

Cyclotrons 2013 observations and remarks

Mike Seidel, PSI



CYCLOTRONS'13

20th International Conference on
Cyclotrons and their Applications
September 16-20, 2013

Welcome

Important Dates

Programs

General

Registration

Accommodation

Author Information

Student Program

Sponsors/Exhibitors

Committees

Contact Us

Poster download

FFAG'13 Workshop

WELCOME

- The submission for abstracts is now closed.
- Early registration deadline has now passed.
- The room block at the hotel will be released **Thursday August 15, 2013**
- Cyclotrons'13 is **now open** for paper submission.

On behalf of the Local Organizing Committee, it gives me great pleasure to welcome you to the 20th International Conference on Cyclotrons and their Applications (CYCLOTRONS'13). The CYCLOTRONS'13 will be held in Canada's West Coast City of Vancouver, British Columbia from September 16th to 20th 2013. This conference is organized and hosted by TRIUMF, Canada's National Laboratory for Particle and Nuclear Physics.

A Scientific Program Committee was assembled last summer and engaged in the conference preparation. The committee has been working diligently on assembling an exciting and stimulating scientific program. One of the main thrusts is to give young physicists and engineers an opportunity to present their work at the conference.

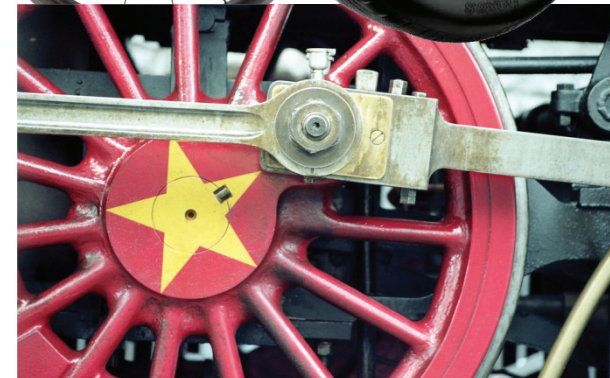
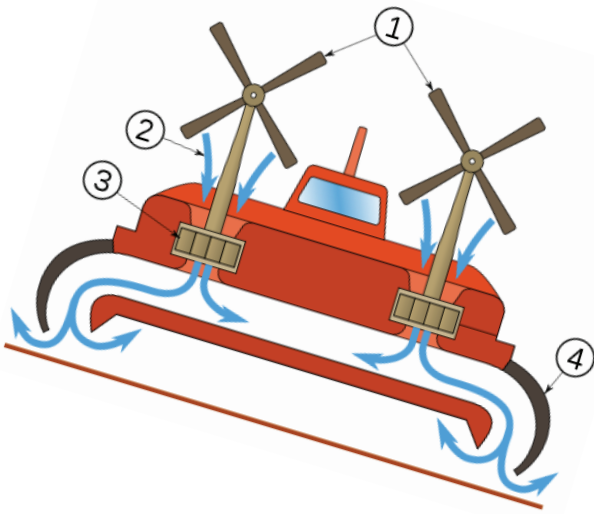
The venue of the conference is the Marriott Pinnacle Hotel in downtown Vancouver. It is a beautiful, dynamic city set in a spectacular natural environment. Vancouver offers visitors both outstanding opportunities for outdoor adventure and the sophisticated amenities of a world-class city. There are indoor and outdoor activities to please everyone in this multicultural city.

This conference website provides information concerning the scientific program as well as registration, accommodation and social activities. All colleagues intending to participate in



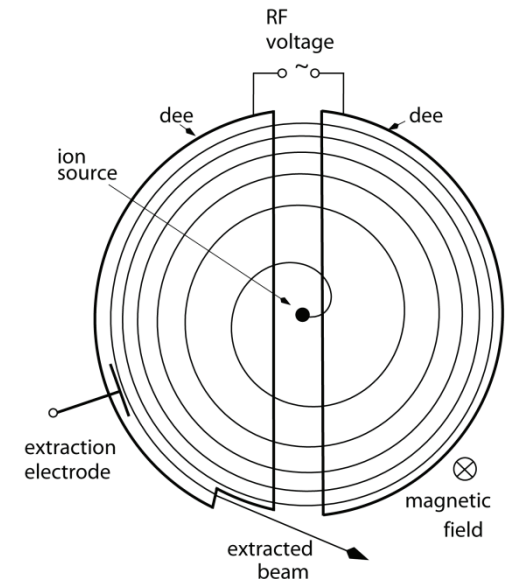
About wheels ...

- reduces friction by 10^2 ; invention by men (not copied from nature)
- simple, effective and is solution to many problems
- though mature (3.000BC), not outdated; new implementations invented every day!
- better solutions for some problems exist today, but with far less pragmatism

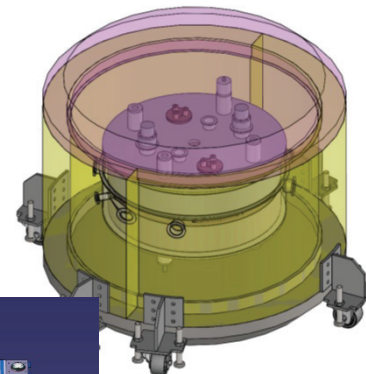
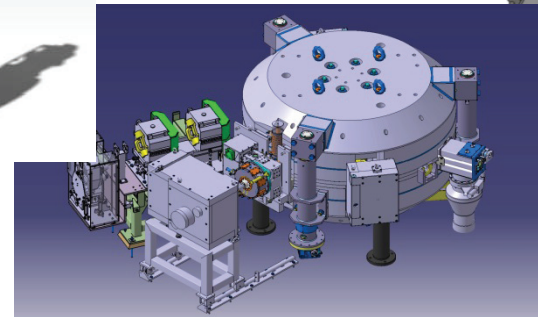
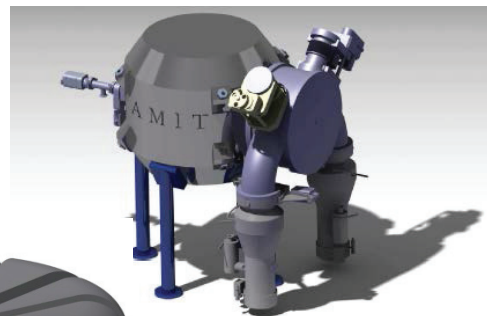
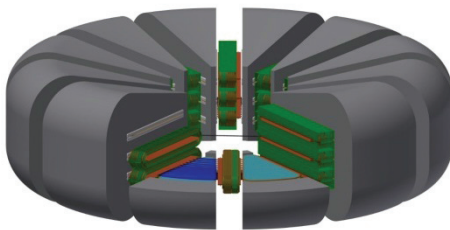
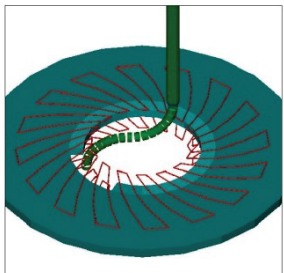


analogy to cyclotrons

- among accelerators cyclotrons are mature, however the concept is strong through its simplicity (though devil in details)
- new implementations and new applications are invented continuously
- this conference with its rich program is the best proof!



- **simple; cost effective**
- **repetitive acceleration**
- **CW operation**



Broad range of themes

abstract

- **Theory [8+20]**
[analytical, numerical]
 - **Concepts/Projects [12+19]**
[new ideas, projects under construction]
 - **Technology [13+42]**
[RF, source, diagnostics, magnets..]
 - **Operation/Upgrades [12+16]**
[experience, many improvements]
 - **Applications [7+9]**
[therapy, diverse themes..]
- **Education [5+5]**
→ important for future

concrete

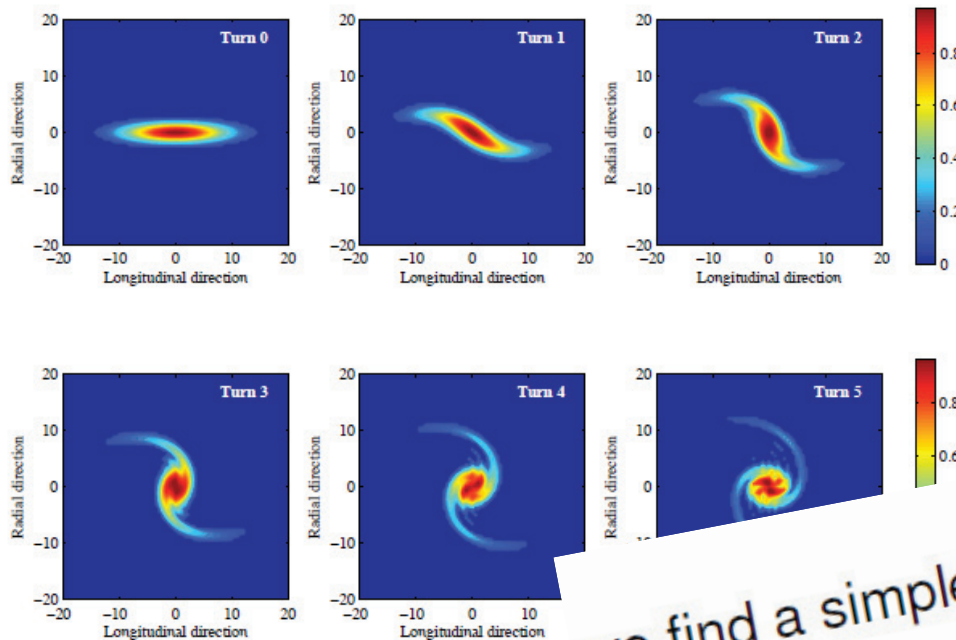
theory

- busy topic: 3 x space charge, derivation of intensity limits; rolled up (long. focused) beam
→ slowly picture more clear; chance for high current operation
- 2 x tracking codes: GEANT, ZGOUBI
- ECR source simulation
- cavity multipacting: OPAL; poster on code
- Paul Trap: equivalent beam dynamics study
- 16 posters on beam dynamics themes

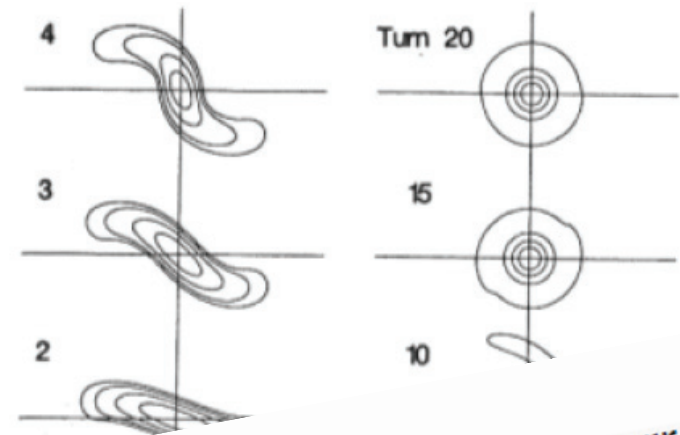
space charge, spiralled beam, Vlasov Eqn. simulation and PICS simulation

[A.Cerfon]

Our simulation



PICS simulation



we find a simple expression for maximum current

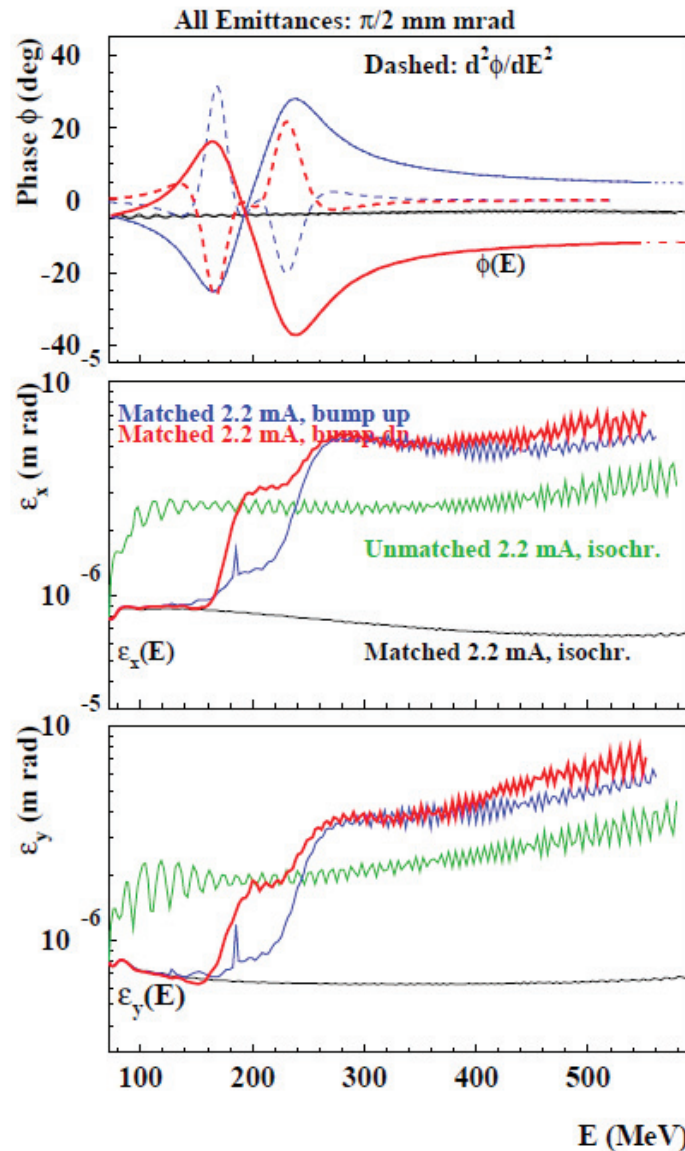
$$I_{\max} = \frac{h}{2g_x \xi^3 \beta^3 \gamma \nu_x^4} \frac{V_{\text{rf}}^3}{V_m^2 Z_0}$$

[R.Baartman]

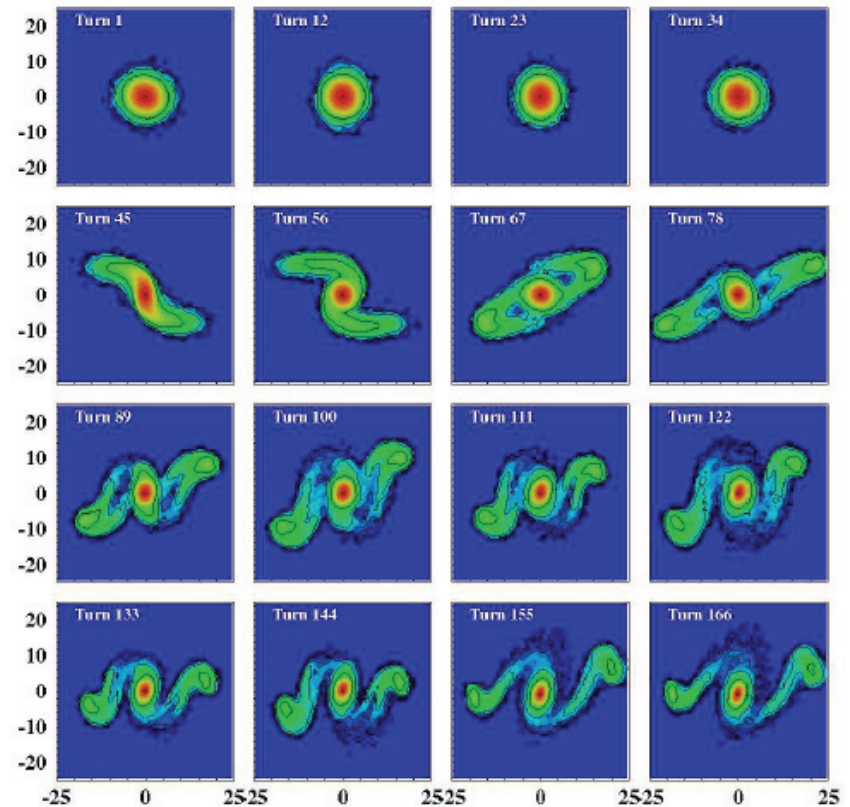
- Good agreement, ev
- Geometrical effects p

space charge simulation (including phase error)

[Ch.Baumgarten]



Matched beam, red phase:



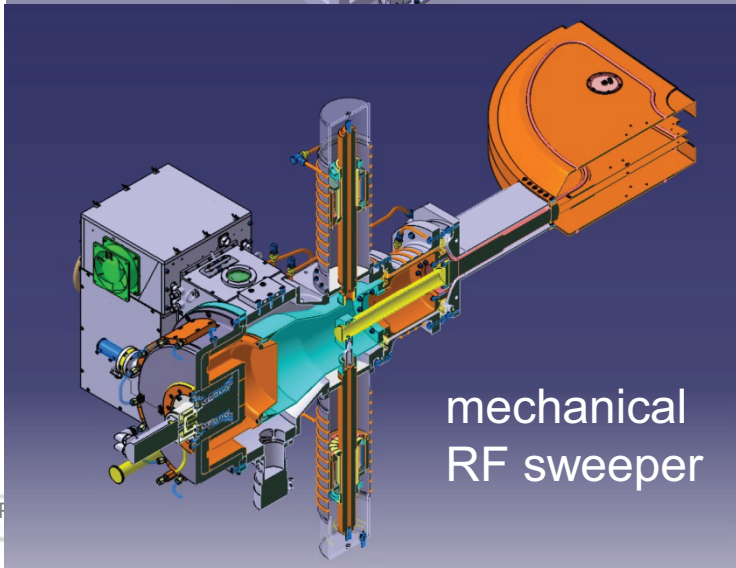
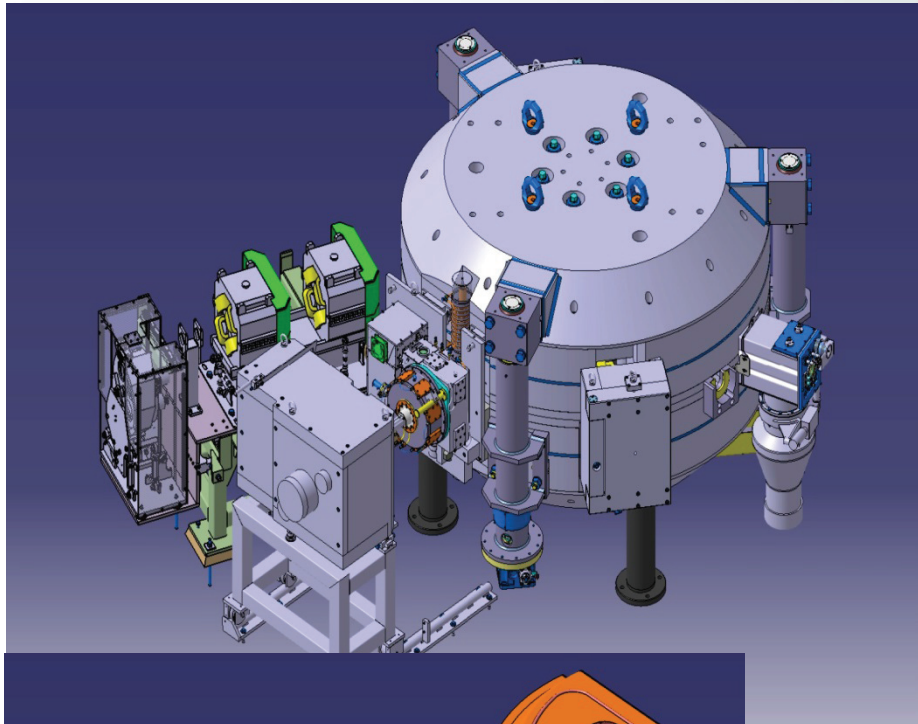
concepts and projects

- sc. synchro-cyclotron (IBA, beam tests started)
- 3x FFAG: EMMA, adv.optics, sc.cavity
- 5x Daedalus poster (H_2^+ , high power)
- channel focusing, stacked cyclotron, talk+poster
- Muon cooling in inverse cyclotron
- 2x coupling with Linac: TERA, synchro vs isochro cyclotron
- 2x sc. compact cyclotron (VECC, CIEMAT)
- RIKEN R3 Ring (M/Q meas., comm. next year)
- 19 posters in this category

S2C2 overview

[W.Kleeven, project]

General system layout and parameters

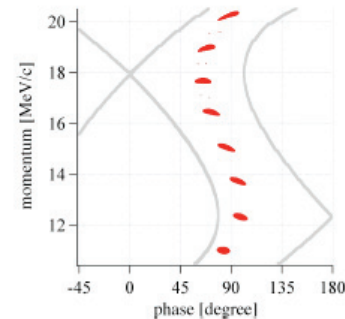


Maximum Energy	230/250 MeV
Size yoke/pole radius weight	1.25 m/0.50 m 50 tons
Coil ramp up rate / time windings/coil stored energy	NbTi - wire in channel 2-3A/min / 4 hours 3145 12 MJ
Magnetic field central/extraction	5.7 T/5.0 T
Cryo cooling initial cooldown recovery after quench	conductive 4 cryocoolers 1.5 W 12 days less than 1 day
Beam pulse rate/length	1000 Hz/7 μ sec
RF system frequency voltage	self-oscillating 93-63 MHz 10 kV
Extraction	Passive regenerative
Ion source	PIG cold cathode
Central region	removable module

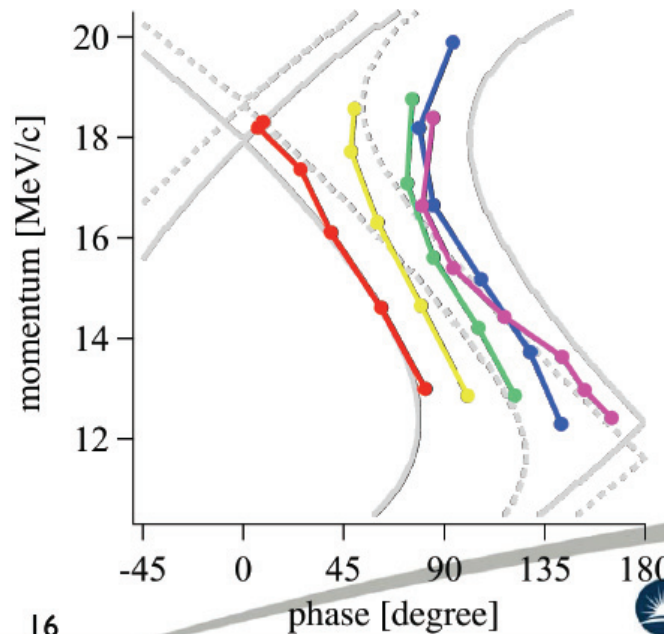
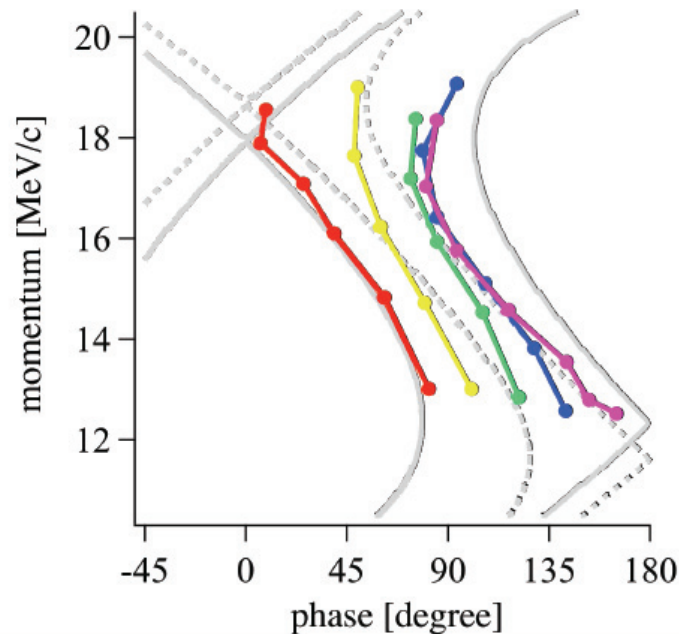
Serpentine channel acceleration

Serpentine channel
acceleration outside
rf bucket

Highlight 2



Longitudinal trajectory measured experimentally.



IC is most compatible cyclotron for injection in CABOTO

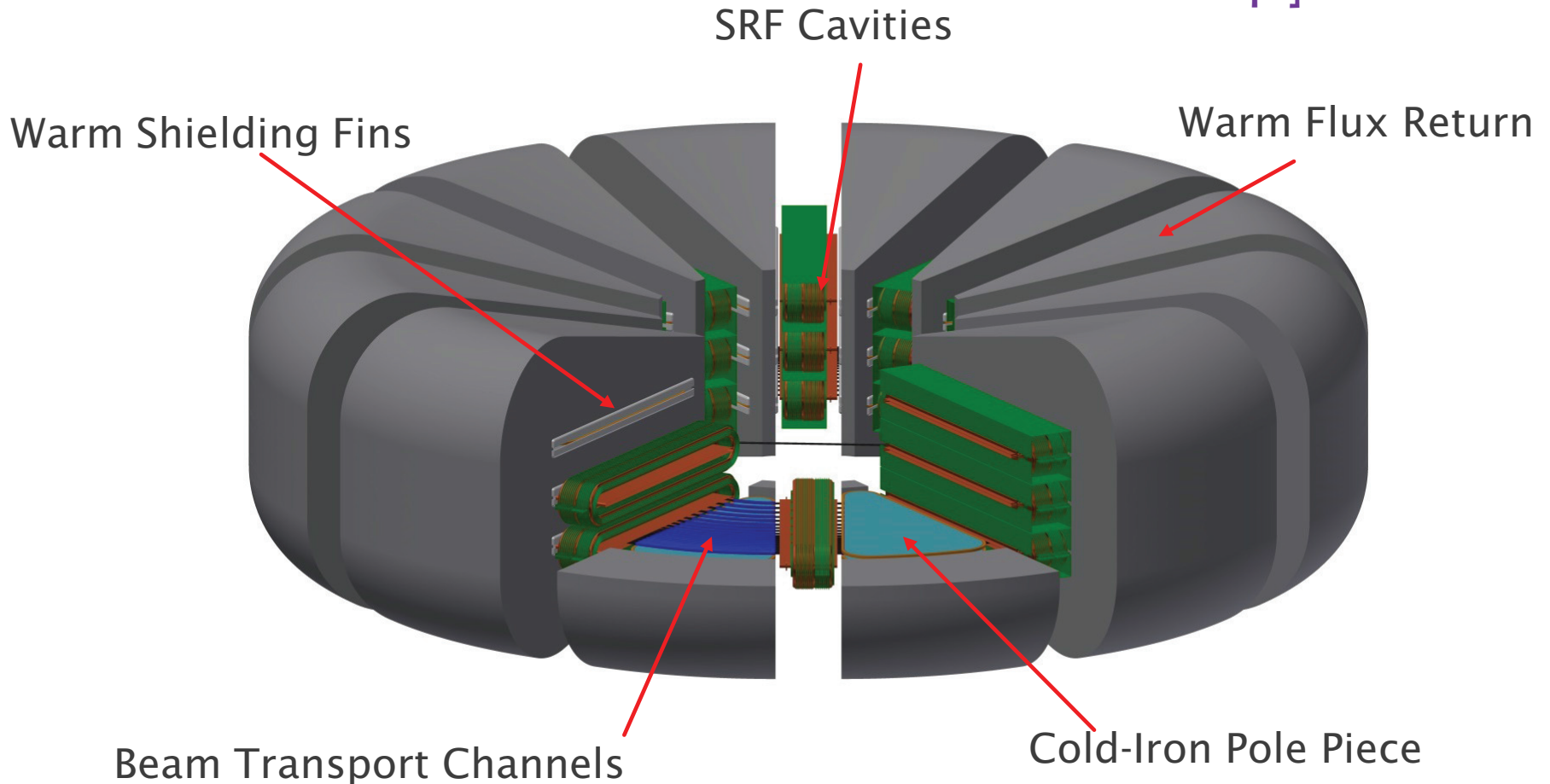
[A.Garonna/TERA, concept]

	IC	SC
q/A	1/2	
Output Energy	230 MeV/u (kinetic)	
Central Field	3.2 T	5.0 T
Pole Type	4 Sectors	Axi-symmetric
Pole Radius	1.2 m	1.1 m
Total Current/Coil	1,1 MA.turns	1.9 MA.turns
Ion Sources	At least 2 (external)	
RF cavities	2 (h=4)	1 (h=1)
RF	98 MHz	38-30 MHz
Voltage at Injection	70 kV peak	28 kV peak
Voltage at Ejection	120 kV peak	28 kV peak
RF Power Supply	100 kW	30 kW
Ejection Method	ED	Bump + ED
Yoke Diameter/Height	4.75 / 2.9 m	4.6 / 3.3 m
Iron Weight	310 tons	330 tons

➡ IC is as heavy as but more reliable than SC

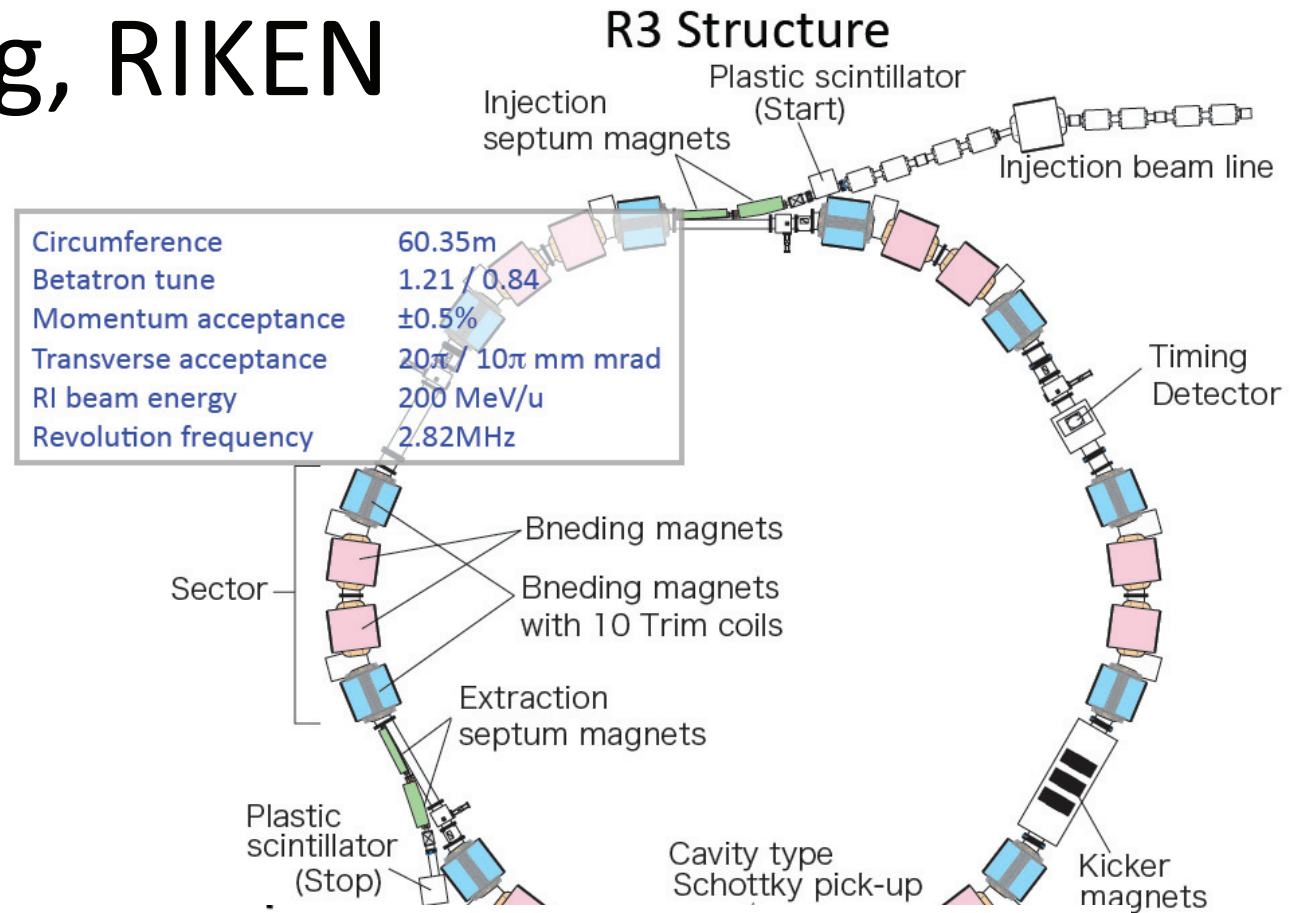
SFC Components

[J.Kellams, P.McIntyre,
concept]



rare RI-ring, RIKEN

[M.Wakasugi, project]



Uncertainty $\frac{\delta(m_1/q_1)}{m_1/q_1} = \frac{\delta(m_0/q_0)}{m_0/q_0} + \frac{\delta(T_1/T_0)}{T_1/T_0} + k \frac{\delta\beta_1}{\beta_1} \rightarrow \sim \text{ppm}$

Known Mass $< 10^{-6}$
TOF Measurement $< 10^{-6}$
 β_1 measurement $\sim 10^{-4}$ ($k \sim 10^{-2}$)

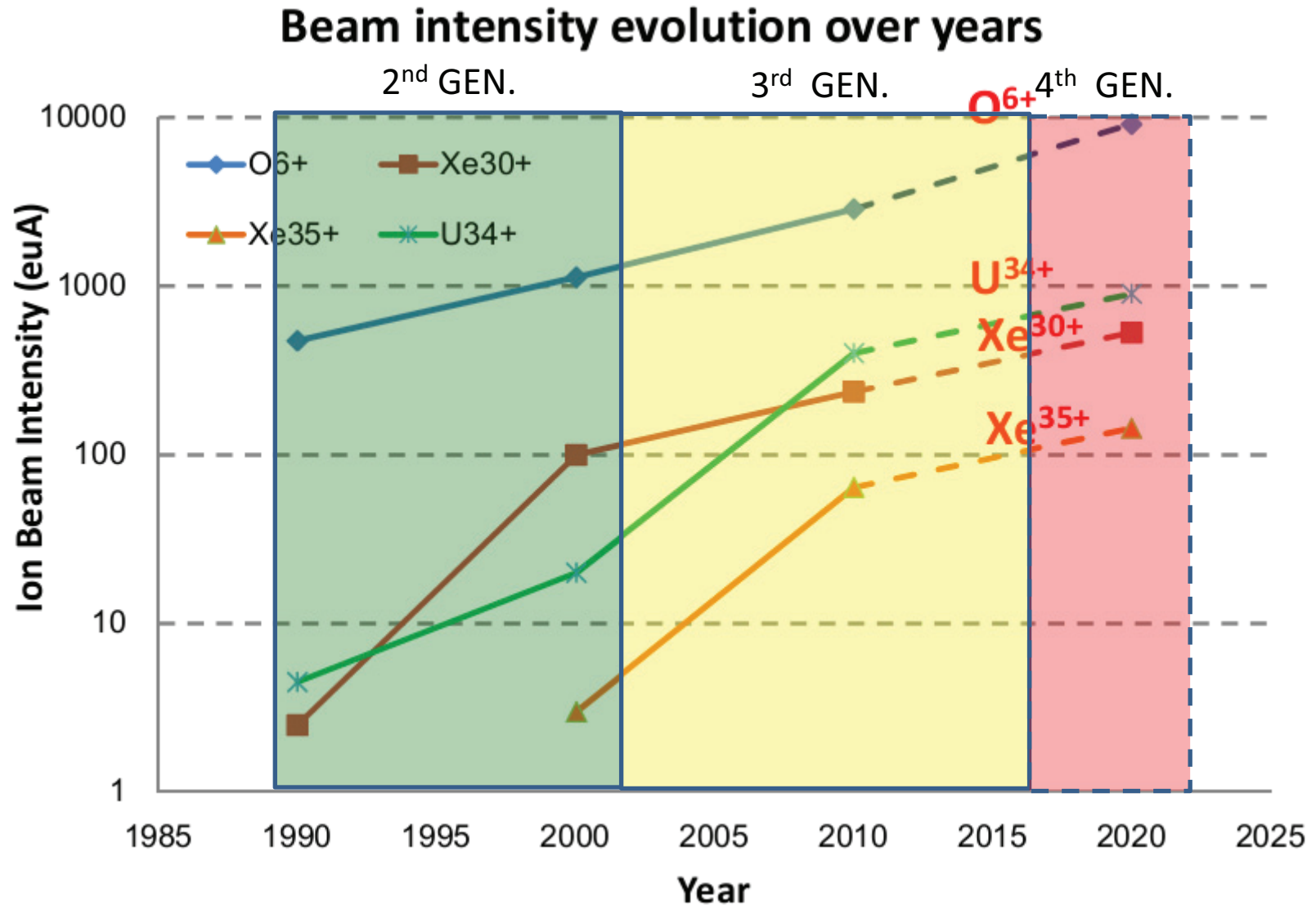
technology

understandably technology is the most extensive theme at the conference; reliable and best performing technology is the foundation of successful operation

- 3x ECR sources
- He stripping, foil stripping
- 2x magnet measurements, iron properties
- buncher, RF separator
- diagnostic: profile, shape, multi leaf Faraday c.
- 42 posters in this category:
 - controls 4; vacuum 2; diagnostics 5; source 7; RF 7; magnet 6; other 11

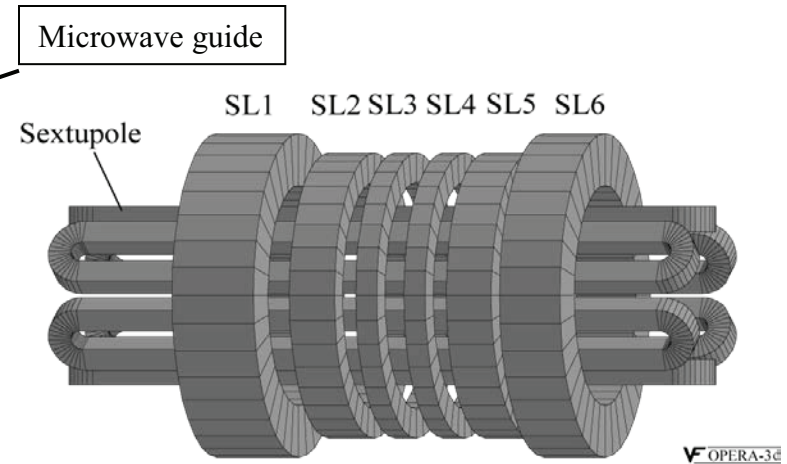
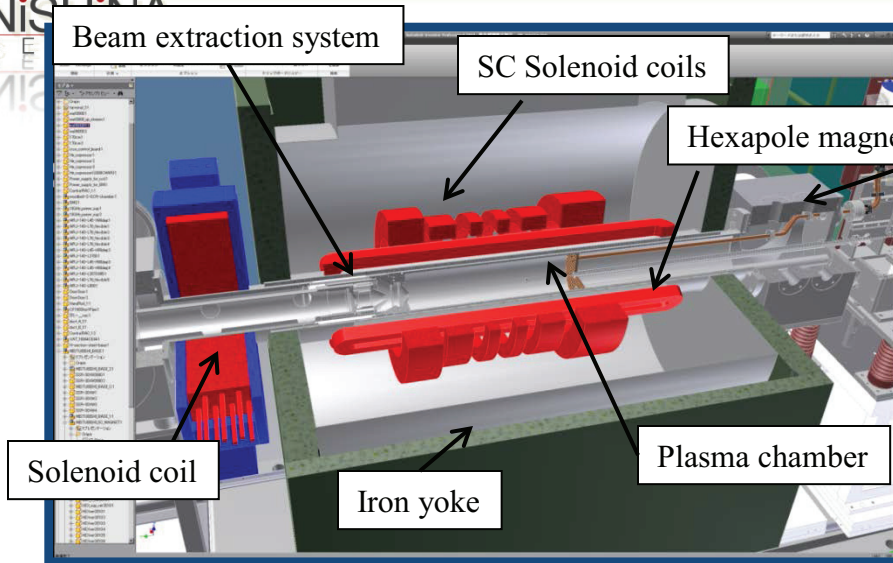
Performance Improvement

[L.Sun, ECR sources overview]

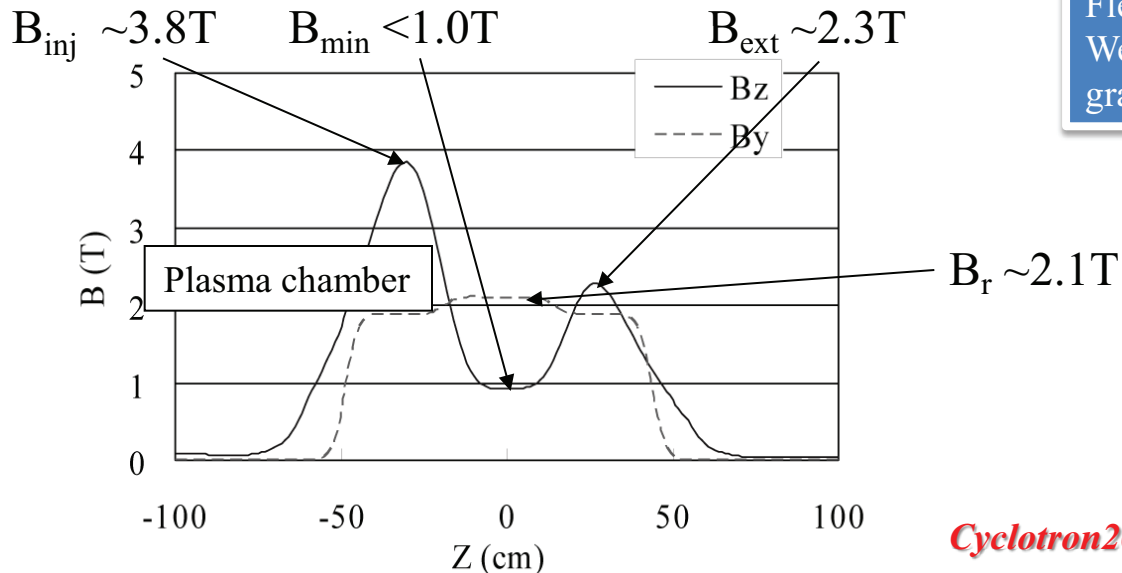




RIKEN 28GHz SC-ECRIS



For 28GHz operations



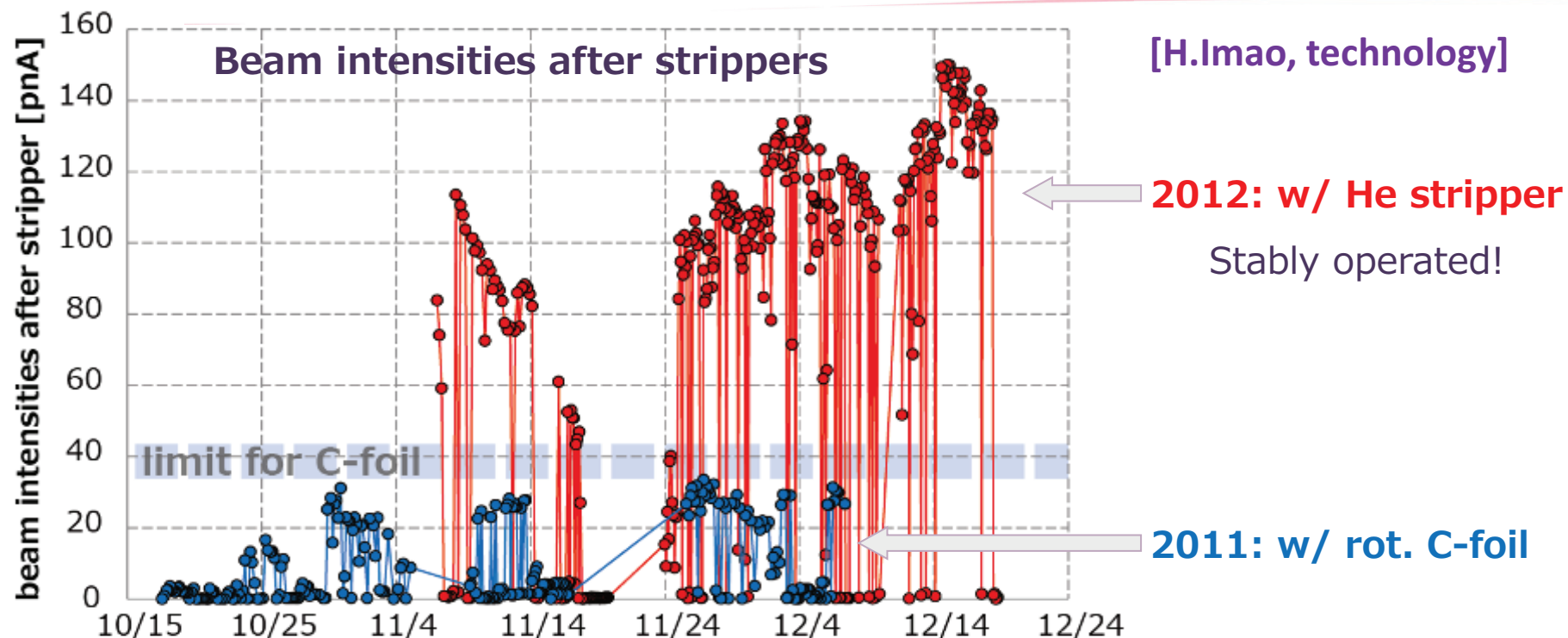
6 solenoid coils
Flexible magnetic distribution
We can change the magnetic field gradient and ECR zone size independently

**High energy Physics
and Nuclear Physics 31(2007)37
J. Ohnishi et al,**

“Flat B_{min} ” structure
G. D. Alton and D. N. Smithe,
Rev. Sci. Instrum. 65 (1994) 775

3. Highlight data

User runs w/ He stripper

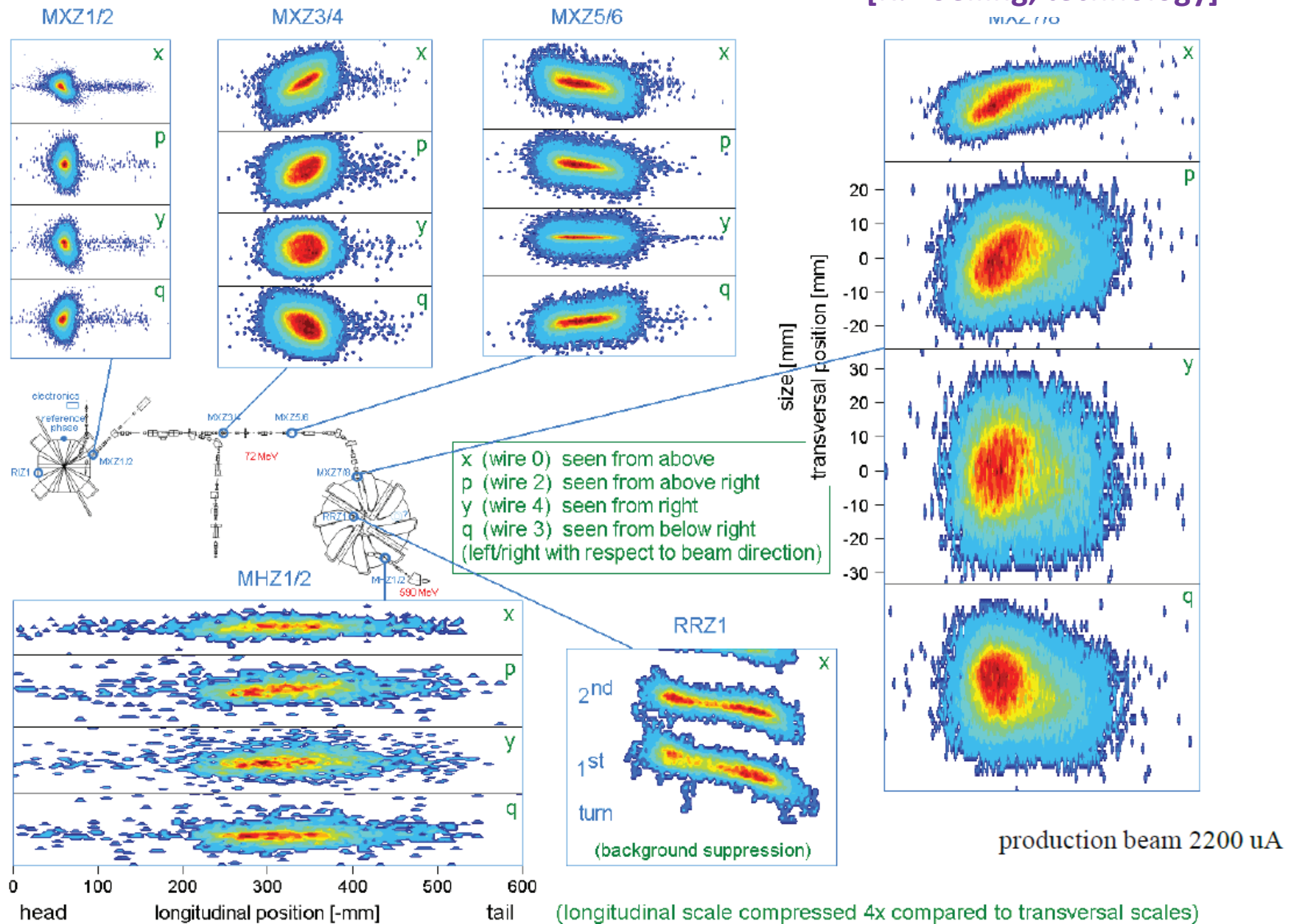


Beam after SRC	2011	2012	
Peak intensity [pnA]	3.6	15.1	$\sim 10^{11}$ /s
Service rate [%]	56.7	80.3	}
Mean intensity [pnA]	1.6	10.2	

[Mean intensity x service rate] $\Rightarrow$ **10 times !!**

beam after at Injector 2

[R.Doelling, technology]

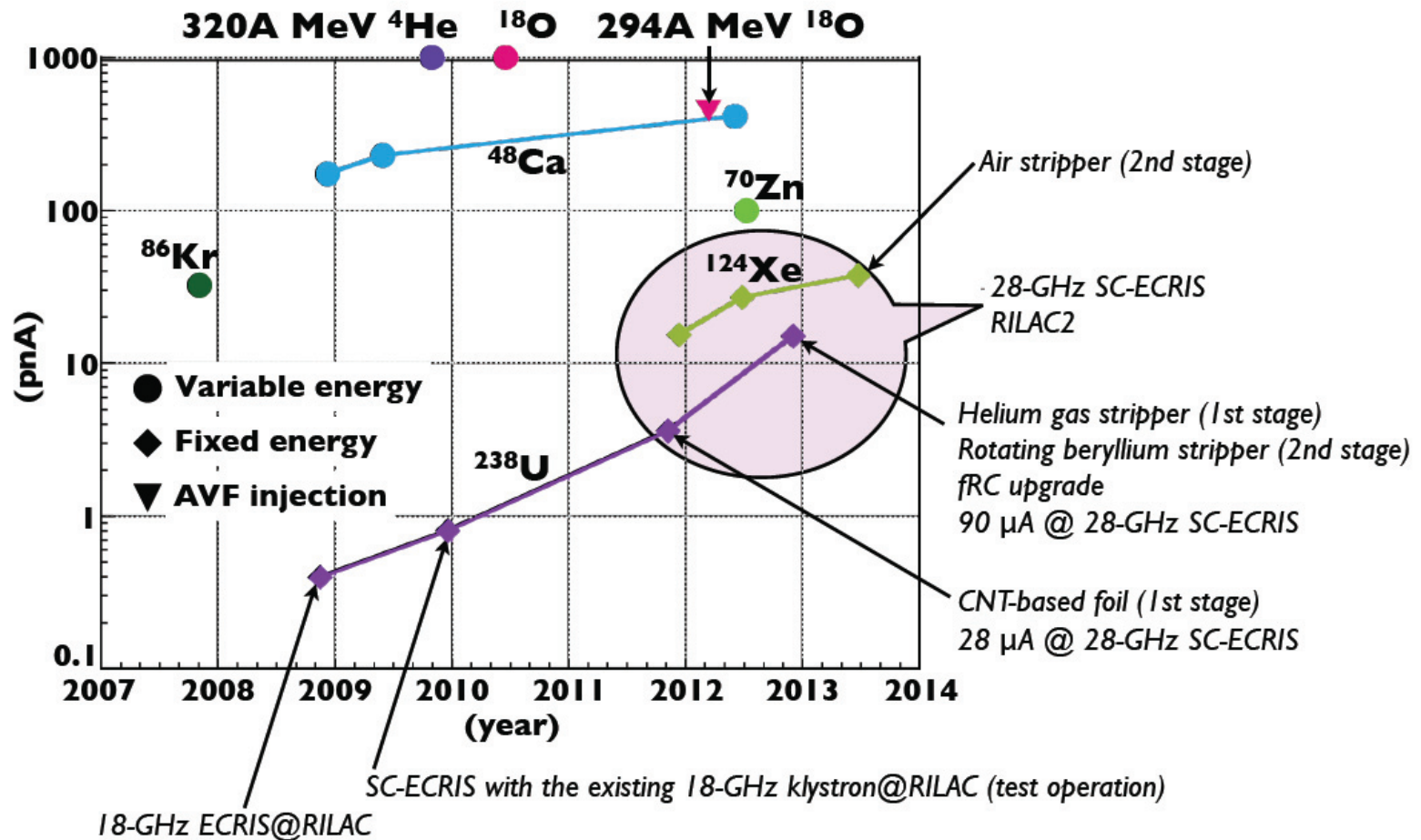


Operation/Upgrades

many of the labs present valuable operational experience and on-going upgrade/improvement programs

- facility developments: RIKEN, 2xNSCL, LBNL, Texas A&M, 2xKVI, KURRI, 2xTRIUMF, PSI
- 16 Posters in this category

History of Beam Intensity Upgrade



Spiral inflector

[D.Todd, LBNL]

- Advantages: no grids, no slowing, lower required voltages
- Disadvantages: narrow range of energies and M/Q.
OK, though—typically used for long runs and can be switched with mirror in hours



Height (A)	25 mm
Magnetic radius (R_m)	32 mm
Tilt (k')	0
Electrode gap	10 mm
Electric field	2.0 kV/mm

Ken Yoshiki Franzen: TUPPT015

Ion Source and Injection Line

[G. Cojocaru and
J.Lofvendahl,
TRIUMF]

TR30-2 beam eroded inflector



applications

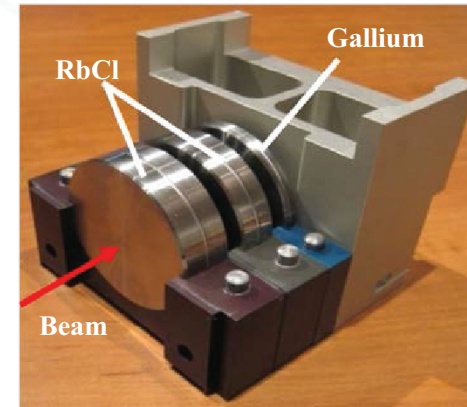
not central theme of Cyc13, thus not representative spectrum of applications

- activation analysis
- hydrophobic surfaces (surface irradiation with α)
- Los Alamos Isotope production
- Univ. Washington cyclotron and neutron treatment
- eye melanoma treatment
- secondary dose investigations
- Tc99 production
- 9 posters in this category



Parasitic Production of NCA Isotopes Utilizing Secondary Neutrons

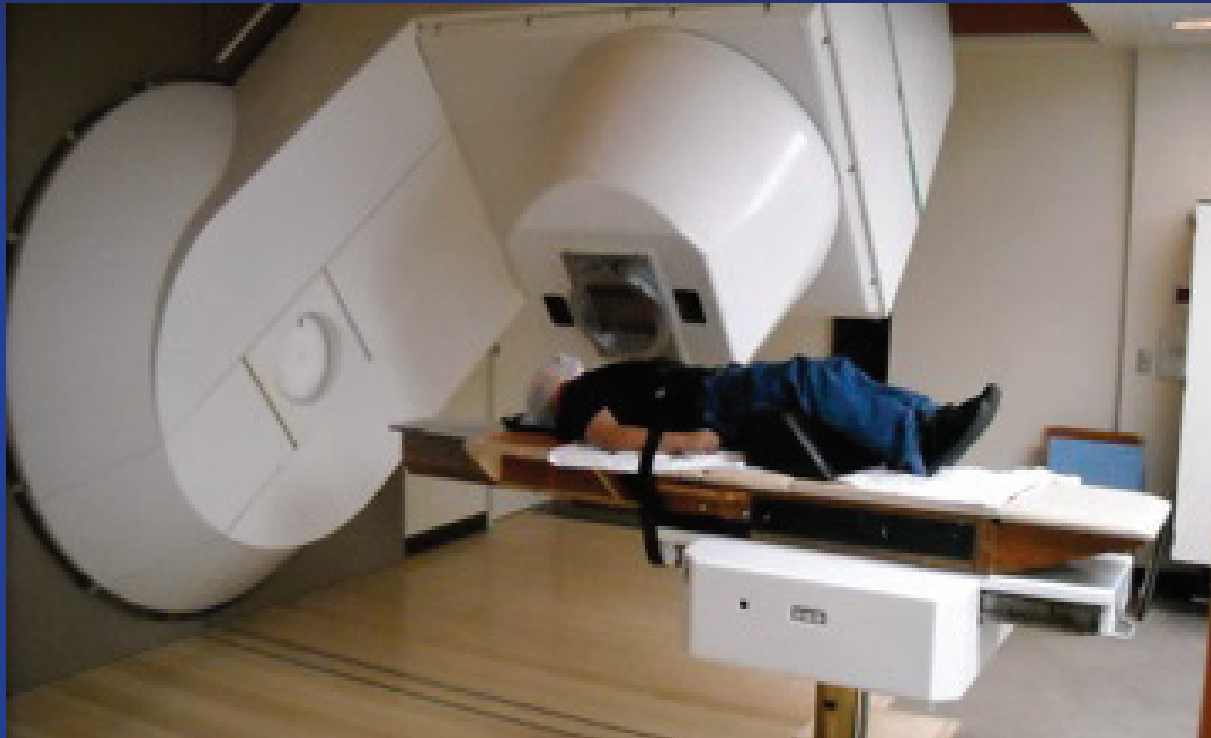
- Presents potential for useful production of No-Carrier-Added isotopes via (n,p), (n,2n) and (n, α) threshold reactions
- Candidate isotopes include ^{36}Cl , ^{63}Ni , ^{64}Cu , ^{67}Cu , ^{85}Kr , ^{89}Zr , ^{212}Pb , ^{225}Ac , ^{229}Th , ^{231}Pa , ^{237}Np
- Inspection of reaction thresholds on target nuclei over a wide mass range shows that thresholds generally vary in the range 0-10 MeV



Target Nucleus	(n,p)	(n,2n)	(n, α)
^{16}O	10.2	16.6	2.3
^{36}Cl	0	8.8	0
^{70}Zn	5.8	9.3	0.2
^{148}Nd	4.1	7.4	0
^{226}Ra	2.9	6.4	0

[F.M.Nortier, LANL]

50.5 MeV H⁺ 70μA Fast Neutron Radiotherapy



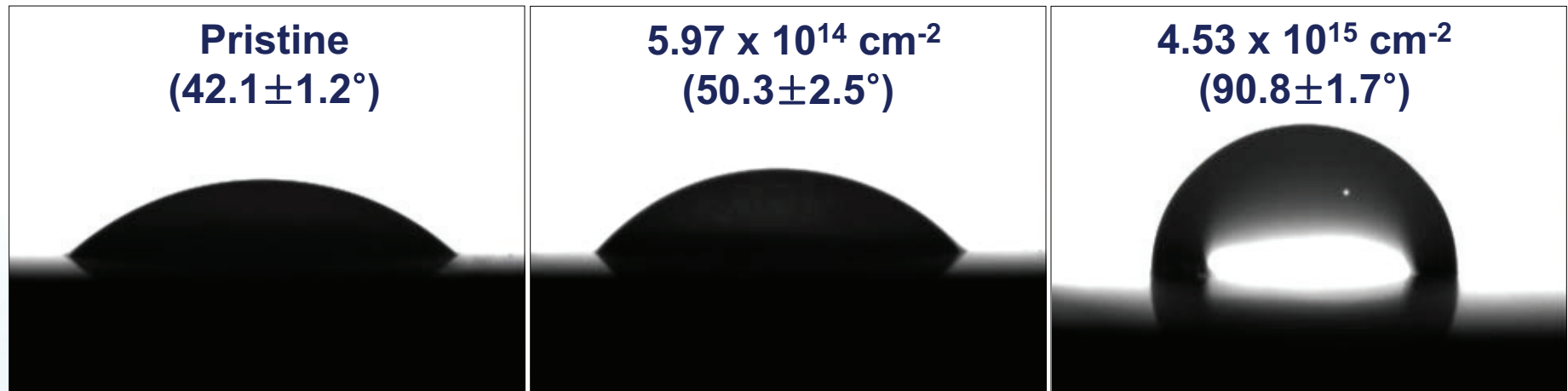
The 50.5 MeV H⁺ beam is the original design purpose of the UWCC. Impinging on a Beryllium target housed in the Isocentric gantry, this is the beam that creates the neutron flux for radiotherapy. We originally ran 60μA on target, but internal modifications to the cyclotron were made so that the target current now operates at 70μA. Of the four Isocentric gantries built for neutron therapy, ours is the only one with a multi-leaf collimator.

[E.D.Dorman, Univ.Washington med. Center]

Results

1. CA

[E.Lee, KAERI]



hydrophilic

hydrophilic

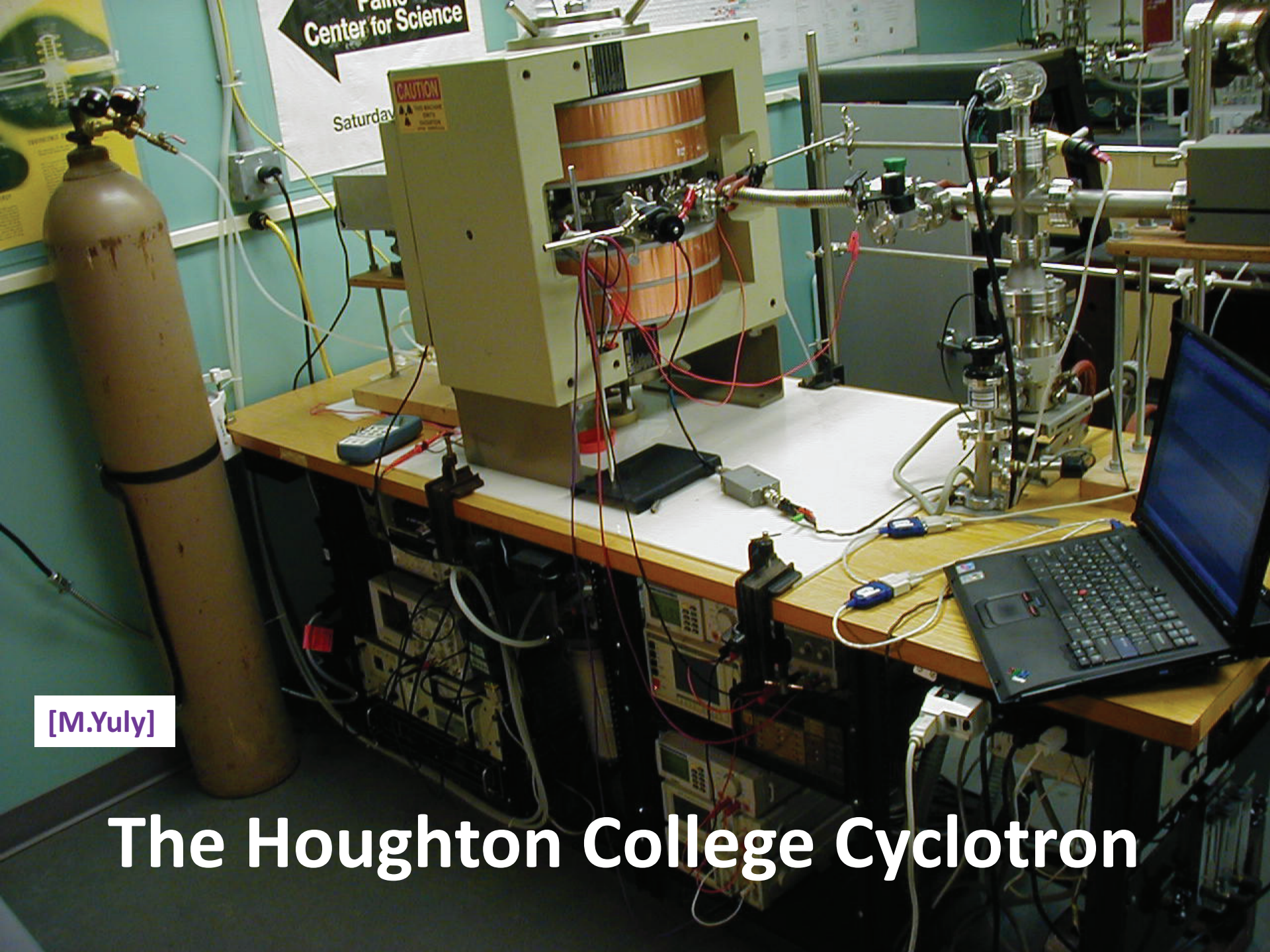
hydrophobic

- Hydrophilic BeO surfaces could be converted to hydrophobic surfaces by sufficient alpha irradiation.

cyclotrons for education

- such projects are very important to interest young people in our field
- cyclotron is simple enough to be realized and studied by students
- nevertheless, it involves all aspects of a particle accelerator [magnet, mechanics, vacuum, controls, RF, diagnostics etc.]

Mark Yuly: **“because it’s a cyclotron, it develops character qualities like patience and perseverance!”**

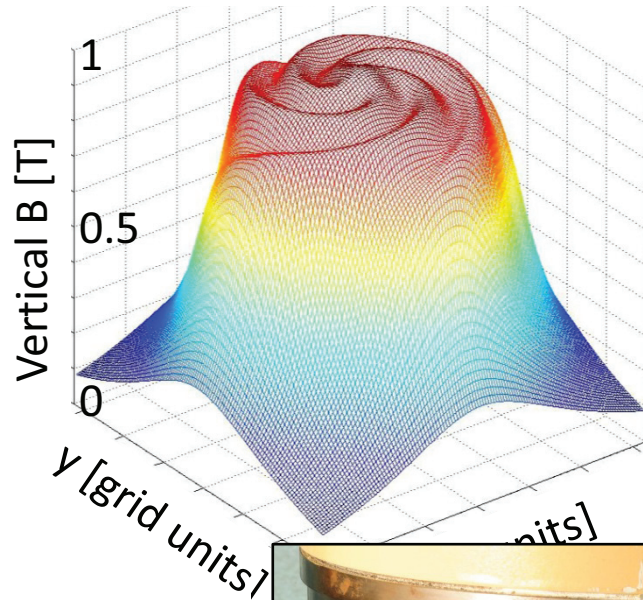


[M.Yuly]

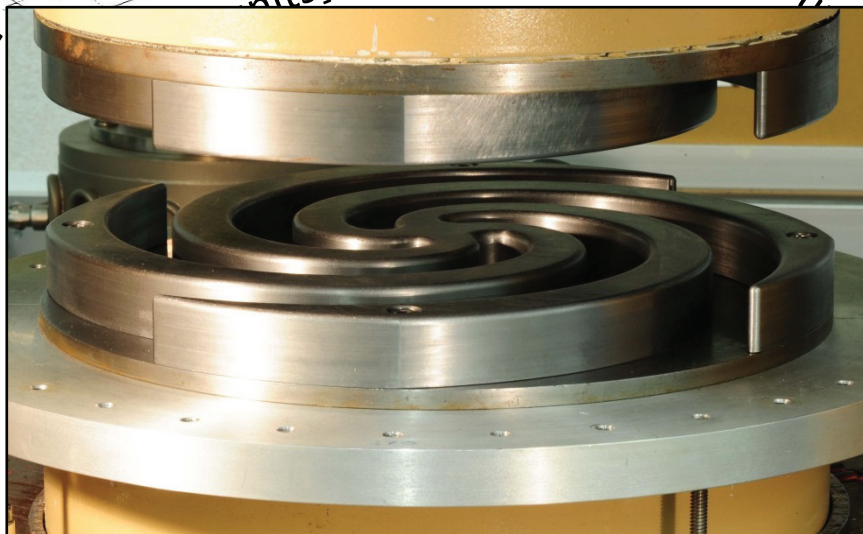
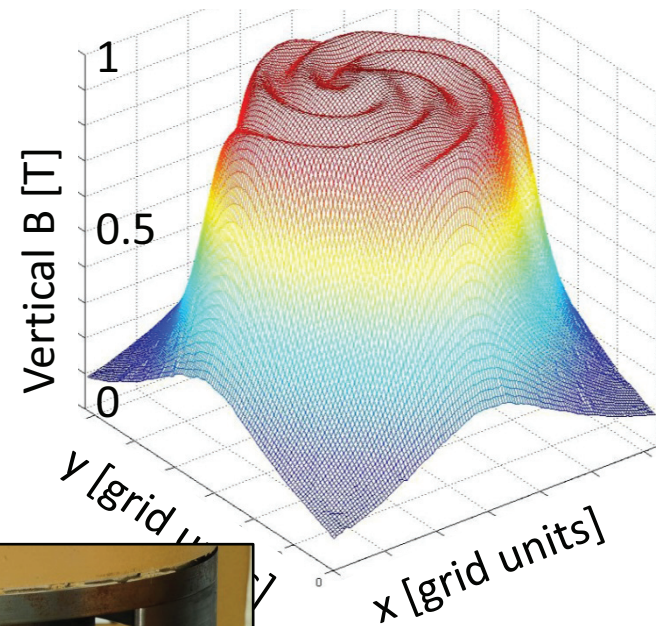
The Houghton College Cyclotron

Field Comparison

Hall Probe Measurement



Simulation



Max. 14% variation
<1% variation in $r < 5''$

[K.Ruisard]



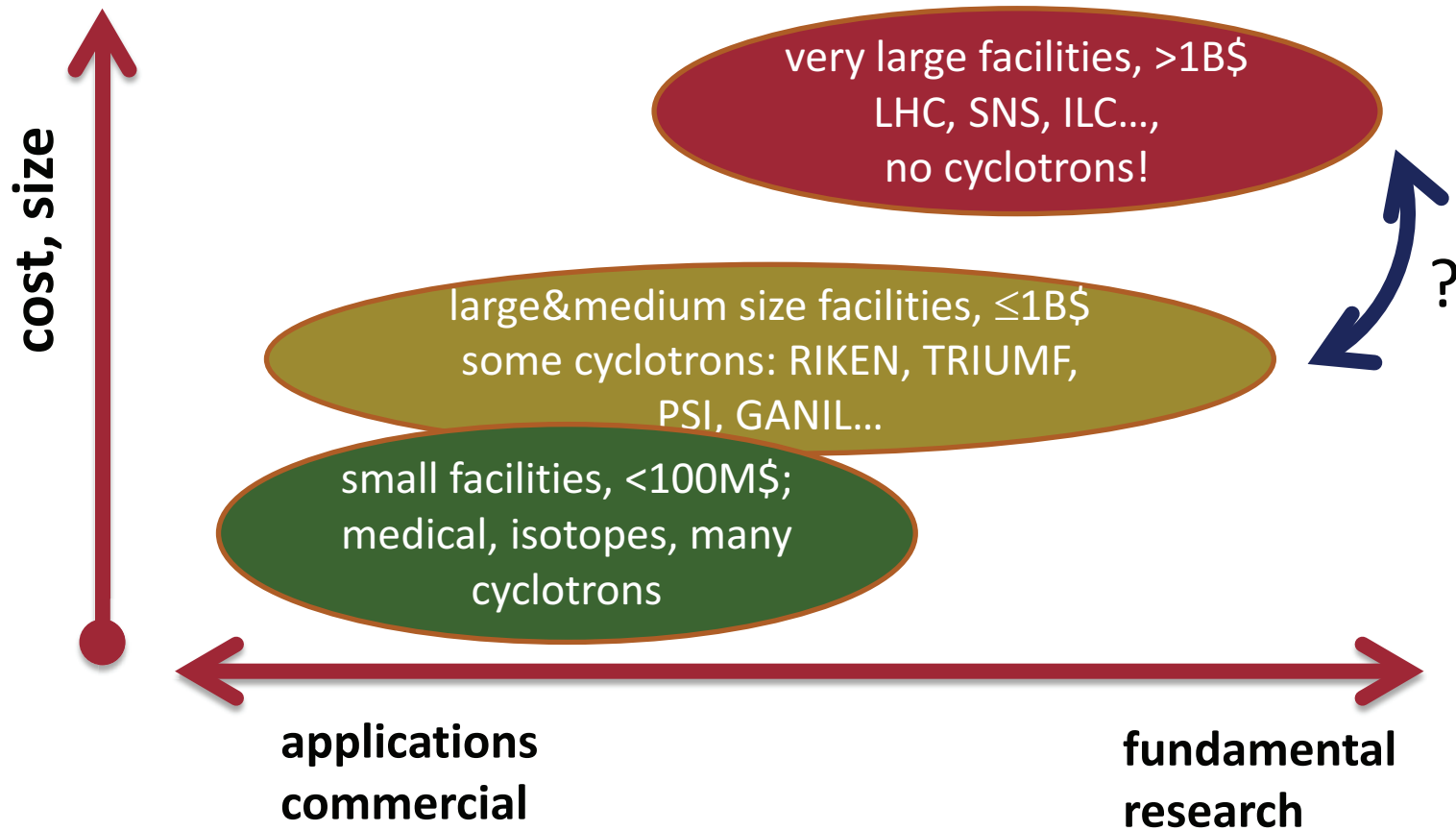
RUTGERS



conclusion

- cyclotrons present an active field of development
- demonstrated by the rich program and the high participation at this conference
- focus on technological improvements and development of new applications; however also new concepts are discussed

Cyclotrons in the Accelerator Landscape



- separation / detachment of communities, cyclotrons rarely considered due to biased experience in energy frontier labs
- better connection to FFAG community desirable

observations on program strategy

- education: very important to keep up future innovations in the field; organizers made a good move
- Student vs. Professor: attempt to give more talks to young people; good feedback
- less status reports; focus on new developments; however, there were kind of “status reports” with a lot of new developments

Cyclotrons on Jacow

Very important effort: Digitization of old conferences
→ many thanks to Mike Craddock and others!

Joint Accelerator Conferences Website

Select Conferences					
☒ ALL					
☐ Cyclotrons'63	☐ PAC'65	☐ Cyclotrons'66	☐ LINAC'66	☐ PAC'67	☐ Cyclotrons'59
☐ Cyclotrons'69	☐ PAC'71	☐ Cyclotrons'72	☐ LINAC'72	☐ PAC'73	☐ PAC'69
☐ PAC'75	☐ LINAC'76	☐ PAC'77	☐ PAC'79	☐ SRF'80	☐ Cyclotrons'75
☐ LINAC'81	☐ PAC'83	☐ SRF'84	☐ LINAC'84	☐ PAC'85	☐ PAC'81
☐ SRF'87	☐ EPAC'88	☐ LINAC'88	☐ PAC'89	☐ SRF'89	☐ PAC'87
☐ EPAC'90	☐ PAC'91	☐ SRF'91	☐ EPAC'92	☐ LINAC'92	☐ LINAC'90
☐ SRF'93	☐ EPAC'94	☐ PAC'95	☐ SRF'95	☐ EPAC'96	☐ PAC'93
☐ PAC'97	☐ SRF'97	☐ EPAC'98	☐ APAC'98	☐ LINAC'98	☐ LINAC'96
☐ PAC'99	☐ SRF'99	☐ ICALEPCS'99	☐ EPAC'00	☐ LINAC'00	☐ DIPAC'99
☐ Cyclotrons'01	☐ DIPAC'01	☐ ICALEPCS'01	☐ PAC'01	☐ SRF'01	☐ APAC'01
☐ LINAC'02	☐ PAC'03	☐ DIPAC'03	☐ ICALEPCS'03	☐ SRF'03	☐ EPAC'02
☐ FEL'04	☐ EPAC'04	☐ APAC'04	☐ LINAC'04	☐ RuPAC'04	☐ Cyclotrons'04
☐ FEL'05	☐ DIPAC'05	☐ ICALEPCS'05	☐ SRF'05	☐ EPAC'06	☐ PAC'05
☐ ICAP'06	☐ FEL'06	☐ FLS'06	☐ RuPAC'06	☐ ABDW-HB'06	☐ LINAC'06
☐ APAC'07	☐ COOL'07	☐ ABDW-ERL'07	☐ DIPAC'07	☐ SRF'07	☐ PAC'07
☐ Cyclotrons'07	☐ FEL'07	☐ EPAC'08	☐ RuPAC'08	☐ PCaPAC'08	☐ ICALEPCS'07
☐ ECRIS'08	☐ FEL'08	☐ ABDW-HB'08	☐ LINAC'08	☐ BIW'08	☐ e+e-Factories'08
☐ SRF'09	☐ FEL'09	☐ ABDW-ERL'09	☐ HIAT'09	☐ ICALEPCS'09	☐ DIPAC'09
☐ PAC'09	☐ ICAP'09	☐ IPAC'10	☐ RuPAC'10	☐ PCaPAC'10	☐ COOL'09
☐ ABDW-HB'10	☐ FEL'10	☐ LINAC'10	☐ ECRIS'10	☐ Cyclotrons'10	☐ BIW'10
☐ FEL'11	☐ PAC'11	☐ PAC'11	☐ COOL'11	☐ ICALEPCS'11	☐ ABDW-ECloud'10
					☐ DIPAC'11

High density of
cyclotron conferences

Covers 55 years!

Inflation of conferences

A background image showing a city skyline with several tall glass skyscrapers. In the foreground, there is a paved walkway along a body of water, with a railing and some greenery. A small boat is visible on the water.

Cyclotrons 2013 in Vancouver

many thanks to the team of TRIUMF
for a perfect organization!

... and many thanks to all participants
for their excellent contributions which
carry our field forward!