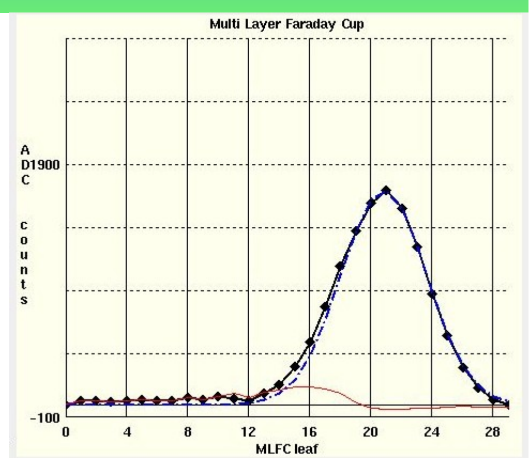

# Operating Experience

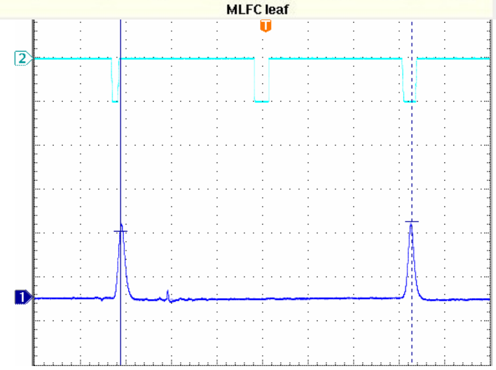
*VERY USEFUL:*

- Big storage area behind each room
- Beam energy monitoring in beam dump MLFC plus range verification in ES line MLFC
- Beam Focus and Position monitoring on wire scanners for each Treatment room (double scattering system in TR1 is extremely sensitive to beam misalignments)
- In addition to centering beam in the Nozzle use two segmented collimators to center beam in the Gantry (missaligned beam has no business in nozzle)
- Beryllium Energy degrader – high transmission efficiency and low background radiation

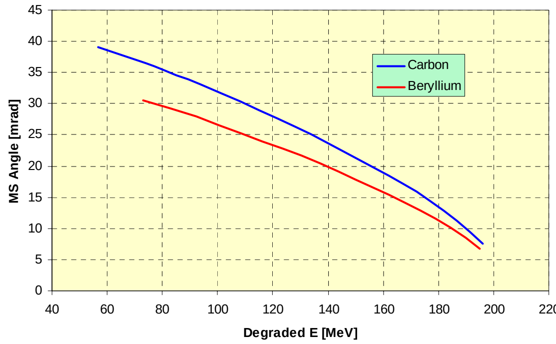
*NOT VERY USEFUL:*

- Momentum selection is not as important



# Beryllium Degrader

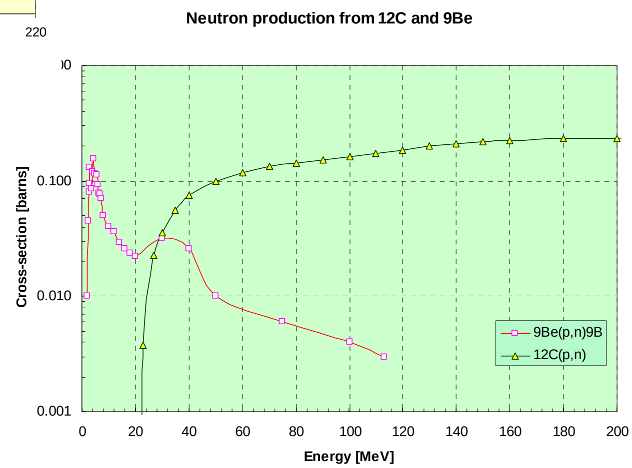



- Small multiple scattering angle in Be minimizes the emittance growth:

$$\varepsilon_1 = \varepsilon_0 + \beta \cdot \langle \theta^2 \rangle$$

- 50nA beam is sufficient for most treatments!!!

- Neutron production x-section in Be is smaller than for C at proton energies above 120MeV
  (figure shows σ_tot for C12 and leading reaction for 9Be(p,n)9B from ENDF-VI B nuclear data library)



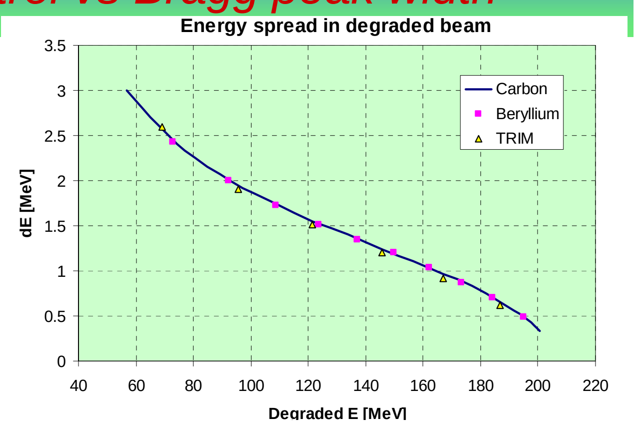


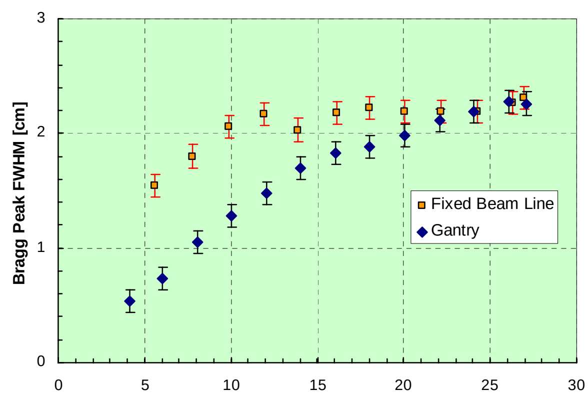

# Momentum Control vs Bragg peak width

- Mono-energetic beam provides sharpest dose distal fall-off
- Energy degrading process increases beam energy spread
- Transmitting the whole energy spectrum preserves the Bragg peak shape

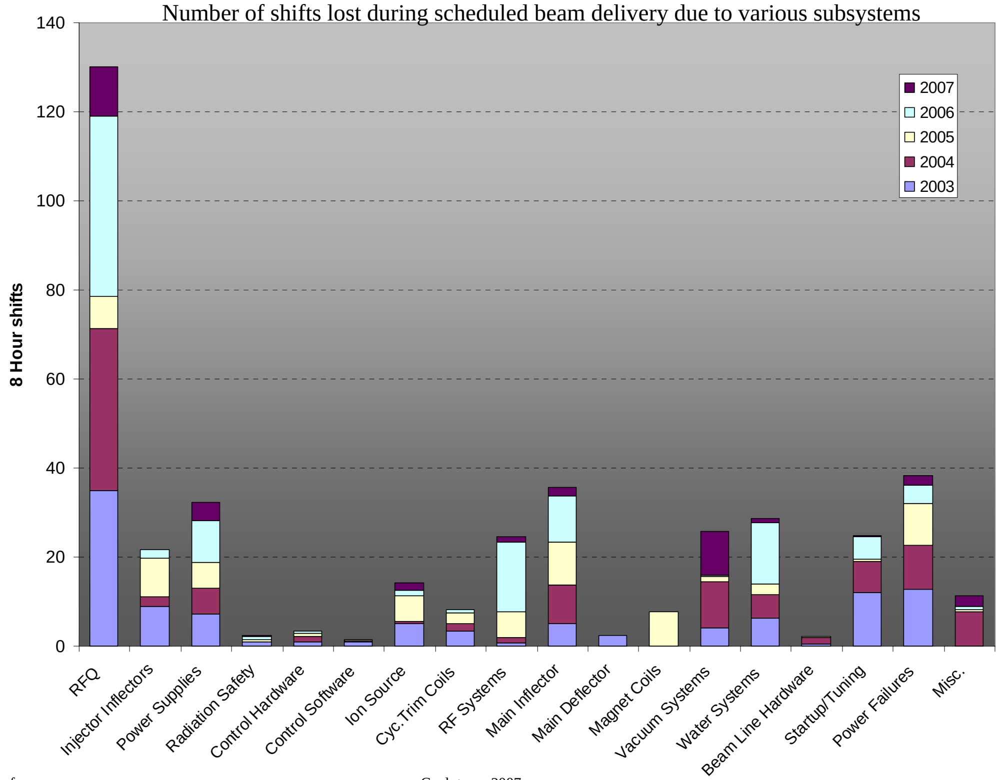
- ES line energy acceptance ±3MeV matches the beam energy spread and preserves the width of Bragg peak
- This enables TR1 to use single library of propellers

- Gantry acceptance is ±1MeV
  - o Width of BP varies with energy
  - o Impacts beam transmission



# Operational Reliability



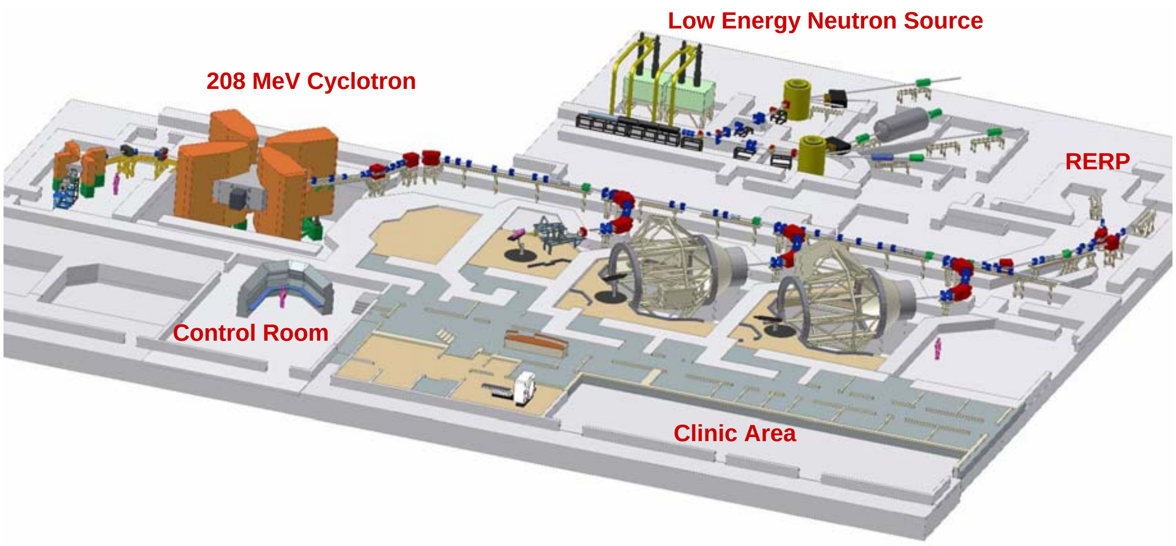



# How to keep accelerator reliable

IUCF operates cyclotron 24h/day 6/days a week without any shutdowns during the year.

- Internal & External design reviews to identify key components that impact the reliability
- IUCF established a 4-year cycle program to refurbish/upgrade aging major equipment
- Proactive maintenance effort every weekend with 4 extended (+1day) maintenance weekends distributed throughout the year.
  - Excluding RFQ the accelerator reliability is >95%
  - TR1 reliability has been >97%

# IUCF Layout in 2007




- Support to the biomedical and material science research is an important part of IUCF mission.
- Fast beam splitting becomes important to support successful Radiation Research program.



# Conclusions

- Converting a research cyclotron to medical operation was fun
  - Plenty of challenges
  - Some design features turned out very useful
  - Some tuned out to be not quite useful
- Dealing with bureaucracy was not fun ☹
- Clinical reliability goal is achievable if you put enough thought into it from the beginning.
- Research Life does not have to end with the start of medical operation.

Acknowledgement: The success of MPRI project was due to efforts of the entire IUCF facility.

Mille grazie!