

# Control System for the Clinical Operation in Proton Therapy Center, NCC, Korea. *(Operation Experience)*

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# Outline

- Introduction of NCC
- Proton Therapy Facility
- Proton Beam Modulation and Delivery
- Safety System
- Maintenance

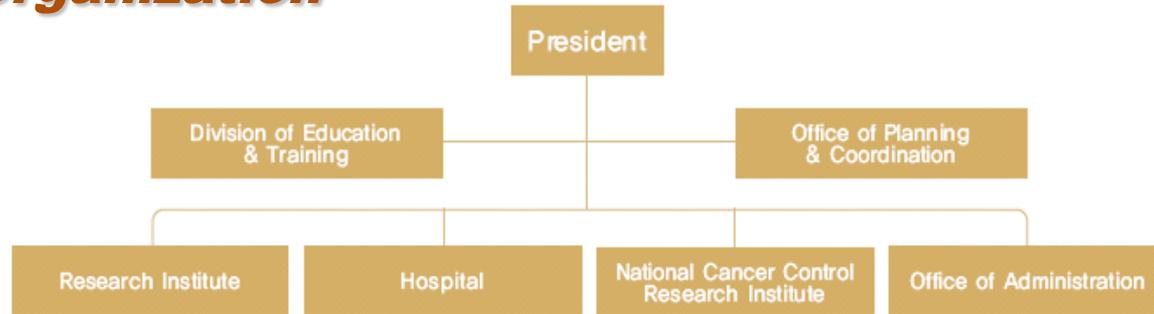


# 1. Introduction of NCC



# Overview of NCC

## Organization



323 Ilsan-ro, Ilsandong-gu, Goyang-si, Gyeonggi-do 410-769, Korea



# Proton Therapy Facility in NCC

- 2005. 2.15** IBA Proteus 235 installation start
- 2005. 10.21** First Beam Production
- 2005. 9.~ 2006. 2.** Beam tuning ( Cyclotron & Beam line )
- 2006. 6.~ 2006.12.** Passive mode beam calibration & acceptance test  
( 1 Fixed Beam & 2 Gantry )
- 2007. 1.~ 2007.2.** GTR2 Commissioning & Beam data taking
- 2007. 3.19.** First Proton treatment start
- ~ 2010.12.** 519 patients treated in Proton Therapy Facility

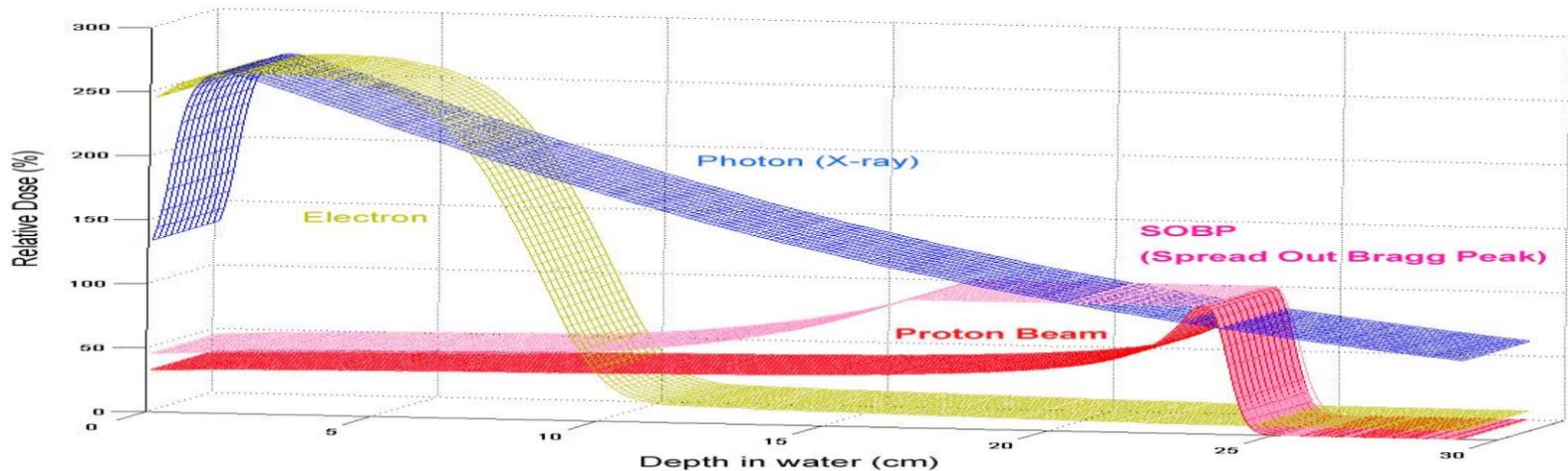


# Proton & Proton Therapy

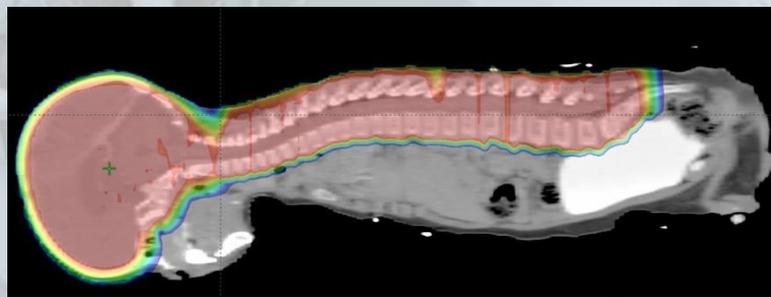
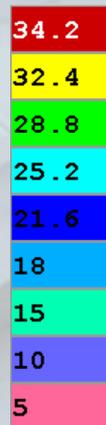
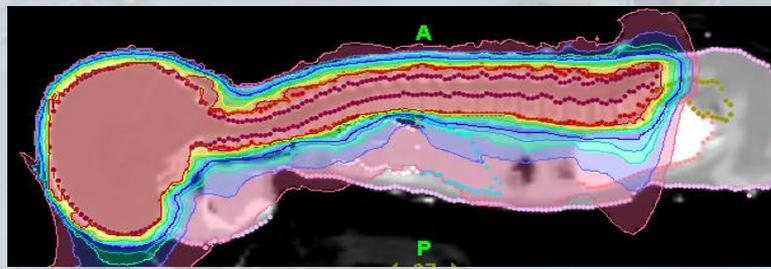
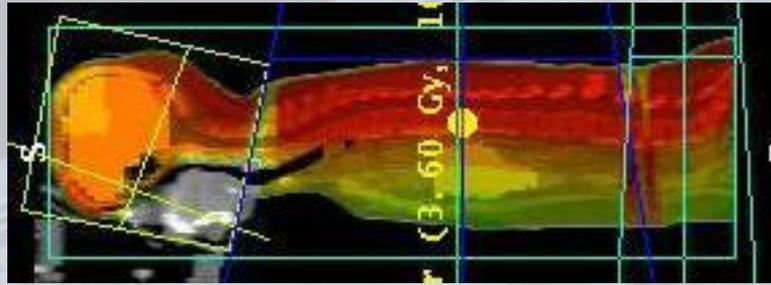
 Proton is a nucleus of Hydrogen atom with positive electron charge which has 2000 times heavy mass than electron. Proton therapy is a radiation therapy using proton.

 Characteristic of proton (**Bragg Peak**)

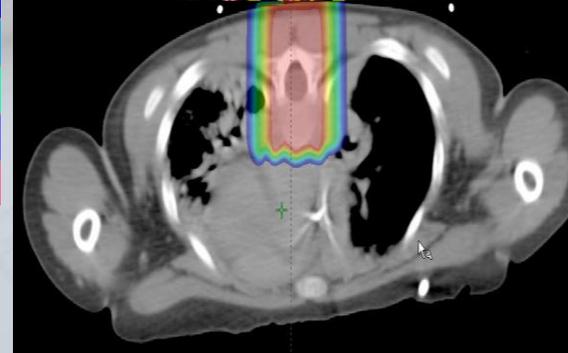
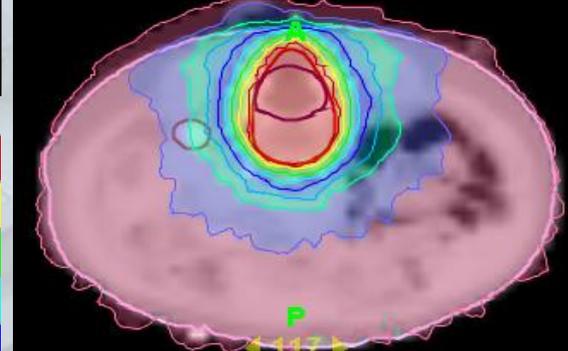
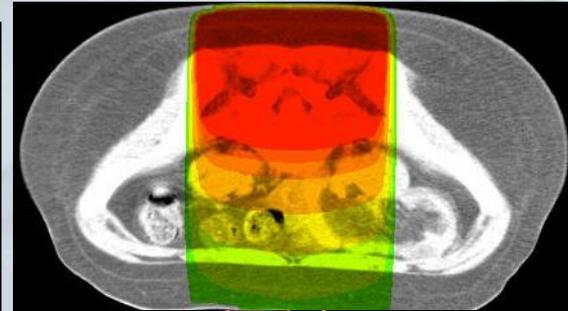
Proton is quite different from x-ray in terms of energy transfer. As it enters a cancer patient's body through skin and tissue, it releases a relatively low dose of energy before it reaches the target. It, however, hits the targeted tumor by depositing the biggest dose of energy on it, then suddenly stopping its activity afterwards. The point where the highest energy is released is called as the Bragg Peak.



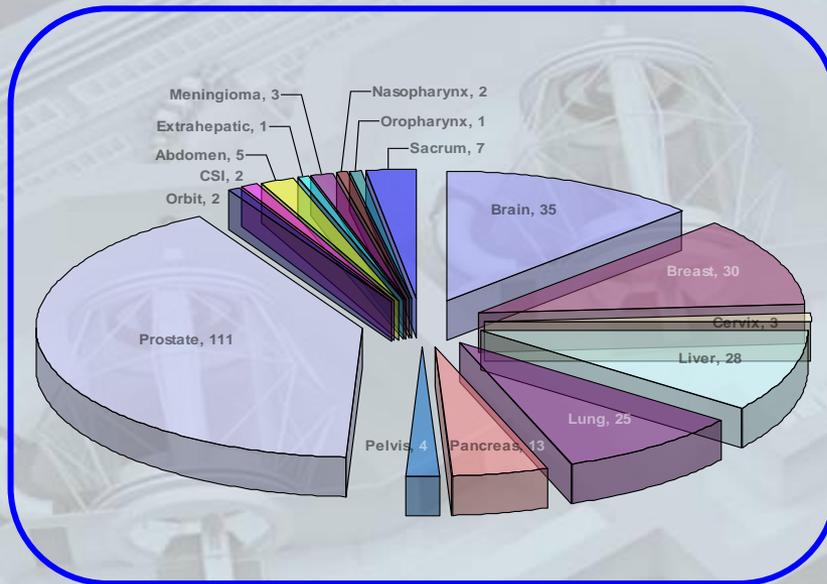
# CSI using 3D CRT, Tomotherapy, and Proton Therapy



5~100% isodose line



# Treatment sites with proton therapy at NCC



Updated in Sept. 2008

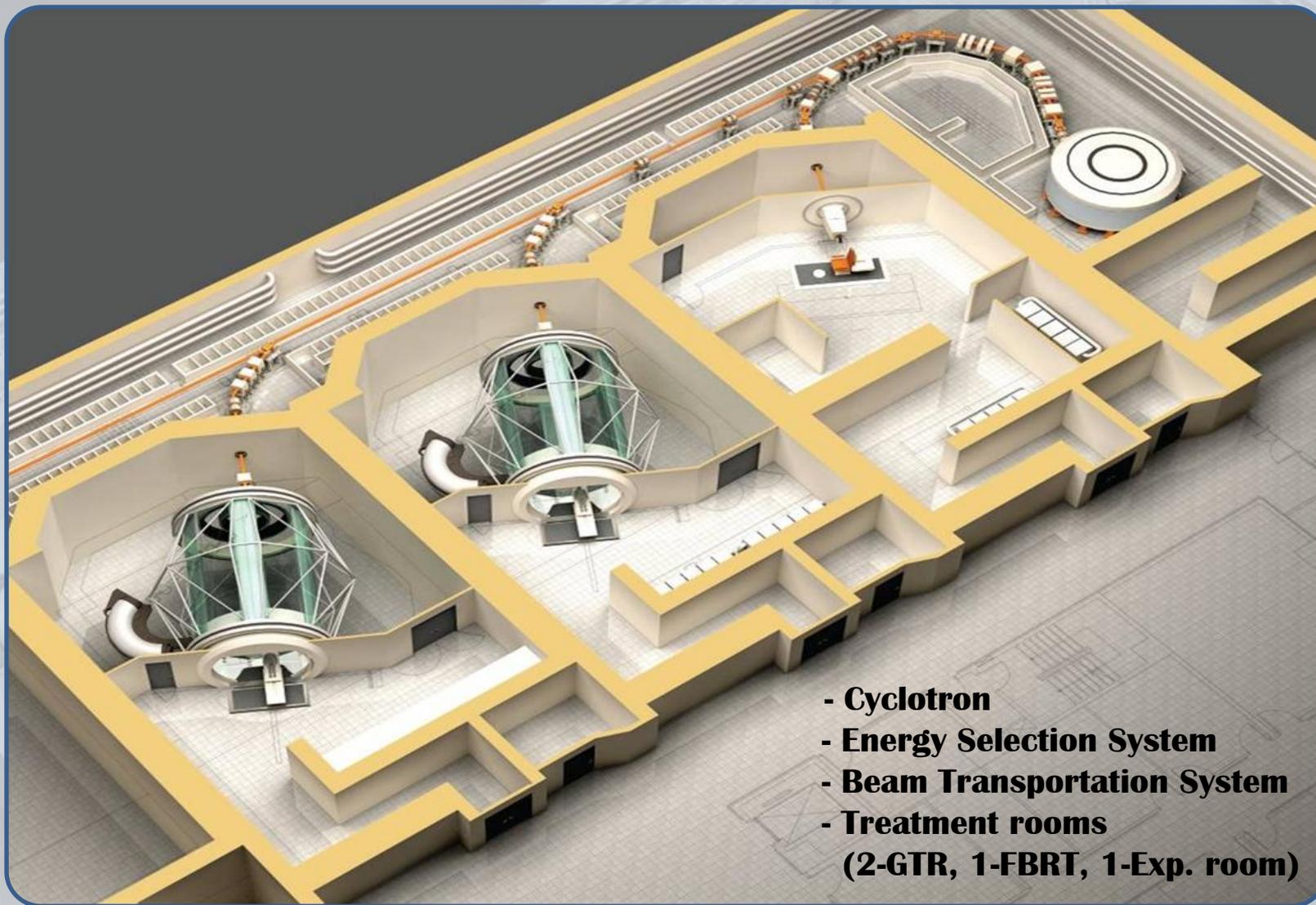
<ul style="list-style-type: none"> <li>Central Nervous System (Brain &amp; Spinal Cord)                             <ul style="list-style-type: none"> <li>glioma</li> <li>pituitary adenoma</li> <li>chordoma</li> <li>vestibular schwannoma</li> <li>meningioma</li> <li>optic glioma</li> </ul> </li> </ul>
<ul style="list-style-type: none"> <li>Orbit (Eye)                             <ul style="list-style-type: none"> <li>choroidal melanoma</li> <li>lacrimonasal gland tumor</li> <li>retinoblastoma</li> </ul> </li> </ul>
<ul style="list-style-type: none"> <li>Head &amp; Neck                             <ul style="list-style-type: none"> <li>oropharyngeal cancer</li> <li>unresectable or recurrent cancer</li> <li>nasopharyngeal cancer</li> </ul> </li> </ul>
<ul style="list-style-type: none"> <li>Thorax and Breast                             <ul style="list-style-type: none"> <li>lung cancer : selective</li> <li>breast cancer : selective</li> <li>esophageal cancer</li> <li>unresectable or recurrent cancer</li> </ul> </li> </ul>
<ul style="list-style-type: none"> <li>Abdomen                             <ul style="list-style-type: none"> <li>liver and pancreas cancer : selective</li> <li>unresectable or recurrent cancer</li> </ul> </li> </ul>
<ul style="list-style-type: none"> <li>Pelvis and Extremities                             <ul style="list-style-type: none"> <li>prostate cancer</li> <li>chordoma</li> <li>sarcoma</li> <li>soft tissue sarcoma</li> <li>unresectable or recurrent cancer</li> </ul> </li> </ul>
<ul style="list-style-type: none"> <li>Pediatric (Child) Tumors                             <ul style="list-style-type: none"> <li>Glioma, medulloblastoma and other primitive neuroectodermal tumors, germinoma, sarcoma, retinoblastoma, soft tissue sarcoma, skull base chordoma and chondrosarcoma</li> <li>recurrent cancer and others : selective</li> </ul> </li> </ul>



## 2. Proton Therapy Facility



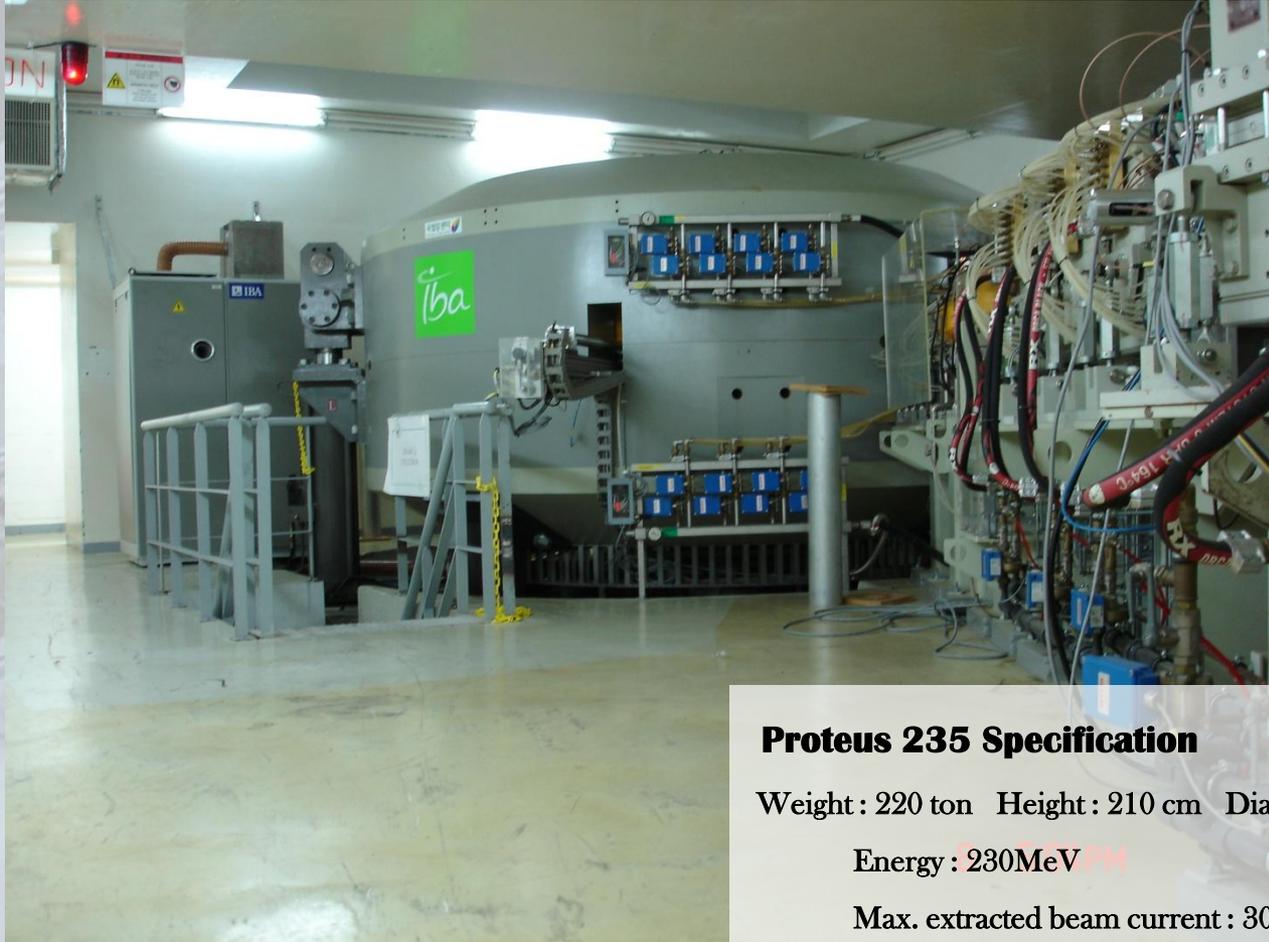
# Layout of Proton beam facility



- Cyclotron
- Energy Selection System
- Beam Transportation System
- Treatment rooms  
(2-GTR, 1-FBRT, 1-Exp. room)



# Cyclotron



## Proteus 235 Specification

Weight : 220 ton Height : 210 cm Diameter : 434 cm

Energy : 230MeV<sub>PM</sub>

Max. extracted beam current : 300nA

RF frequency : 106 MHz



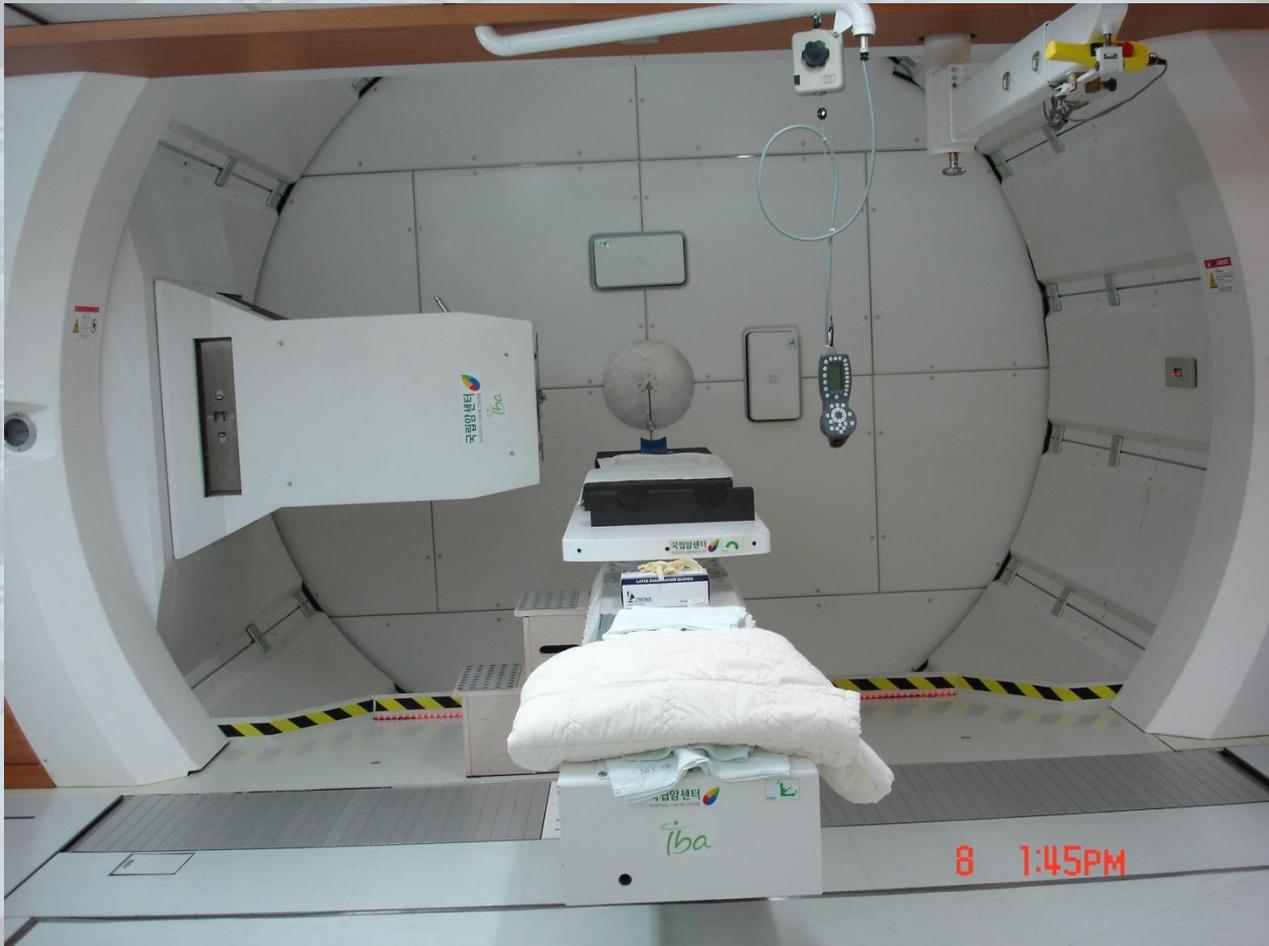
# Energy Selection System



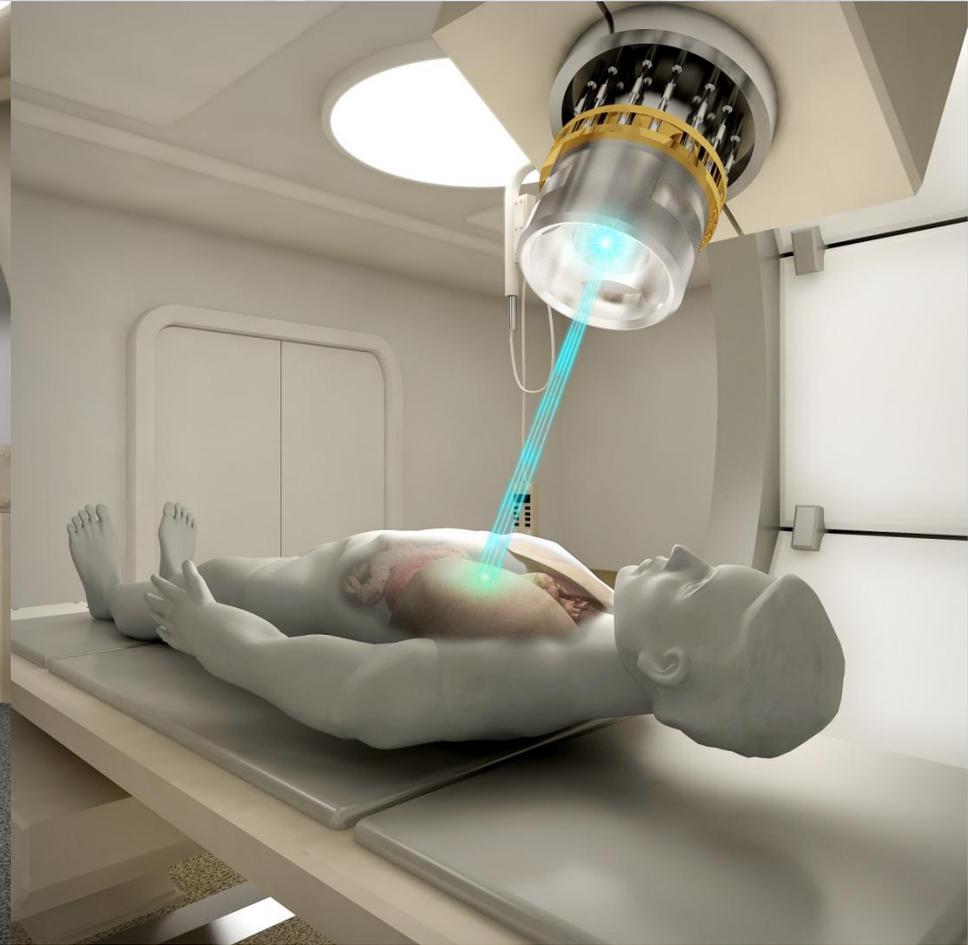
# Beam Transportation System



# Gantry Treatment Room - 1



# Gantry Treatment Room - 2



# Fixed Beam Treatment Room



# Experiment Room



# Main Control Room : operation consoles



# Main Control Room : ISEU, RF, Magnet E



# Milling Machine Shop



# 3. Proton Beam modulation and Delivery



# MCR - Beam Production

Cooling  
 Vacuum  
 Magnet  
 RF  
 Radial Probe  
 Ion Source  
 ISEU  
 Deflector  
 Extraction Quads  
 Extraction Steering

...

PLC <-> P.S. Serial Link Fail

Session Name: Service Session

Cyclone 235 General Status

ACU Health status: NOK  
 ACU counter: 0

**Main Coil PS**  
 I Main Coil: 0.000 A  
 I Coil 1-3: 0.000 A  
 I Coil 2-4: 0.000 A  
 Main Coil Tuning: I Compensation Coil: 0.00 A

**Source PS** Arc Tuning  
 I Fil.: 0.0 A  
 V Arc: 0.00 V  
 I Arc: 0.00 mA  
 Motor Position: 0 Digits  
 Position Status:

LLRF → SSA → IMPA → FPA → RF Cavity  
 External Interlocks X External Conditions X External Conditions  
 Forw Pw: 0.00 kW  
 V Dee 1: 0.00 kV  
 V Dee 2: 0.00 kV  
 Vdee Setpoint: 0 Digits

**Deflector PS**  
 V PS: 0.0 kV  
 I PS: 0.0 mA  
 Motor1 Pos.: 0 Digits  
 Motor2 Pos.: 0 Digits

**Radial Probe**  
 Position: 0.0 mm  
 Energy: 0.0 MeV  
 In Limit Switch  
 Out Limit Switch

Q1&Q2  
 I Q1: 0.0 A  
 I Q2: 0.0 A

**ALARM**  
 Safety Not OK

Steering 1 PS  
 Steering 2 PS

Save Eqt Parameters Edit Eqt Parameters ESS layout ESS Magnets Control

Cyclone Vacuum Penning1: 0.0E+00 mbar  
 Hydraulic Station Cooling

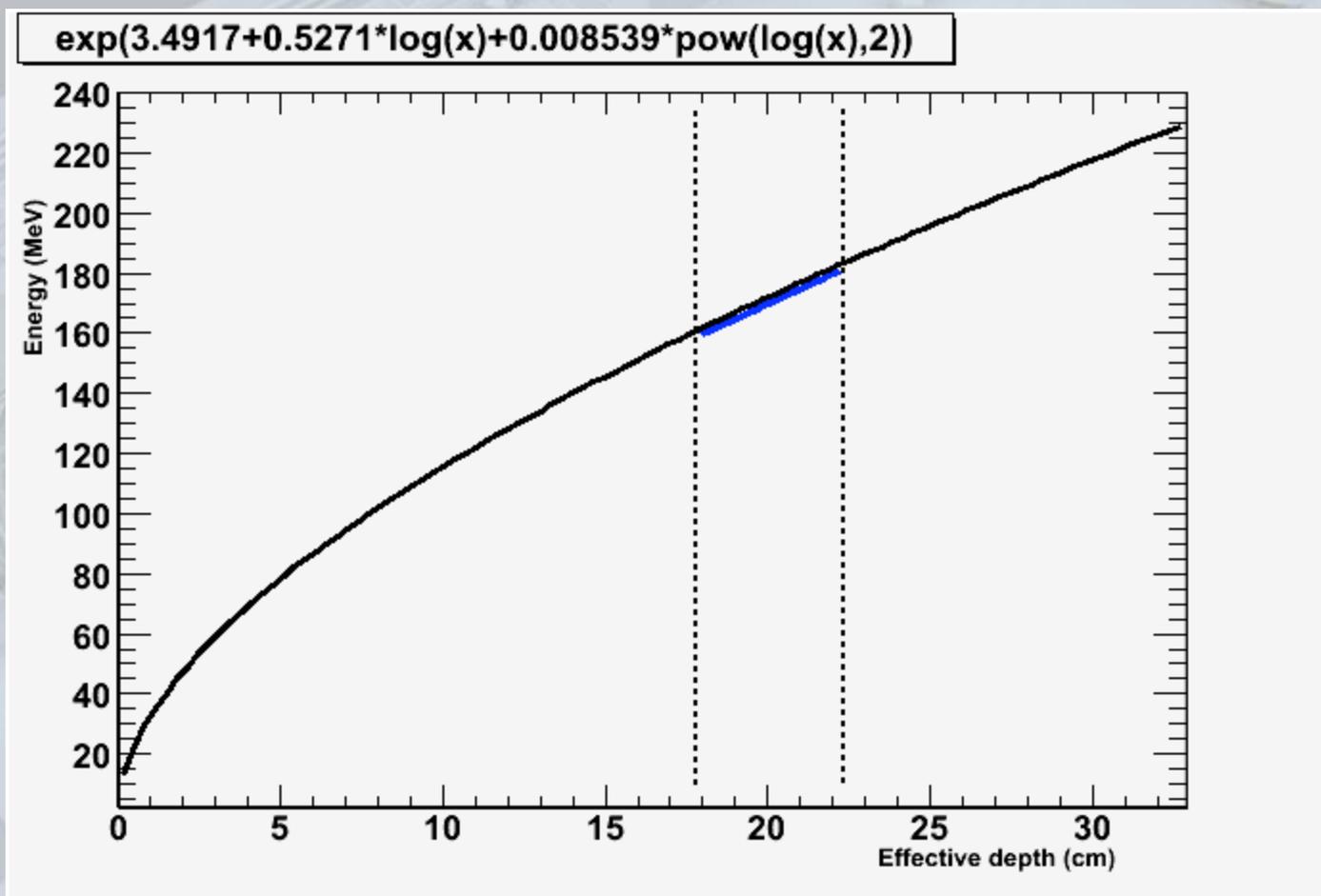


# Clinical Beam Specifications

Item	Singles Scattering	Double Scattering	Uniform Scanning
Range in Patient (g/cm <sup>2</sup> )	3.35-20.4	4.51-28.42	3.42-32.1
Range modulation (g/cm <sup>2</sup> ) adjustment & Size	0.4(R>6), 0.17 9.2	0.2 20.75	0.5 Full
Range adjustment(g/cm <sup>2</sup> )	0.09(R>6),0.05	0.1	0.1
Average dose rate (Gy/min)	5.93	3	1.15
Max. Field Size (cm)	4 (D)	24.3 (D)	40X30
Dose Uniformity (%)	1.25	1.05	1.5(R), 2.6(L)
Effective SAD (m)	2.55	2.19	2.12
Distal Penumbra (g/cm <sup>2</sup> )	0.21	0.23	0.13
Lateral Penumbra(cm)	0.17	0.48	0.30(y), 0.22(x)
Clinical Use	H&N, RS	General	Large Size

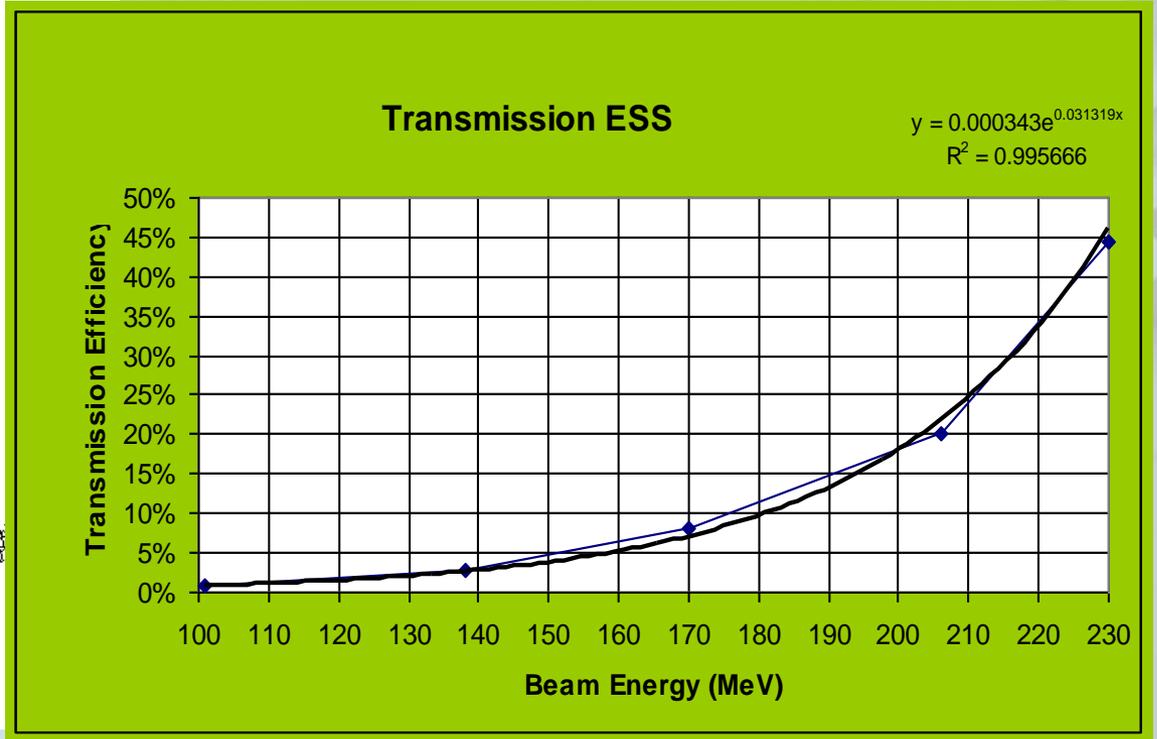
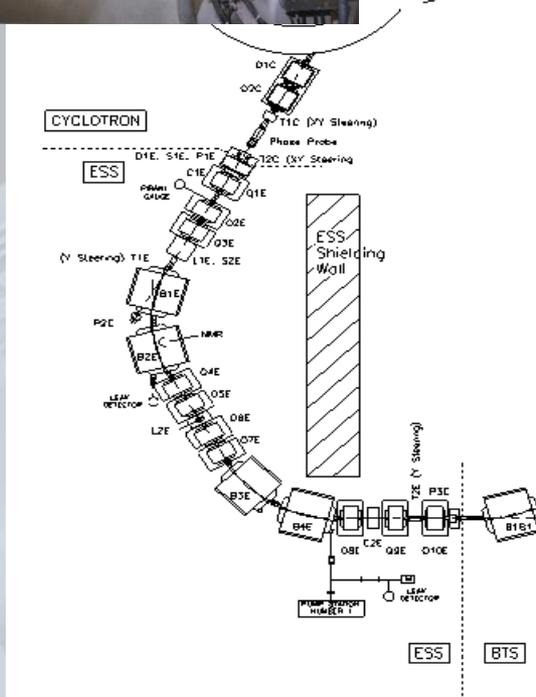


# Kinetic Energy(P) vs. Effective Range in Water





# Transmission efficiency ESS



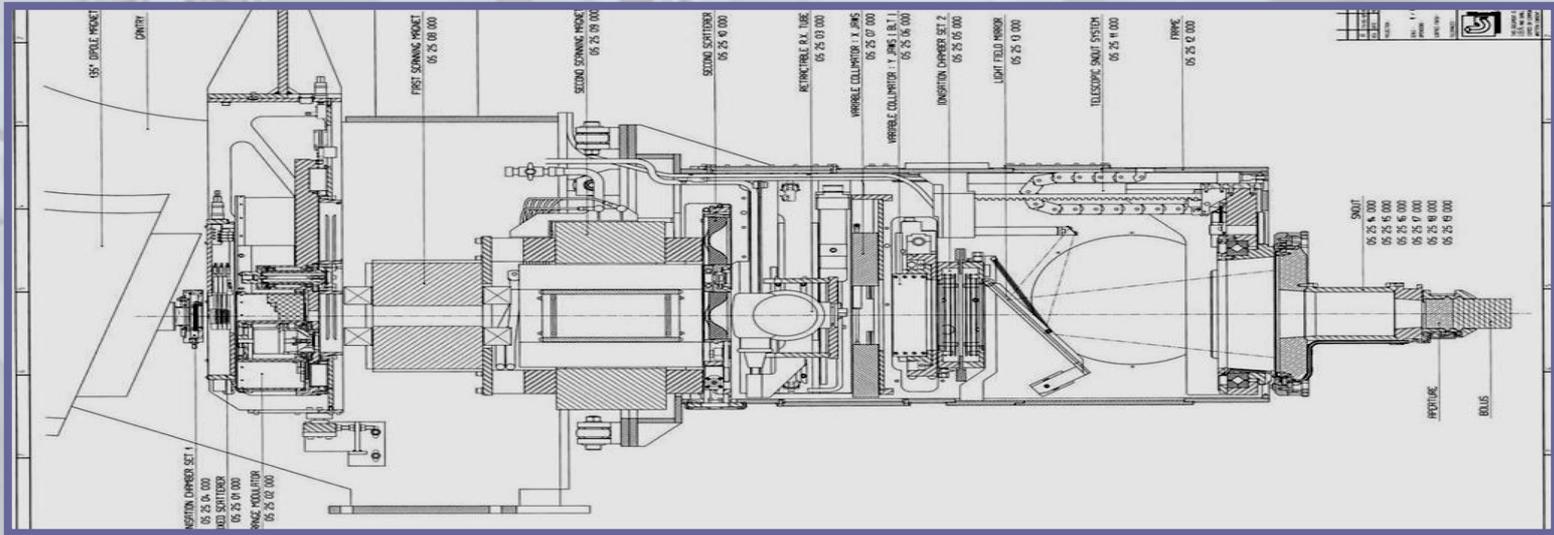
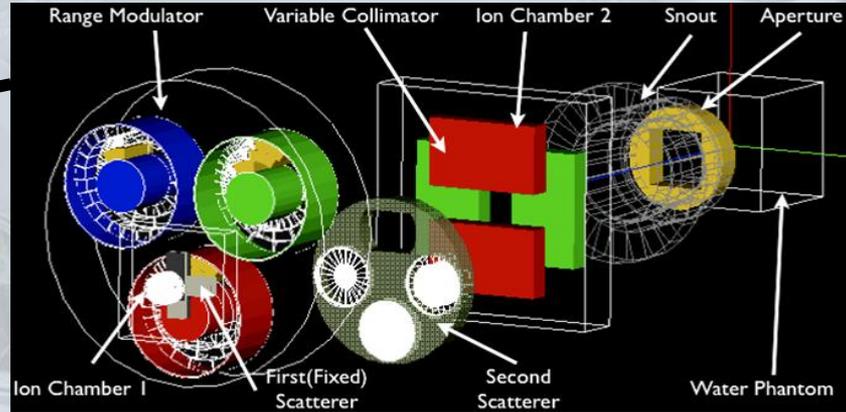
Max Beam current in treatment room = 300 nA x Transmission ESS

\* transmission ESS to treatment room = ~100%

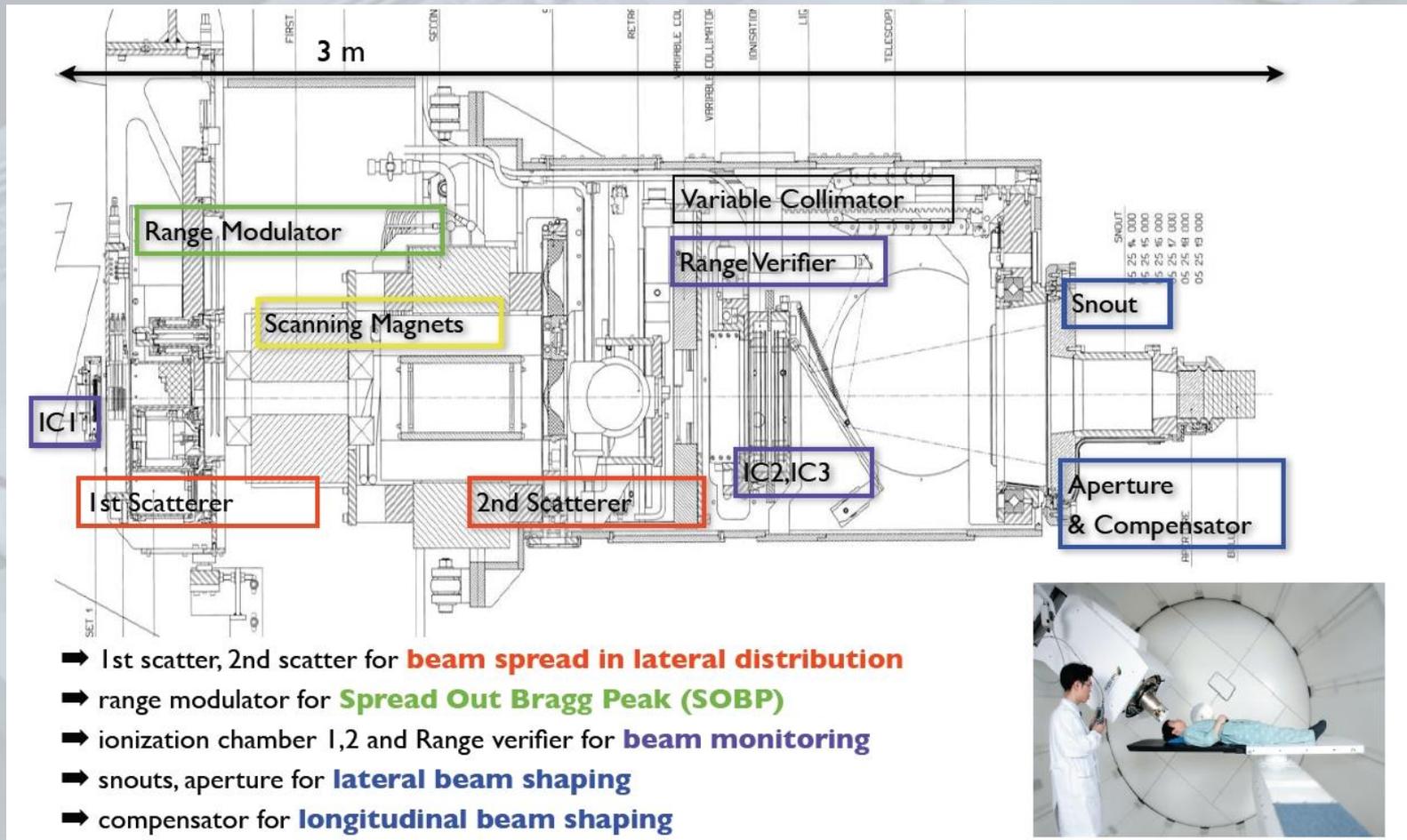
\* 300 nA =  $4.8 \times 10^{12}$  protons/sec.



# Proton Beam Nozzle – Beam Modulation

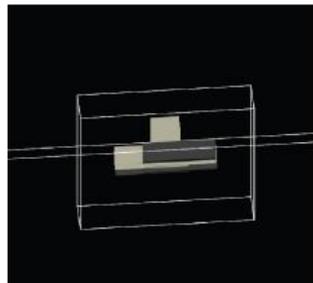


# Schematic Plot of Beam Nozzle



# 1<sup>st</sup> and 2<sup>nd</sup> Scatterers

## 1st (fixed) scatterer



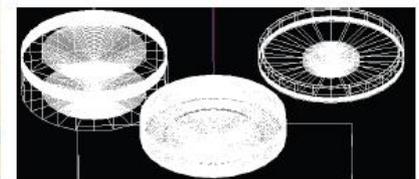
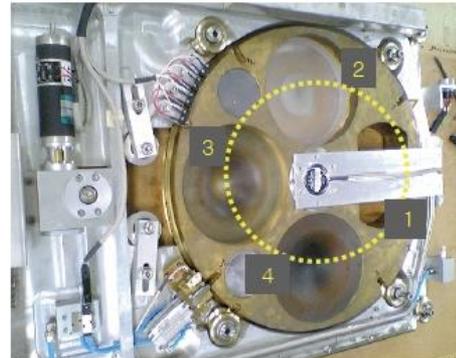
# User commands  
 /GTR2/FS/lollipops 3 5 9  
 /GTR2/FS/all\_in  
 /GTR2/FS/all\_out



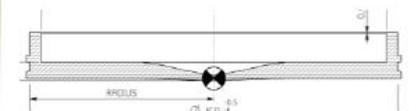
### 9 Lollipop

- 1 : Lexan (Dark gray)
  - range shifting in Uniform Scanning
- 2,3,4,5,6, 7 : Lead (Gray)
  - scattering in
  - Double Scattering, Uniform Scanning
- 8,9 : Lexan (Dark gray)

## 2nd scatterer



# User command  
 /GTR2/SS/select 3

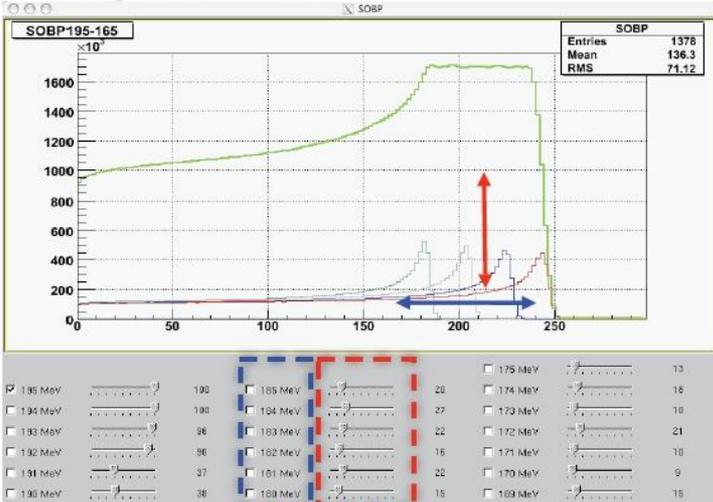


High-Z material (Lead or Titanium)  
 Low-Z material (Lexan)



# Range Modulation wheels

## Principle of SOBP

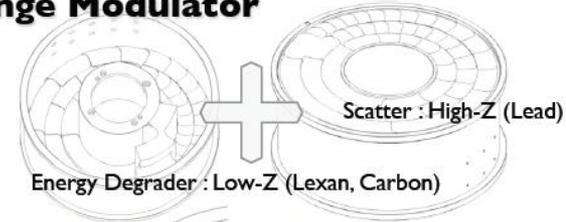


Beam Current Modulation (BCM) → Total 52 BCM records

Stop digit determines width of SOBP

Weighting\_table stands for cyclotron current to determine flatness of SOBP

## Range Modulator



#user commands

#Track (Large wheel rotation)

/GTR2/RM/track 5

#SOBP (Small wheel rotation)

1. position mode (pristine beam)

/GTR2/RM/angle deg 80.26

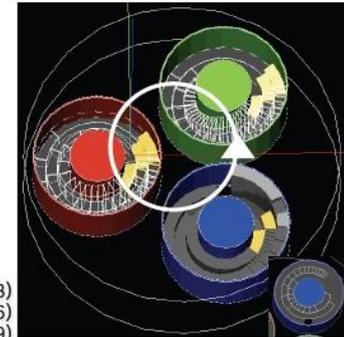
2. speed mode (SOBP)

/beam/bcm weighting\_table SD

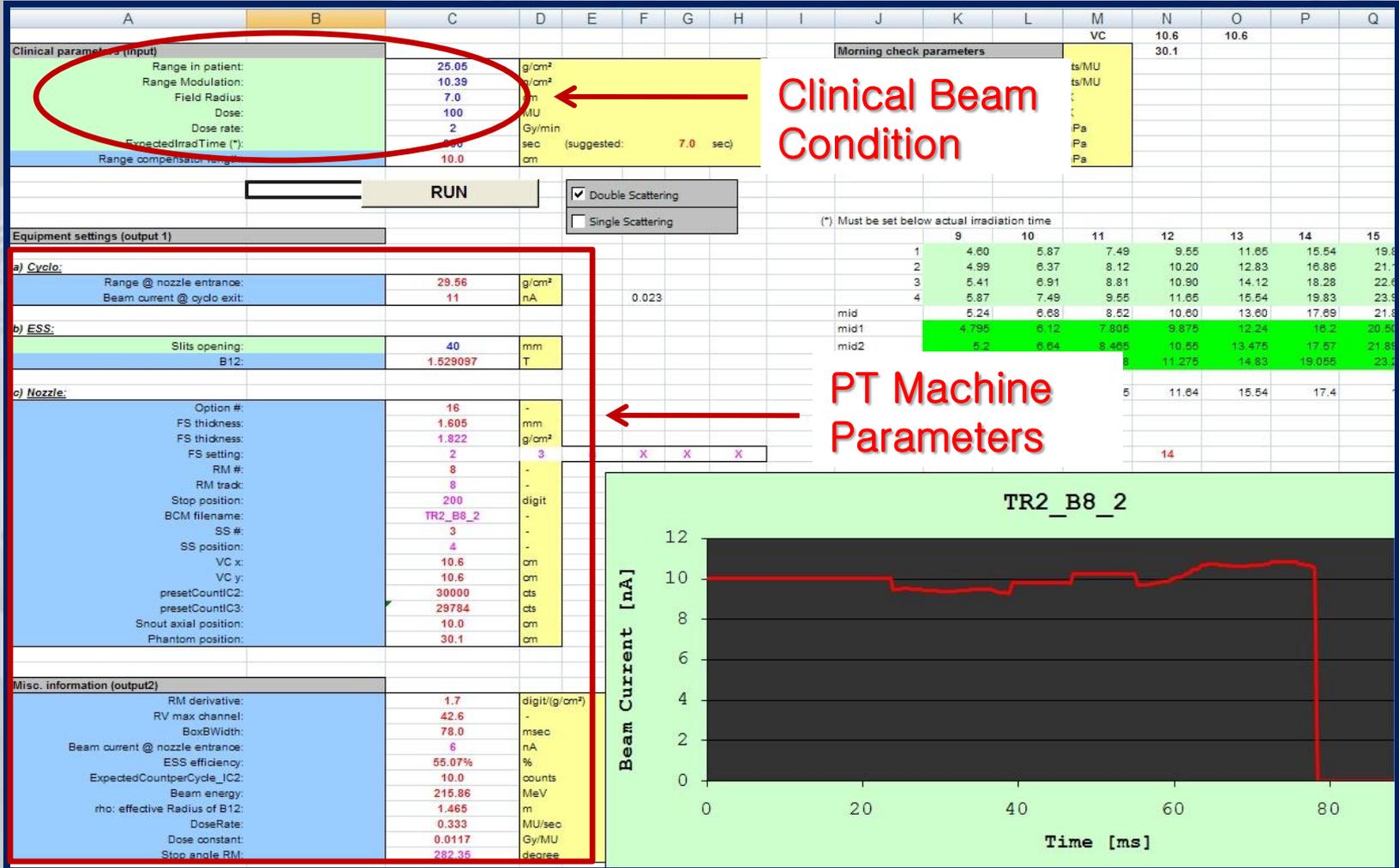
- SW 1 (Track 1,2,3)

- SW 2 (Track 4,5,6)

- SW 3 (Track 7,8,9)

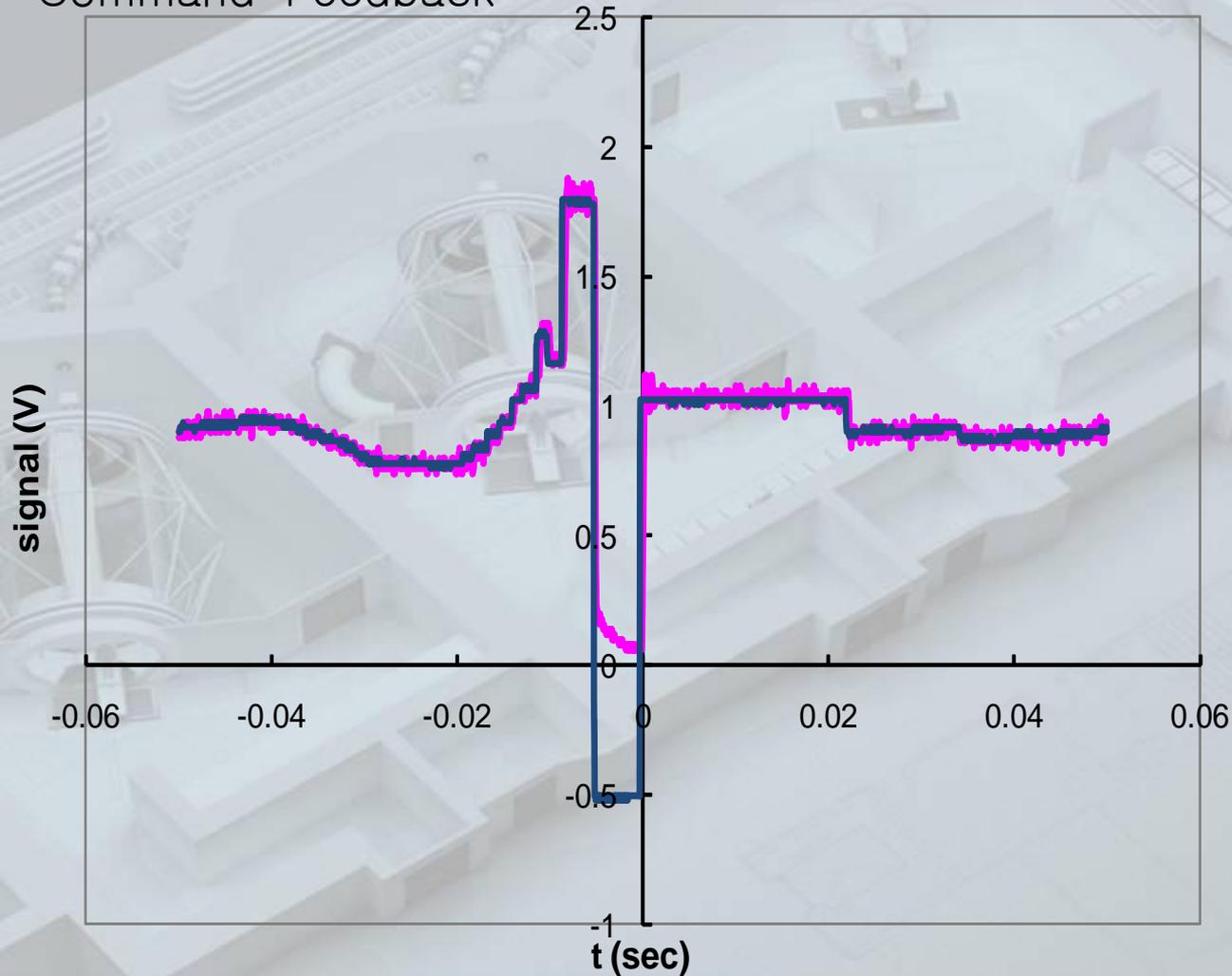


# Parameters for Beam Range, SOBP

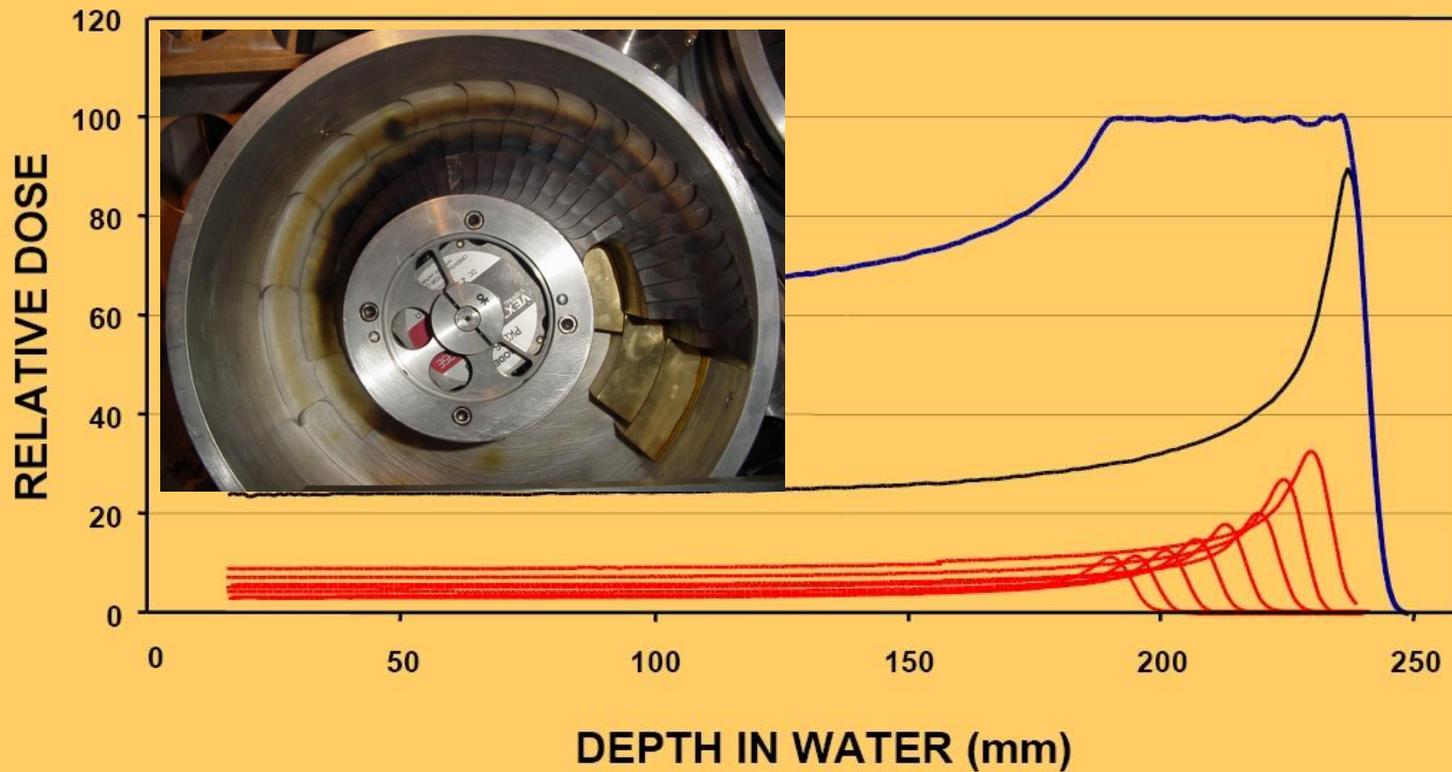


# Accurate beam intensity modulation, up to 2.5 kHz.

Command-Feedback



# Spread-out Bragg Peak (SOBP)

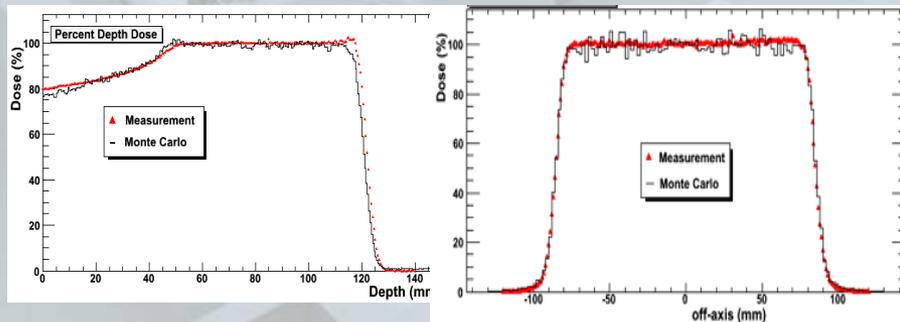
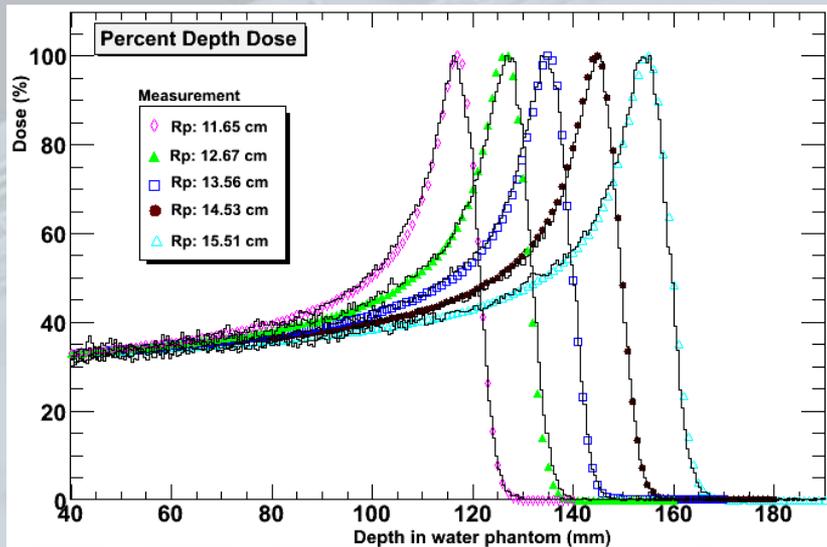


# Simulation of Proton beam Delivery

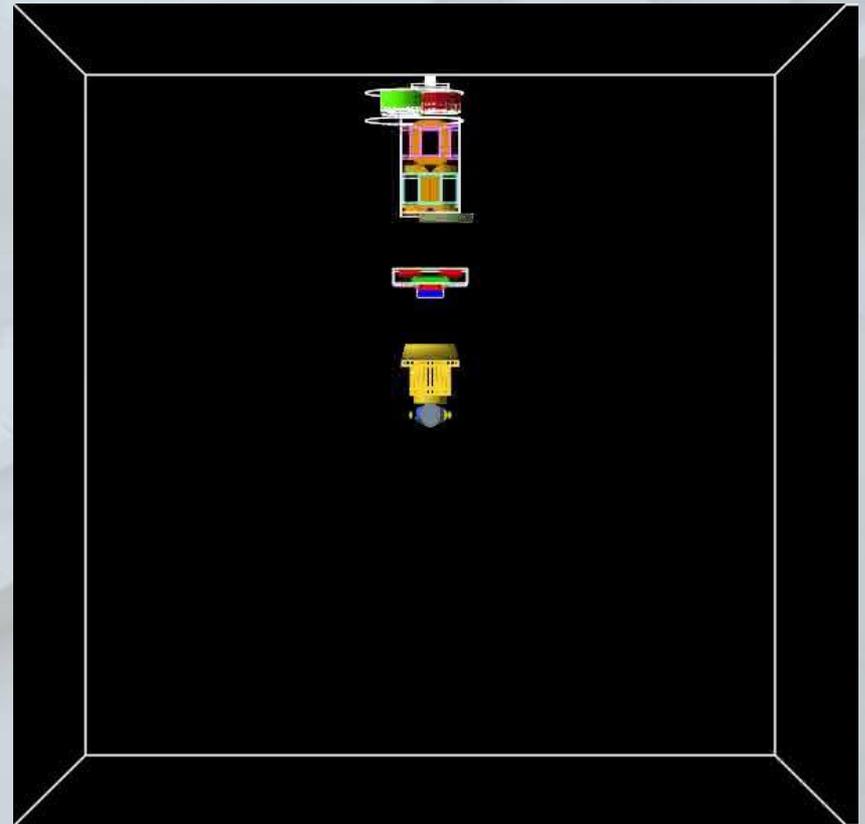
Geant4 version: 8.2.p01

- EM model : G4hIonization with ICRU49 parameterized table
- Hadronic : LHEP\_PRECO\_HP ( precompound model )

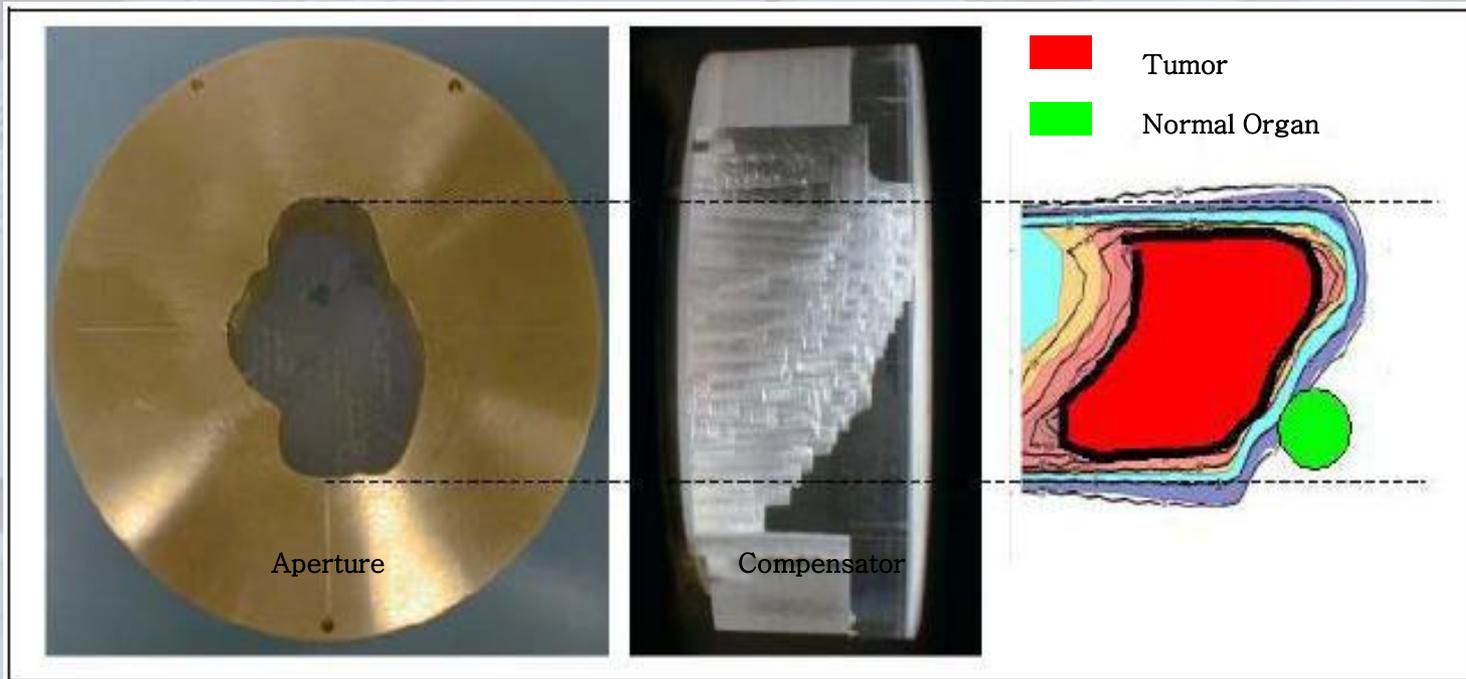
## MC Simulation



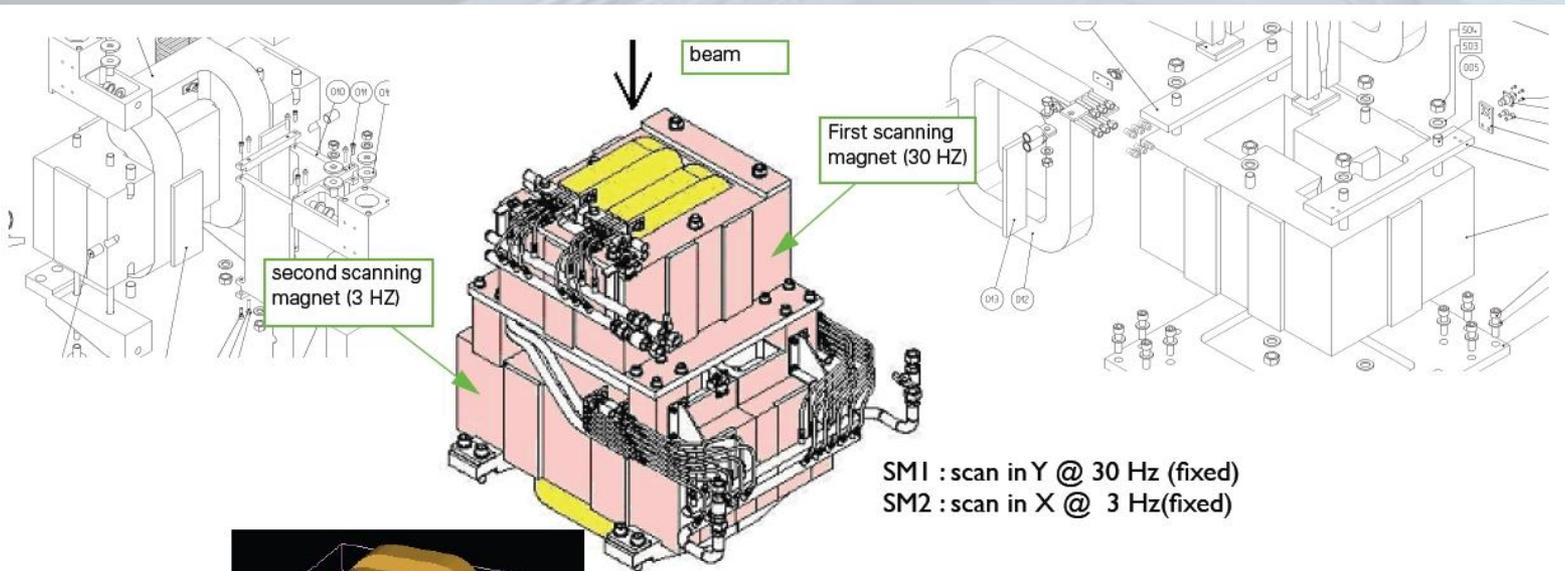
## NCC Proton Beam Delivery MC Simulation



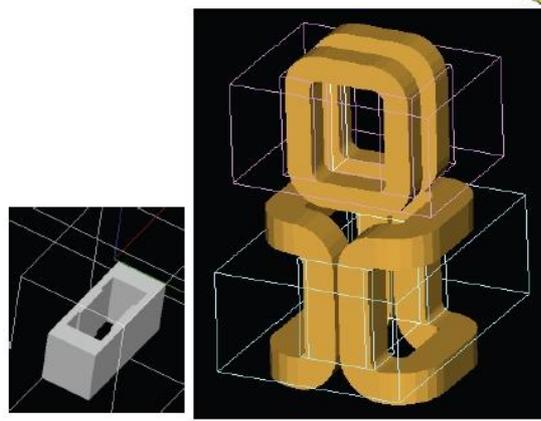
# Patient dedicated Devices : Aperture & Compensator



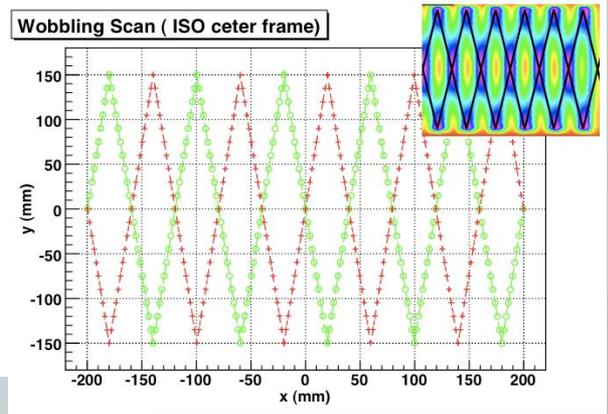
# Beam Scanning Magnets



SM1 : scan in Y @ 30 Hz (fixed)  
 SM2 : scan in X @ 3 Hz (fixed)

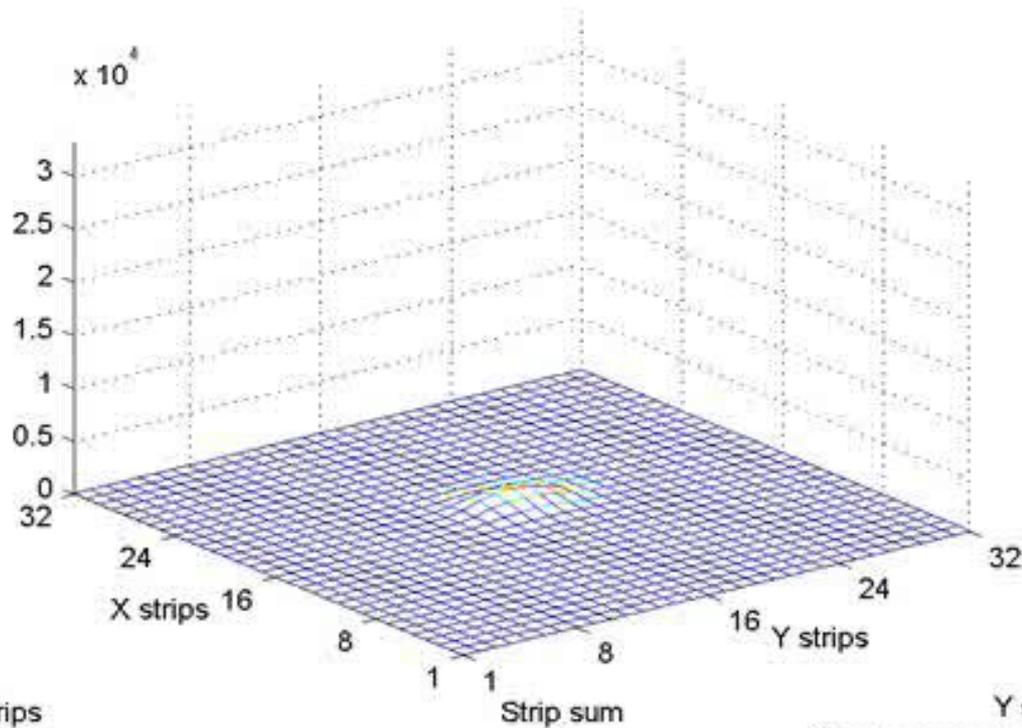


```
# User commands ( B-Field Y , X)
/GTR2/SMAG/magnet tesla 0.027 0.0049
/GTR2/SMAG/magnet cm 8 -5
#loop
loop /GTR2/SMAG/magnet tesla 0.027*i 0.0049*i
```

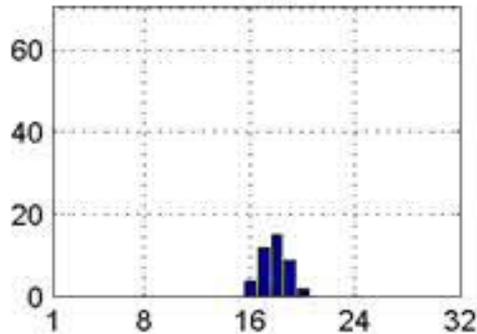


# Demonstration of Pencil Beam Scanning

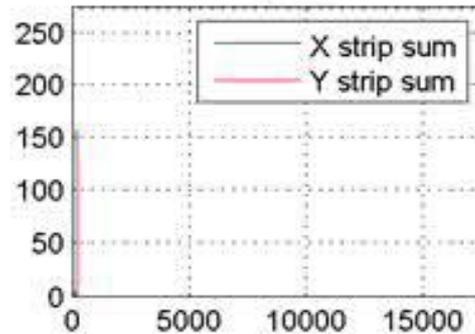
195 ms



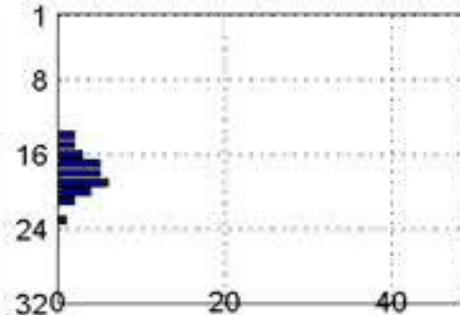
X strips



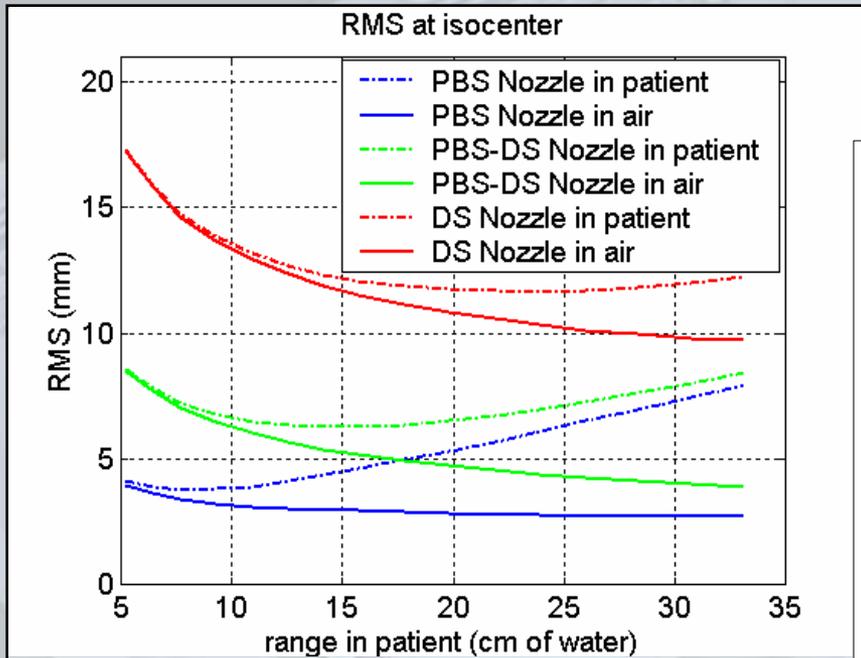
Strip sum



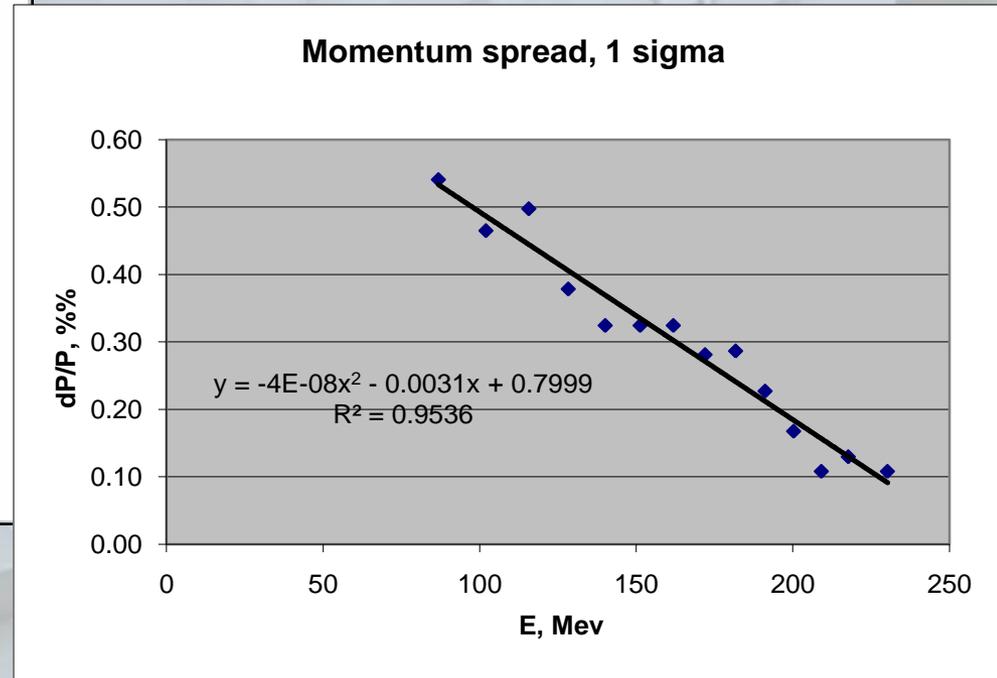
Y strips



# Proton Beam Specifications



Beam sigma at the isocenter

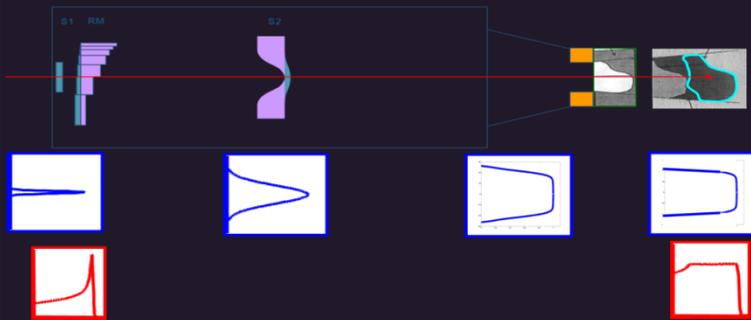


Beam Momentum Spread at Nozzle entrance

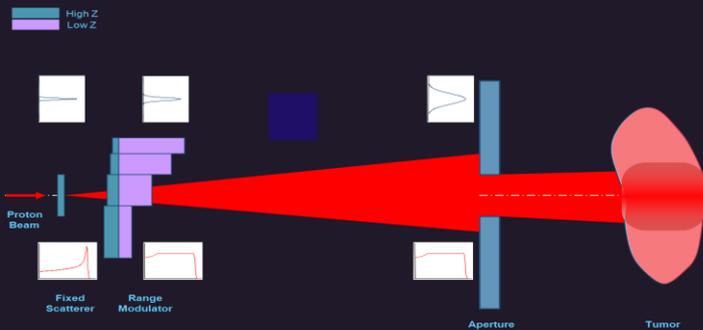
# Proton Beam modulation methods

## Passive mode

### Double Scattering mode

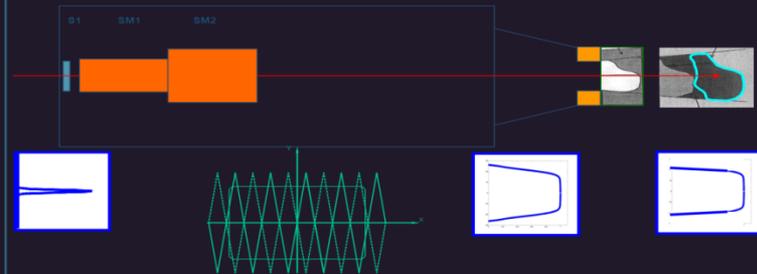


### Single Scattering mode

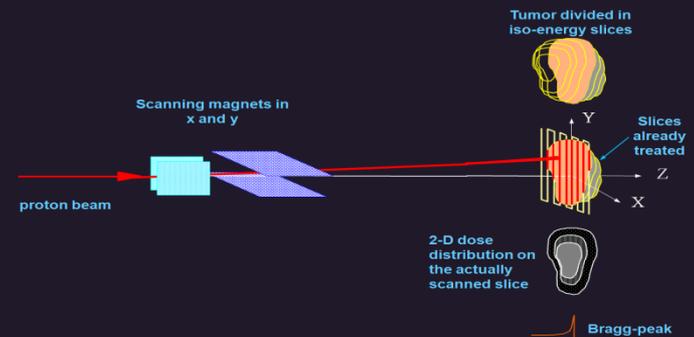


## Dynamic mode

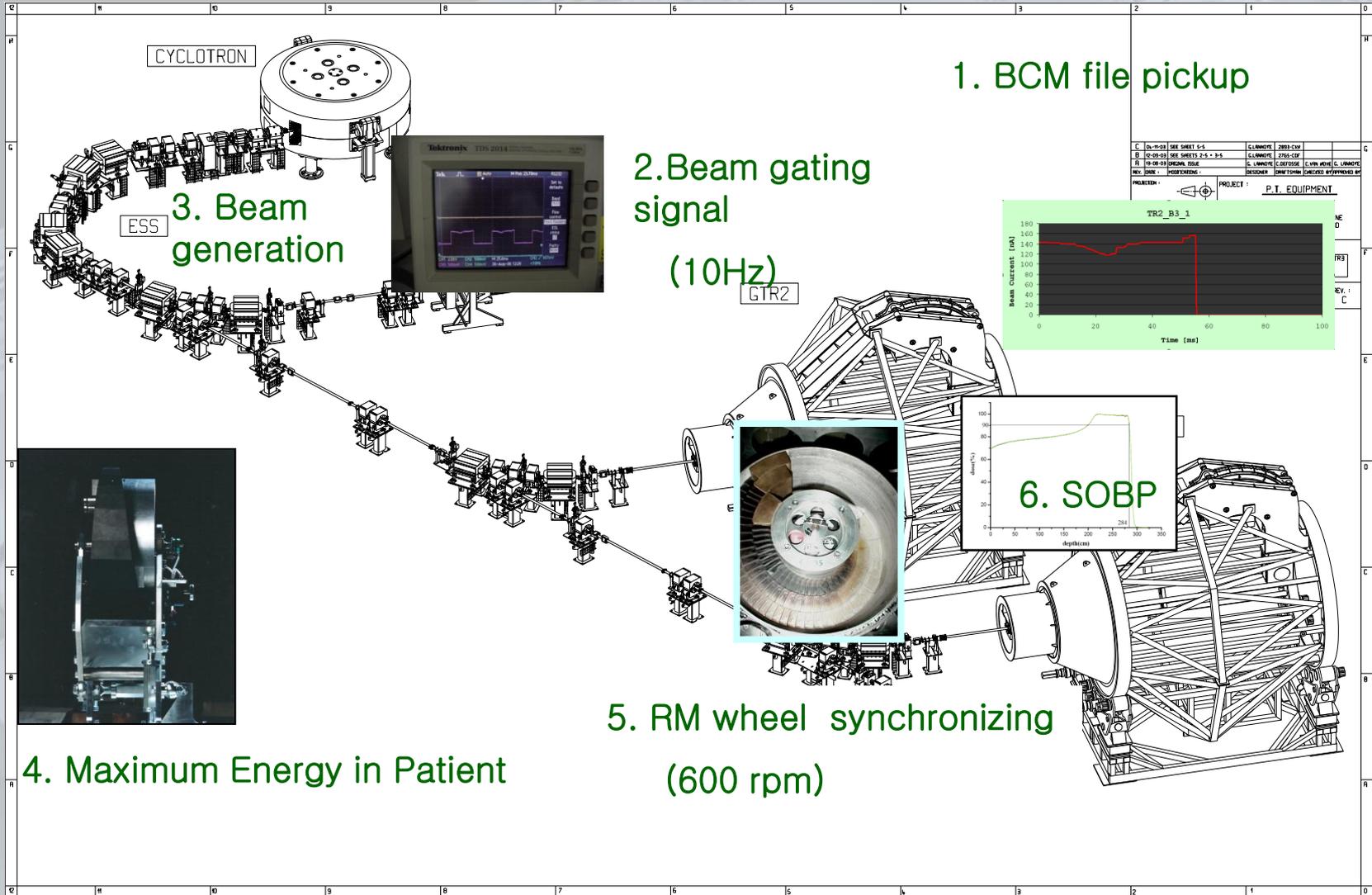
### Uniform Scanning mode



### Pencil Beam Scanning mode



# SOBP on Scattering mode



# Proton Beam time Schedule (11 shift/week)

time	Mon	Tue	Wed	Thu	Fri	Sat	Sun
6	<b>Morning QA work for daily Patient Treatment</b>					Patient Treatment (Reserved)	Beam data Measurement, Machine QA & Research
7							
8	Patient Treatment						
9							
10							
11							
12							
13							
14							
15							
16							
17	Patient QA & Beam data Measurement	Patient QA & Beam data Measurement	Patient QA & Beam data Measurement	Patient QA & Beam data Measurement	Patient QA & Beam data Measurement		
18							
19							
20							
21							
22							

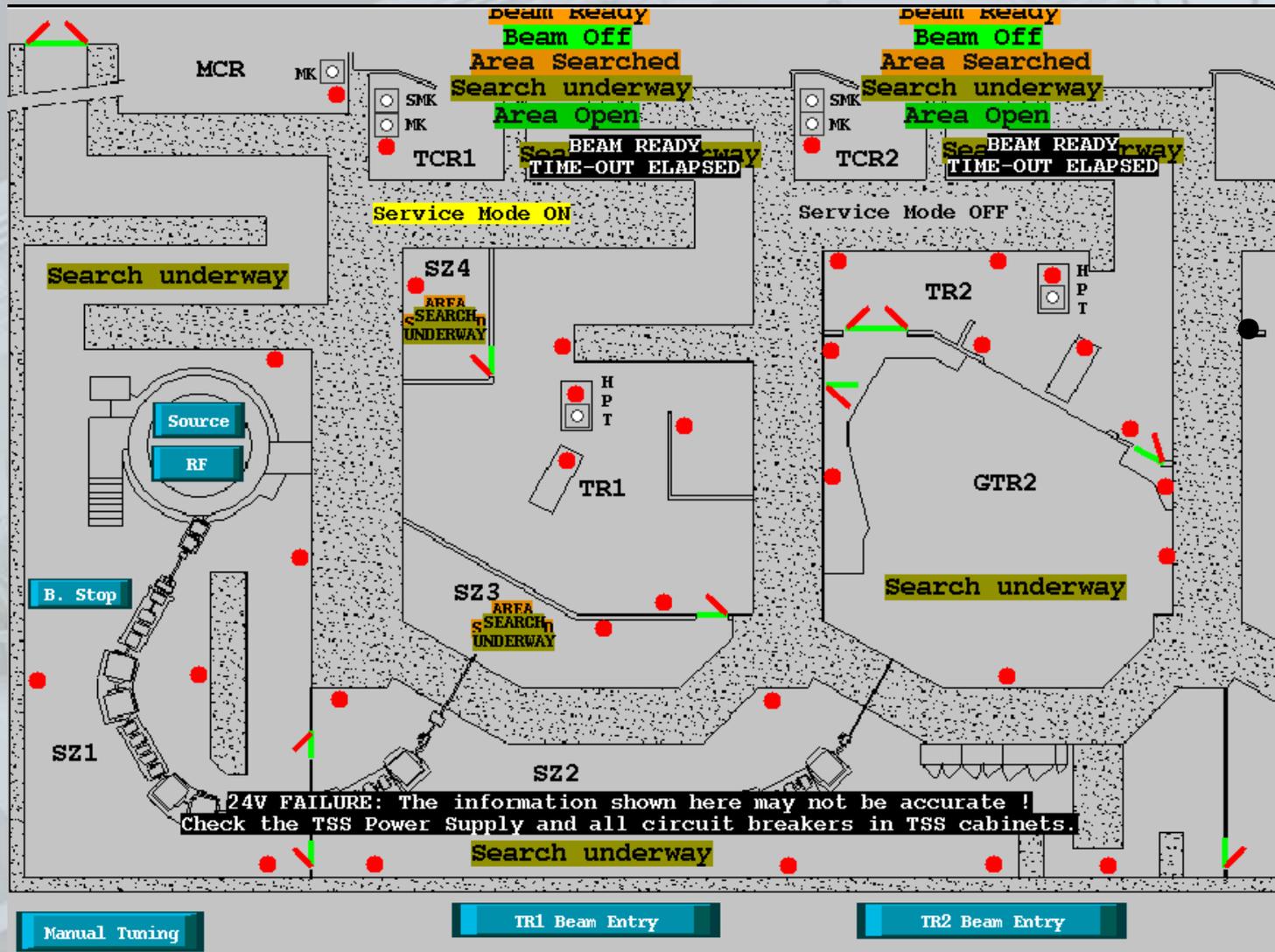




# 4. Safety system



# Building Interlock



# System Monitoring & Safety System Interlock

## Safety System Interlocks Summary

<p><b>Computer Health</b></p> <table border="1"> <thead> <tr> <th>TSS</th> <th>SCU</th> <th>TCS</th> <th></th> </tr> </thead> <tbody> <tr><td>■</td><td>■</td><td></td><td>ACU</td></tr> <tr><td>■</td><td>■</td><td></td><td>EGU</td></tr> <tr><td>■</td><td>■</td><td></td><td>BLPSCU</td></tr> <tr><td>■</td><td></td><td>■</td><td>SCU</td></tr> <tr><td>■</td><td>■</td><td></td><td>MCRS1</td></tr> <tr><td>■</td><td></td><td></td><td>TGU1</td></tr> <tr><td>■</td><td>■</td><td></td><td>PCU1</td></tr> <tr><td>■</td><td></td><td></td><td>TGU2</td></tr> <tr><td>■</td><td>■</td><td></td><td>PCU2</td></tr> </tbody> </table> <p>ALL HEARTBEATS PRESENT</p>	TSS	SCU	TCS		■	■		ACU	■	■		EGU	■	■		BLPSCU	■		■	SCU	■	■		MCRS1	■			TGU1	■	■		PCU1	■			TGU2	■	■		PCU2	<p><b>Room Security</b></p> <table border="1"> <thead> <tr> <th>TSS</th> <th>SCU</th> <th></th> </tr> </thead> <tbody> <tr><td>■</td><td>■</td><td>SubZone 2</td></tr> <tr><td>■</td><td>■</td><td>Cyc Vault (SZ1)</td></tr> <tr><td></td><td>■</td><td>MCR Master Key</td></tr> </tbody> </table> <hr/> <table border="1"> <thead> <tr> <th>TSS</th> <th>SCU</th> <th></th> </tr> </thead> <tbody> <tr><td>■</td><td>■</td><td>SubZone 3</td></tr> <tr><td>■</td><td>■</td><td>Subzone 4</td></tr> <tr><td></td><td>■</td><td>ICR1 Master Key</td></tr> <tr><td>■</td><td>■</td><td>TR 1</td></tr> </tbody> </table> <p>Beam Ready Time-out elapsed</p> <hr/> <table border="1"> <thead> <tr> <th>TSS</th> <th>SCU</th> <th></th> </tr> </thead> <tbody> <tr><td>■</td><td>■</td><td>Gantry 2</td></tr> <tr><td></td><td>■</td><td>ICR2 Master Key</td></tr> <tr><td>■</td><td>■</td><td>TR 2</td></tr> </tbody> </table> <p>Beam Ready Time-out elapsed</p> <p>■ Open/OFF    ■ Secure/ON</p>	TSS	SCU		■	■	SubZone 2	■	■	Cyc Vault (SZ1)		■	MCR Master Key	TSS	SCU		■	■	SubZone 3	■	■	Subzone 4		■	ICR1 Master Key	■	■	TR 1	TSS	SCU		■	■	Gantry 2		■	ICR2 Master Key	■	■	TR 2	<p><b>Gantry</b></p> <table border="1"> <thead> <tr> <th>TR1</th> <th>TR2</th> <th></th> </tr> </thead> <tbody> <tr><td>■</td><td></td><td>Crash Status</td></tr> <tr><td>■</td><td></td><td>Access Pt PreC</td></tr> <tr><td>■</td><td></td><td>Snout locked</td></tr> <tr><td>■</td><td></td><td>CW LS</td></tr> <tr><td>■</td><td></td><td>CCW LS</td></tr> <tr><td>■</td><td></td><td>Cab1 Press.</td></tr> <tr><td>■</td><td></td><td>Cab2 Press.</td></tr> <tr><td>■</td><td></td><td>Brk Press.</td></tr> <tr><td>■</td><td></td><td>PCU Sgls PPD Sel</td></tr> <tr><td>■</td><td></td><td>PCU Brk Rel Rq</td></tr> <tr><td>■</td><td></td><td>Drv1 Enabled</td></tr> <tr><td>■</td><td></td><td>Drv2 Enabled</td></tr> <tr><td>■</td><td></td><td>Motion Enable</td></tr> </tbody> </table>	TR1	TR2		■		Crash Status	■		Access Pt PreC	■		Snout locked	■		CW LS	■		CCW LS	■		Cab1 Press.	■		Cab2 Press.	■		Brk Press.	■		PCU Sgls PPD Sel	■		PCU Brk Rel Rq	■		Drv1 Enabled	■		Drv2 Enabled	■		Motion Enable	<p><b>PPS</b></p> <table border="1"> <thead> <tr> <th>TR1</th> <th>TR2</th> <th></th> </tr> </thead> <tbody> <tr><td>■</td><td>■</td><td>PGU Sgls PPD Sel</td></tr> <tr><td>■</td><td>■</td><td>Access Pt PreC</td></tr> <tr><td>■</td><td>■</td><td>Crash Status</td></tr> <tr><td>■</td><td>■</td><td>Collision Memory</td></tr> <tr><td>■</td><td>■</td><td>Motion Enable</td></tr> </tbody> </table>	TR1	TR2		■	■	PGU Sgls PPD Sel	■	■	Access Pt PreC	■	■	Crash Status	■	■	Collision Memory	■	■	Motion Enable
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**SOME CIRCUIT BREAKER(S) TRIPPED IN THE TSS.  
THE INFORMATION SHOWN HERE MAY NOT BE ACCURATE !**

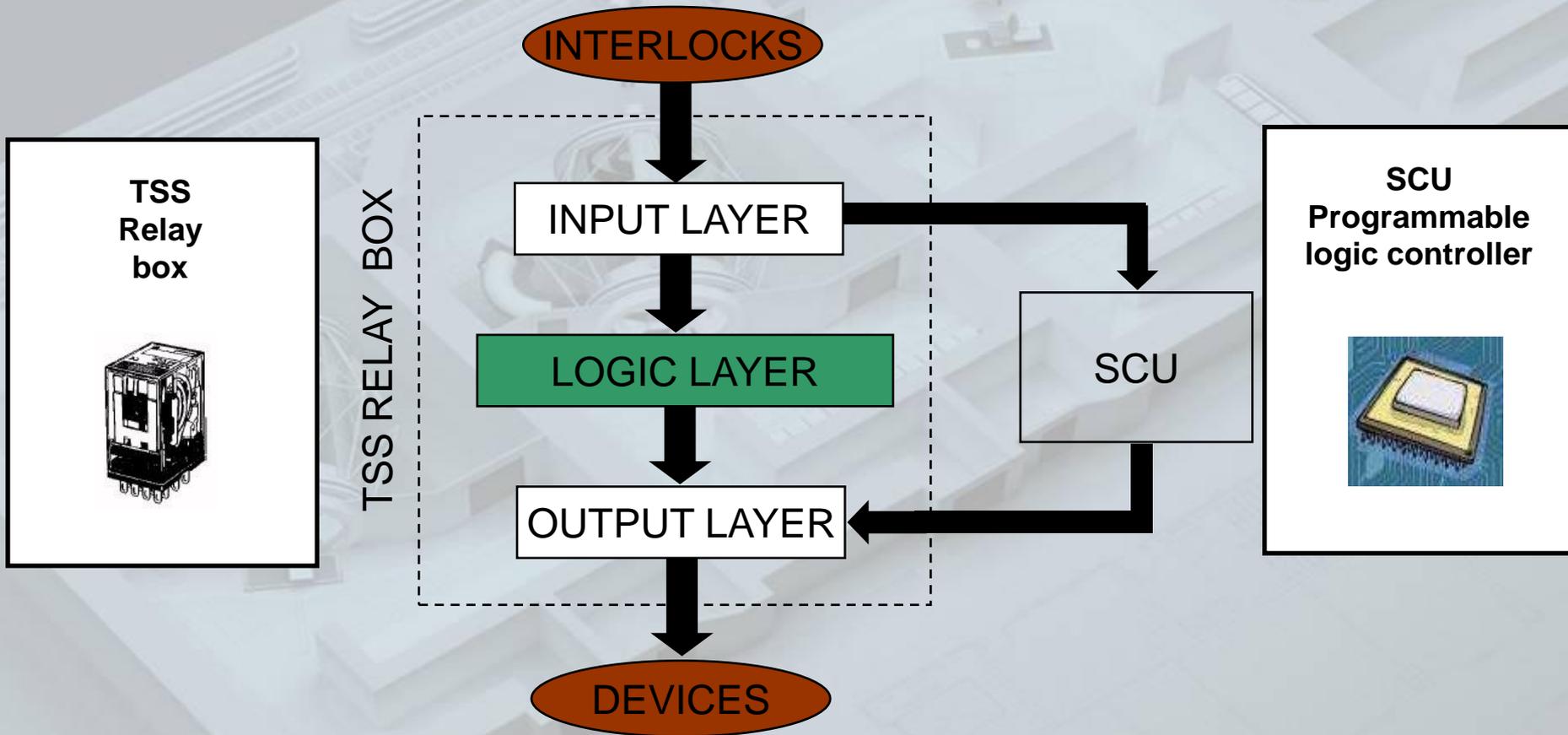


# Detailed Troubleshooting

## TR2 GANTRY HARDWARE & OTHER CONDITIONS

	TSS	SCU
✓ PCU health status OK Press the h.s. reset button in TSS	✓	✓
✓ SCU health status OK Press the h.s. reset button in TSS	✓	✓
✓ MCRS1 health status OK Press the h.s. reset button in TSS	✓	✓
✓ Snout locked		✓
✓ CW limit switch		✓
✓ CCW limit switch		✓
✓ Brakes pneumatic cabinet 1 supply pressure		✓
✓ Brakes pneumatic cabinet 2 supply pressure		✓
✓ Brakes air pressure		✓
NOT APPLICABLE (NO ACCESS POINT ACTIVE)	✓ Single patient positioning device selected in PCU	✓
	✓ Brakes release request from PCU	✓
	✓ Motor driver 1 enabled	✓
	✓ Motor driver 2 enabled	✓

# Structure of the relay circuitry



# Main Control Room : TSS relay racks



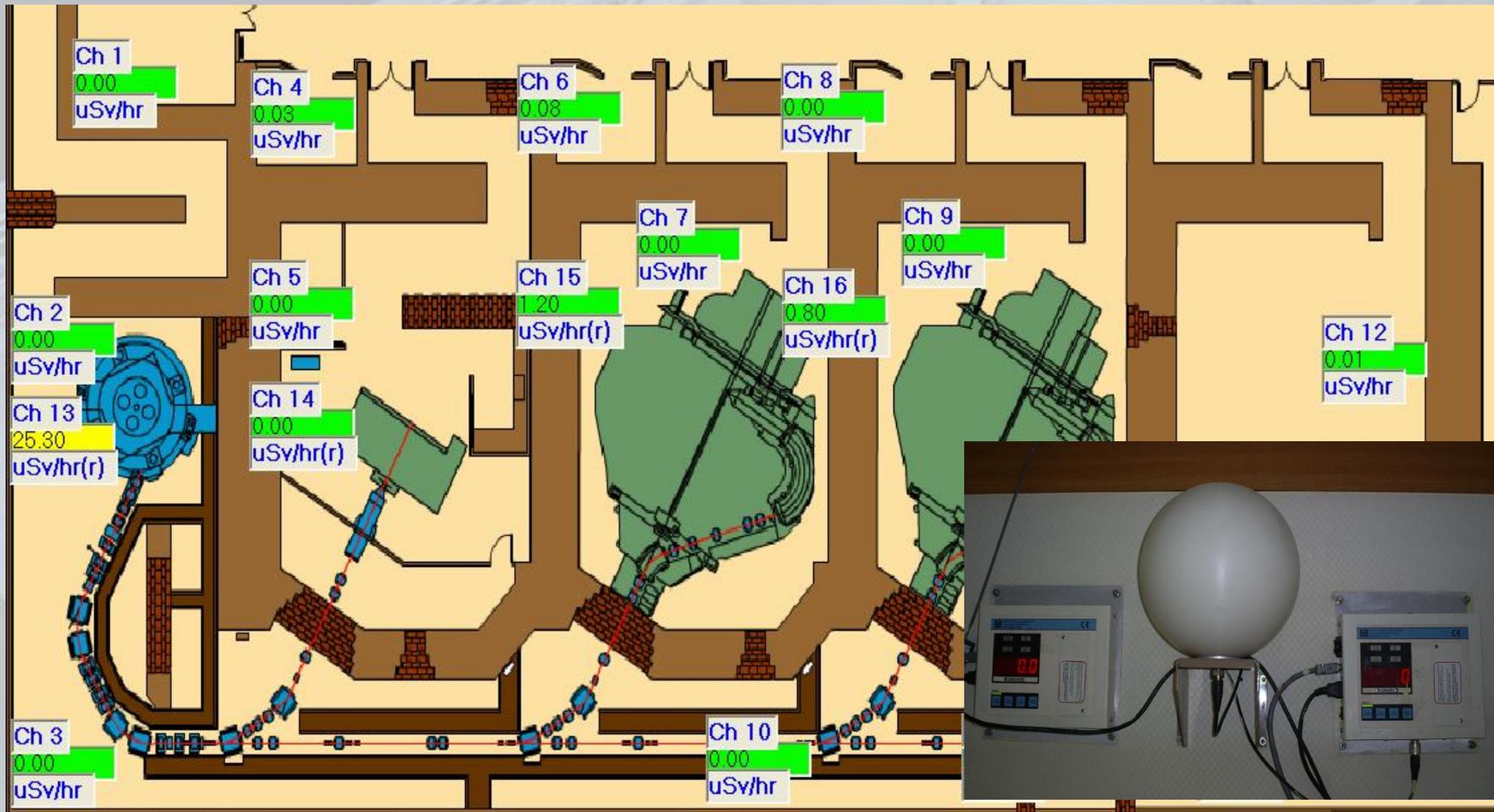
# CCD camera system



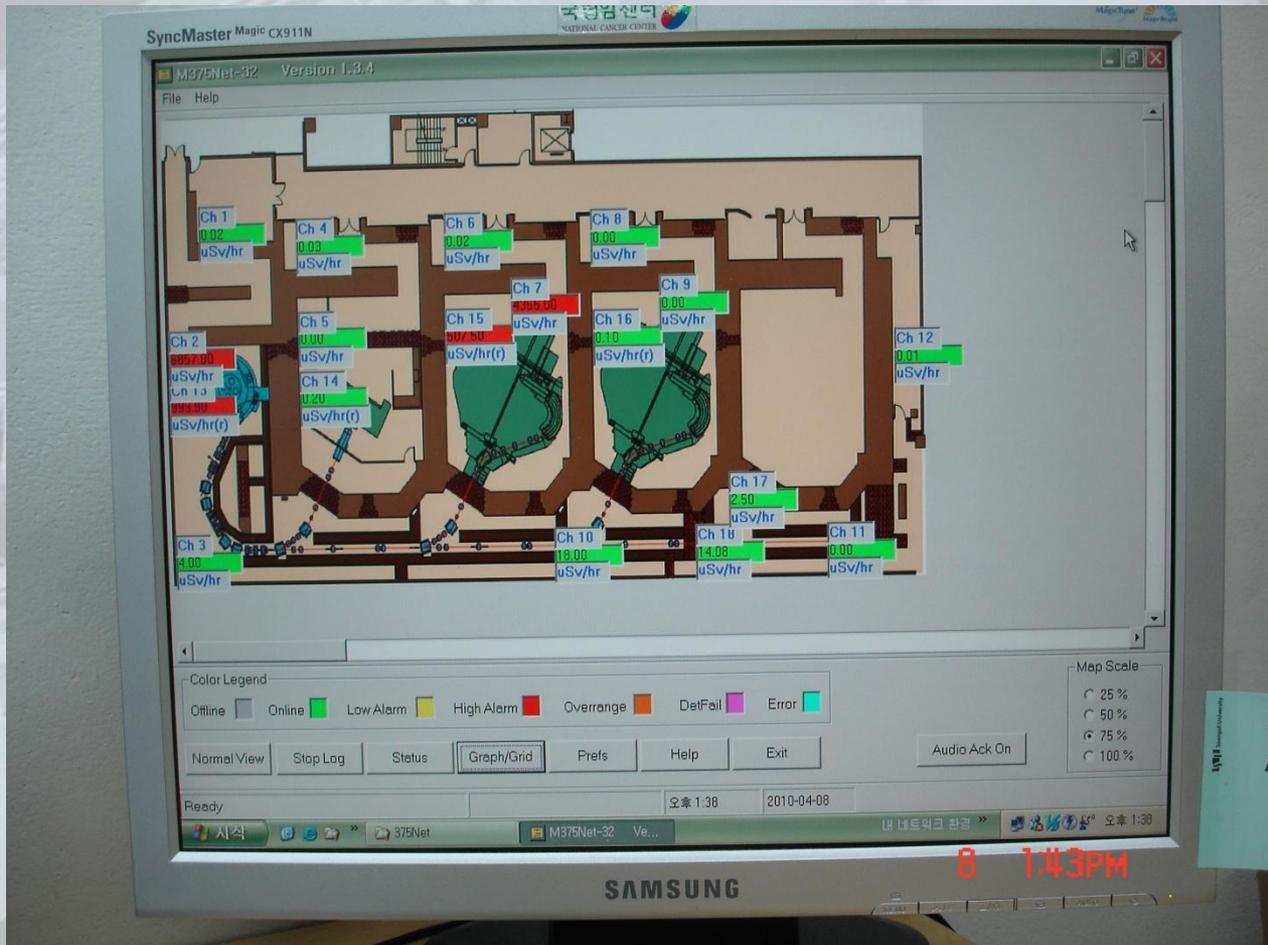
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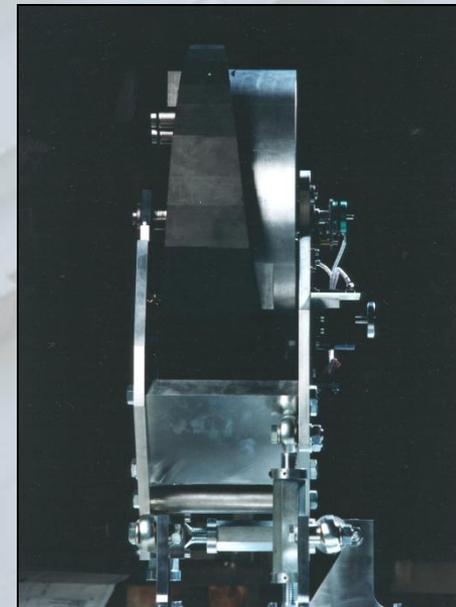
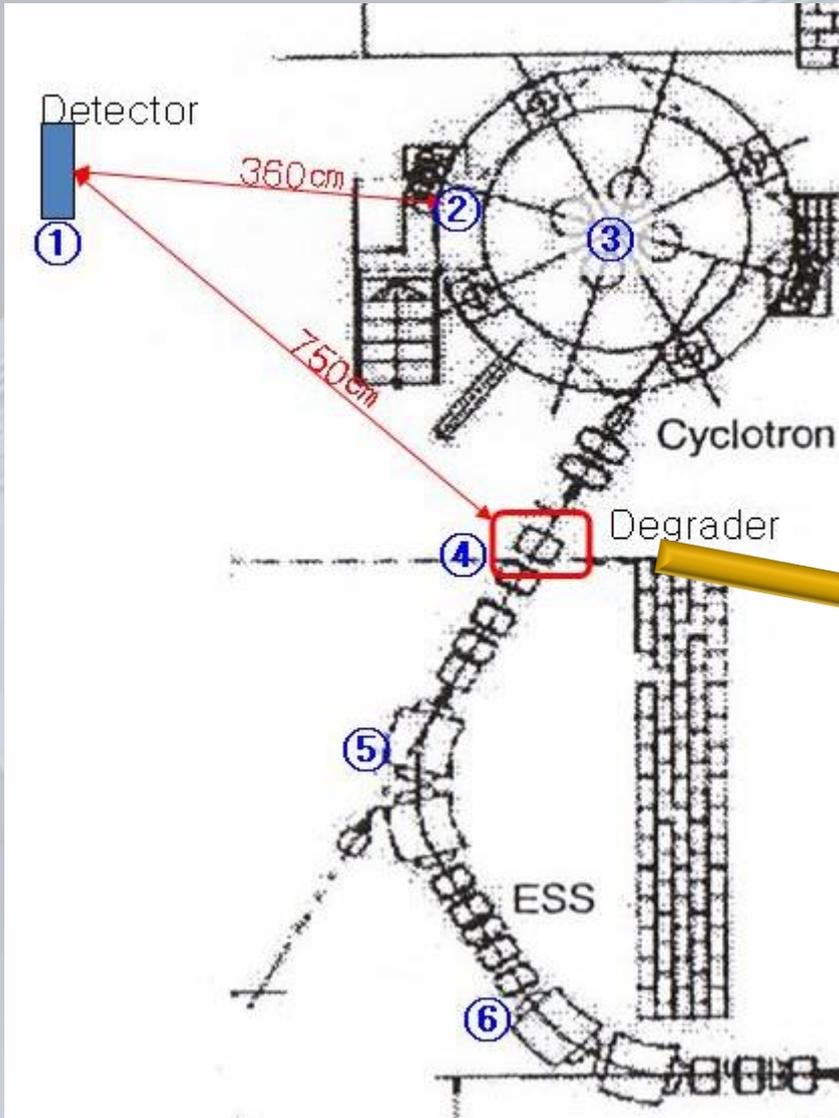
# Radiation level monitor with Area detectors



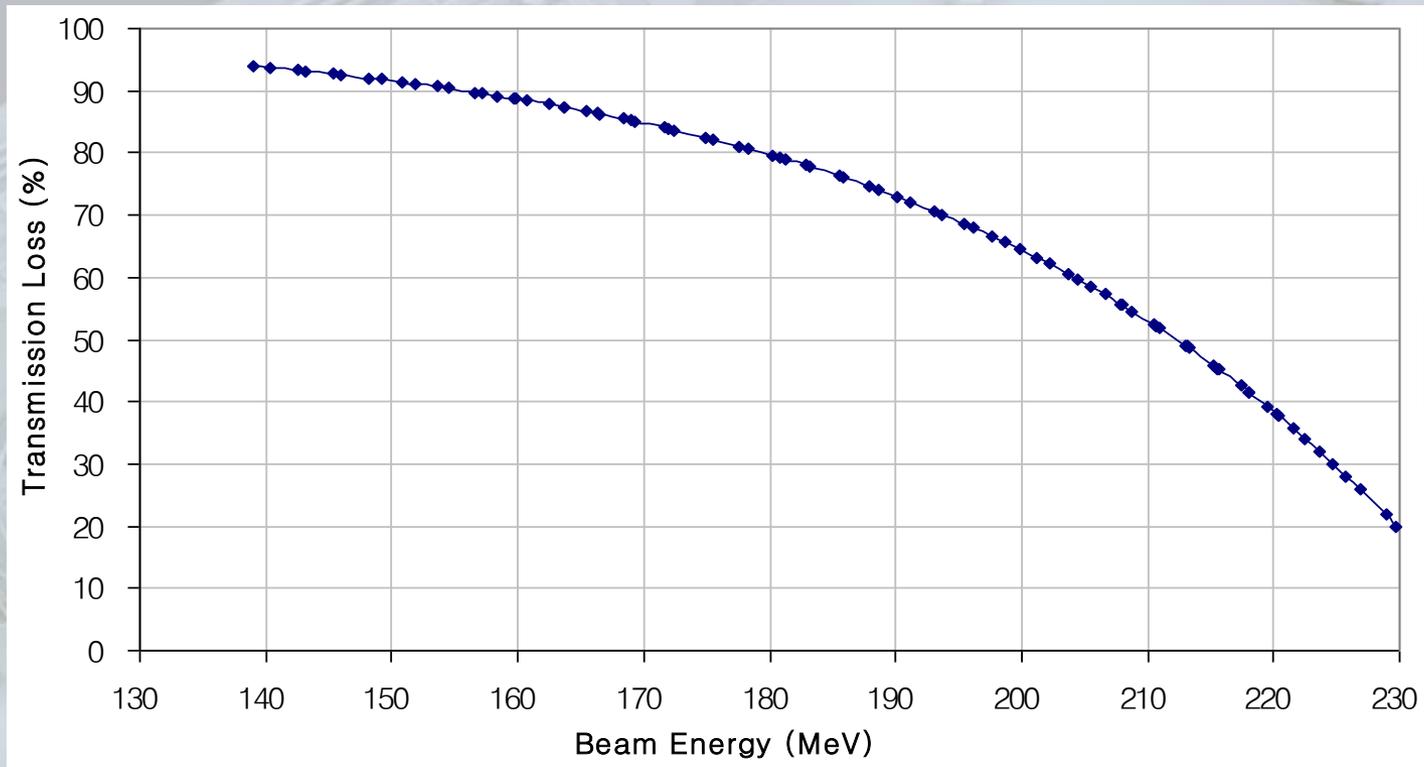
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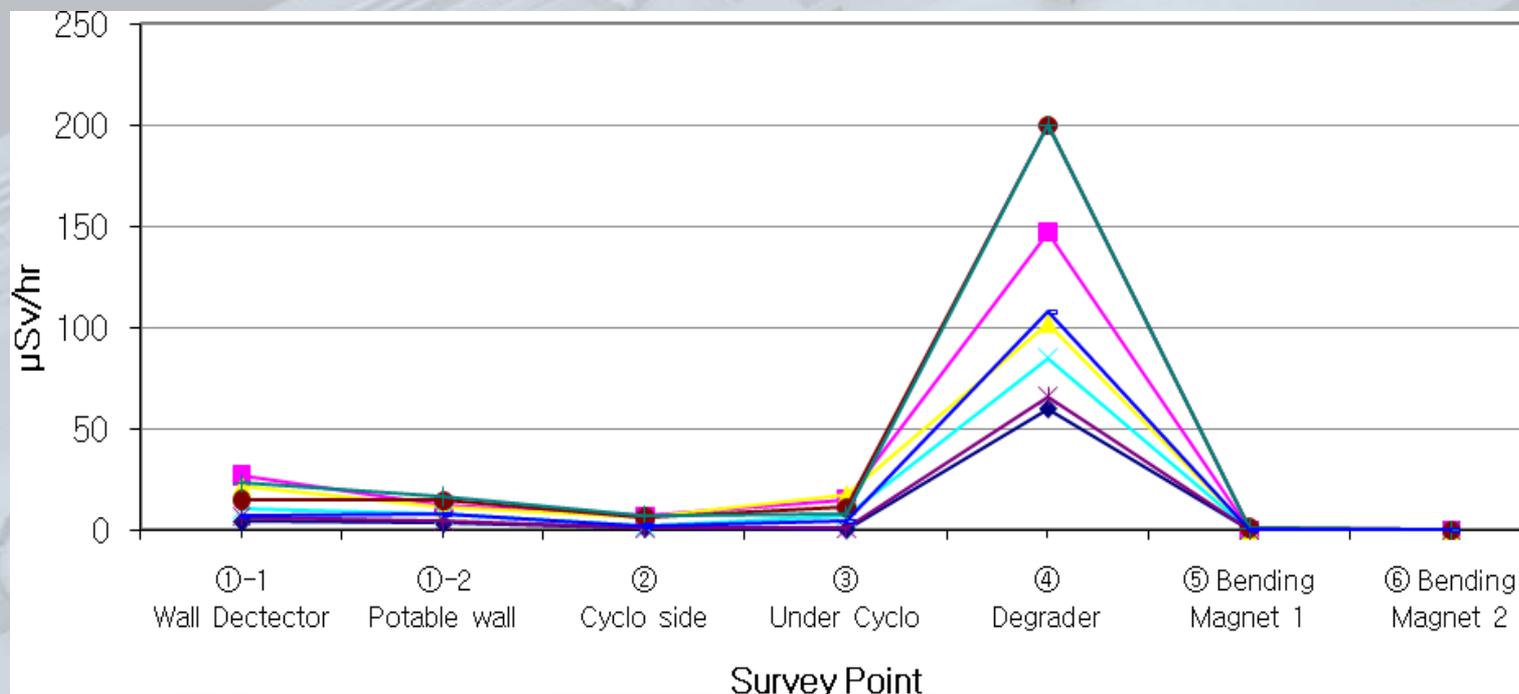
# Layout of Cyclotron and ESS(Energy selection system)



# ESS (Energy selection system) transmission loss (%)

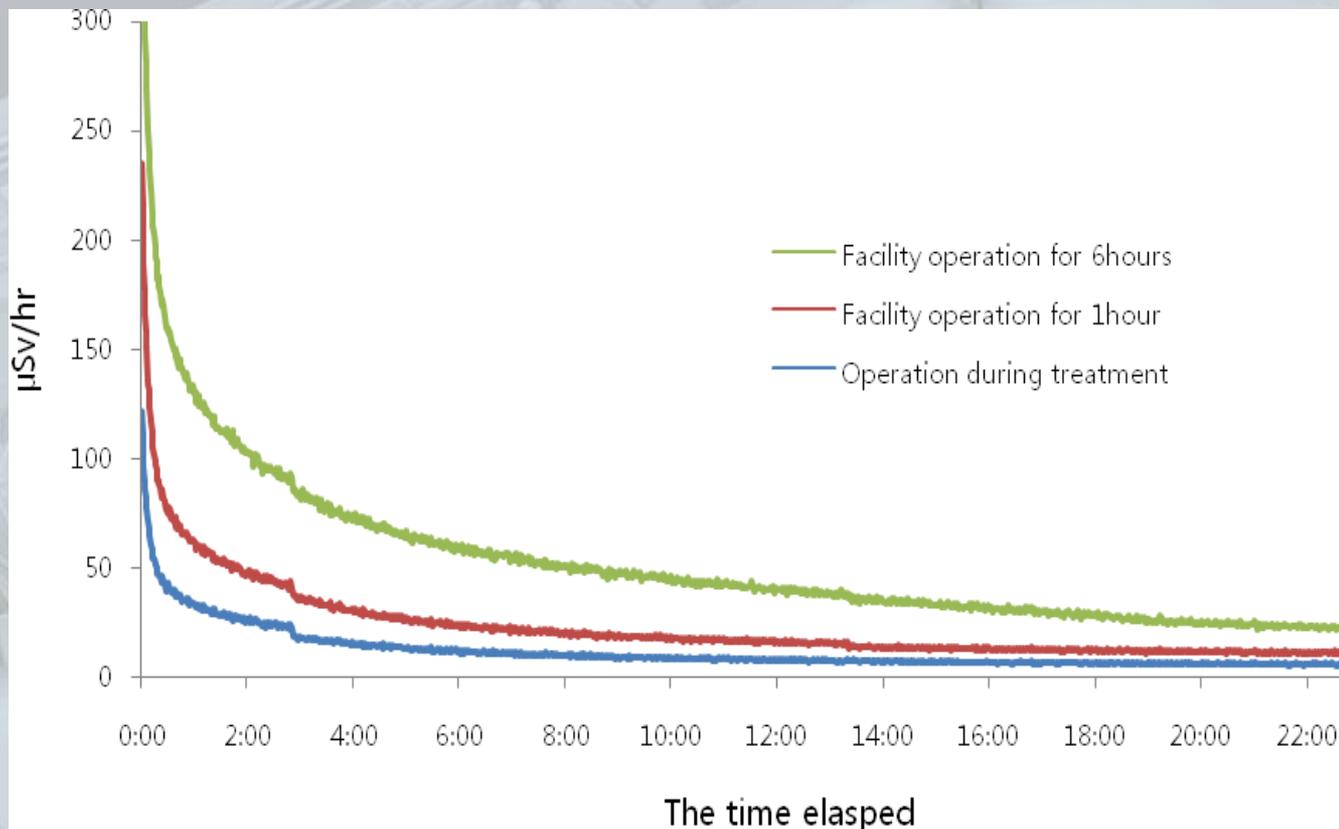


# Radiation level after beam stop



A level of radiation around cyclotron and energy selection system area through random measurements after accelerator operation.

# A level of radiation attenuation by operation condition



# Working under radiation exposure



# Radiation Exposure statistics for workers

Category	Exposure Dose in 2009
Therapists	< 1 mSv
Medical Physicists	< 1 mSv
MCR Operators	0.7 ~ 2.5 mSv
Maintenance Engineers	4.5 ~ 7.0 mSv



# 5. Maintenance Issues



# NCC PT Maintenance manpower

- **Biomedical Engineers : 2.5 man/year**
    - 1 RF & PT system Engineer : 100%
    - 1 Electronics Engineer : 100 %
    - 1 Mechanics Engineer : 30 %
    - 1 Software Engineer : 20%
  - **MCR Operators(PTC) : 1.2 man/year**
    - 4 Engineers of IBA certification for Cyclotron OP
    - Operation 70% + Maintenance support 30%
- \* IBA's technical supports (Regular + Emergency visit from Belgium)



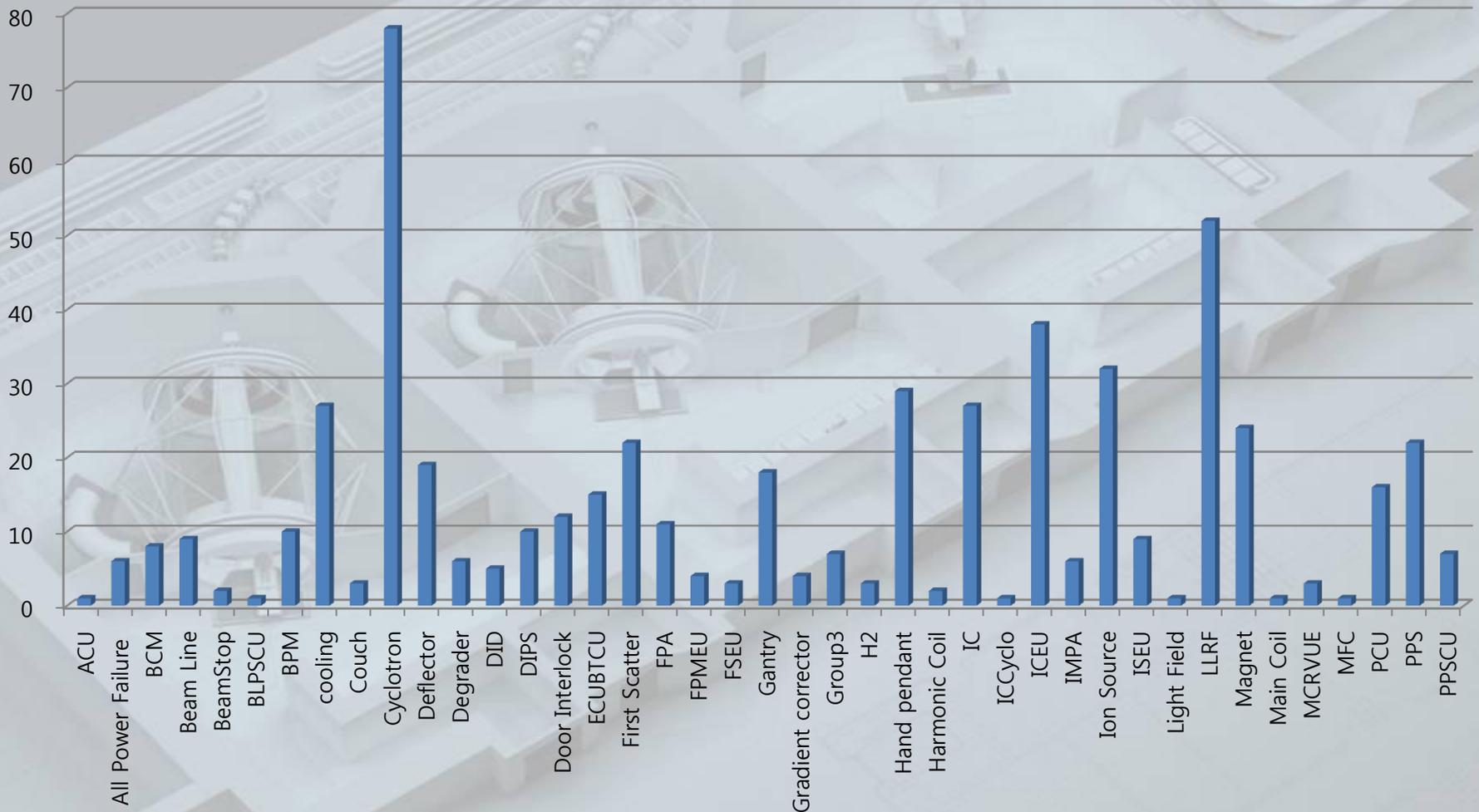
# All PM Tasks for PT in NCC

1	2	A	B	C	D
1	2	Area	IntervalDays	ProcedureDescription	Task Description
·	9		30	Cleaning & Lubricating BPM Pneumatic Pistons	Cleaning & Lubricating BPM Pneumatic Pistons
·	10		180	Servicing Cooling Water Y-strainers	Servicing Cooling Water Y-strainers
·	11		180	Servicing the Water-Cooling System	Check water cooling valves & lines for leaks
·	12		360	Testing the BPMs, Beam Stops (fixed), & Radial Probe Signal Insulation	Test BPM & BCM signal insulation
·	13		360	Checking a Cooling Water Flow Switch	Checking a Cooling Water Flow Switch
·	14		360	Testing Dipole Magnet Thermal Switches	Testing Dipole Magnet Thermal Switches
·	15		360	Testing the BPM System and BCM High-voltage Cable	Test BPM high voltage & HV cables
·	16		360	Servicing the Pneumatic System	Check Pneumatic System Hoses
-	17	BTS (2)			
+	33	BTS (3)			
+	41				
+	51	BTS (RA)			
+	59	Computer Room			
+	61	Cyclotron			
+	101	ESS			
+	116	Facility			
+	119	FBR1			
+	160	GTR2			
+	218	GTR3			
+	277	MCR			
+	281	Other			
+	283	PSR			
+	311	WCR			
·	312		30	Procedure needs to be written or approved	Switch the running ODP cooling pump
·	313		30	Filling the Cooling Water Tanks	Check water level of MC & General cooling water tanks
·	314		30	Procedure needs to be written or approved	Switch the running MC cooling pump
·	315		30	Procedure needs to be written or approved	Switch the running General Cooling pump
·	316		720	Servicing the Water-Cooling System	Perform OEM service of General cooling pumps
·	317		180	Servicing the Water-Cooling System	Check water cooling valves & lines for leaks
·	318		720	Servicing the Water-Cooling System	Perform OEM service of MC cooling pumps
·	319		360	Servicing Cooling Water Y-strainers	Servicing Cooling Water Y-strainers
·	320		360	Servicing the Cooling Water Heat Exchangers	Servicing the Cooling Water Heat Exchangers
·	321		360	Checking a Cooling Water Flow Switch	Checking a Cooling Water Flow Switch
-	322				

**320 items per day, week, month, year**

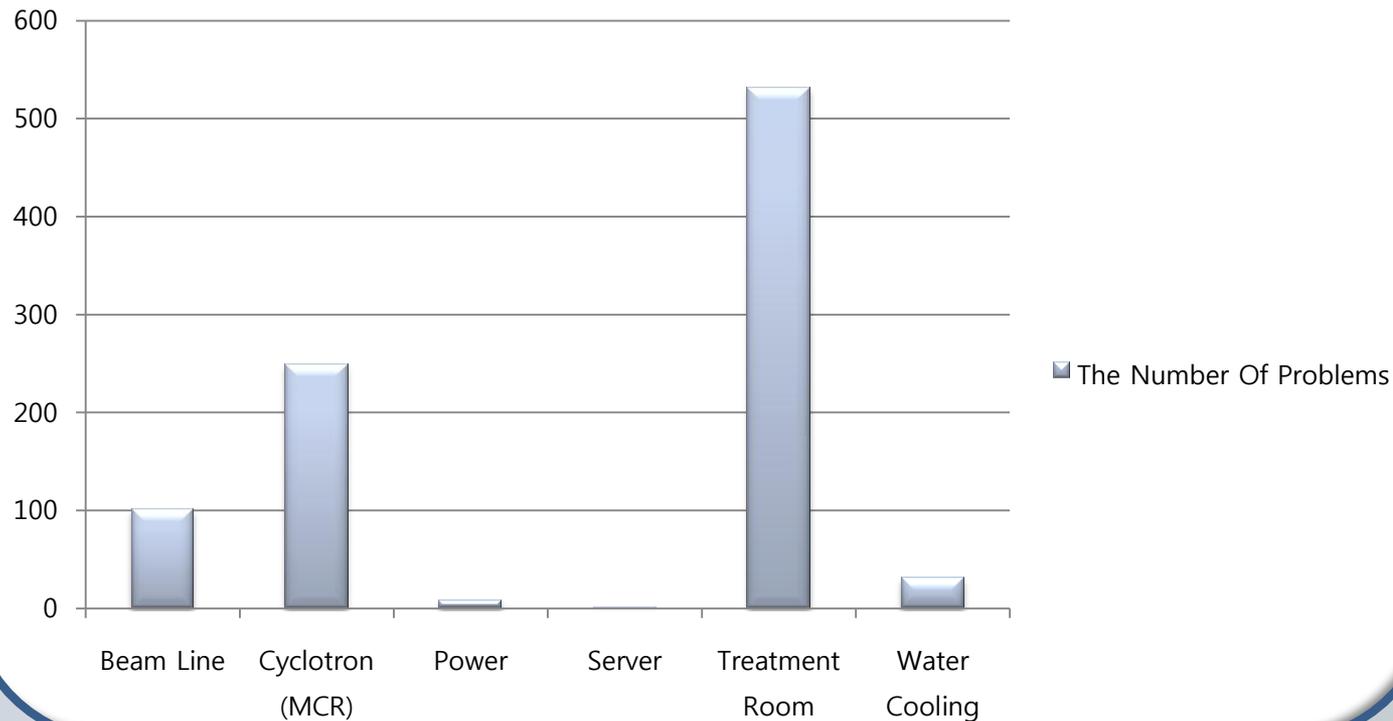


# Statistics of trouble parts



# Statistics of trouble parts

## The Number Of Problems In KNCC



## Summary

- Proton Therapy facility in NCC is successfully operating since Mar. 2007.
- We are lack in manpower for PTS maintenance.  
( ~ 94% operation rate, Potential radiation risks, etc.) So, we are going to strengthen the support for cyclotron maintenance to improve operation rate.





Thank you!

