KU LEUVEN

Medicis-Promed Workshop:
CARBON-11 FOR ION BEAM THERAPY
16 - 18 January 2019
Wiener Neustadt, Austria
http://medicis-promed.web.cern.ch
Organizing Committee: Thierry Stora (CERN), Claus Schmitzer (MedAustron), Andrea Mairani (CNAO), Liviu Penescu (Abstract Landscapes), Cristina Ferrari (CERN), Nicole Rauchlechner (MedAustron)

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TDR-Chapter 2: Post-accelerated ^{11}C-Past results

Simon Stegemann

MEDICIS-Promed Workshop on
CARBON-11 FOR ION BEAM THERAPY
16/01/2019, Wiener Neustadt, Austria

European Commission

Outline

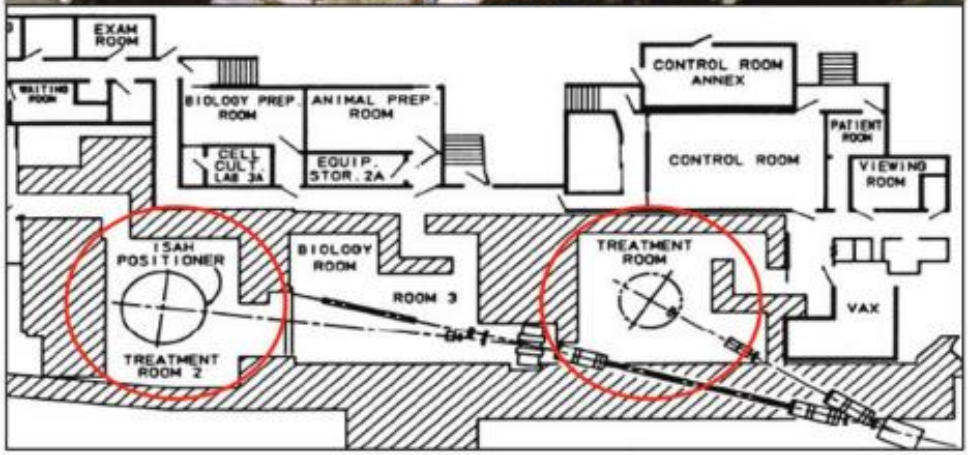
- Lawrence Berkeley National Laboratory
- Centre de Recherche du Cyclotron
- GANIL
- CERN ISOLDE
- ISAC/TRIUMF
- HIMAC/NIRS

Lawrence Berkeley National Laboratory

Berkeley Hills, California, USA

(Bevalac, BEARS project)

Bevalac (1974 – 1993)



SuperHILAC + Bevatron

Linac (8.5 MeV/u) p-synchrotron (6.2 GeV)

- Heavy ion beam production for research and radiation therapy
- 1977-1992: 433 patients treated (mostly 670 MeV/u Ne-beam)

^{11}C beam production

Projectile fragmentation

Machine Parameters	
Primary beam	^{12}C, (^{18}O, Ne^{10+})
Targets	7.8 cm Be, (2.5 cm Be, polystyrene)
Energy	350 MeV/u
Intensity	$1 \cdot 10^{10}$ ions per pulse
Magnet Resolving power	1/500
Results	
^{11}C Energy	~250 MeV/u
Angular spread	+/- 10 mrad (12 mrad)
Momentum spread	+/- 1 % (2 %)
Intensity	$2 \cdot 10^{7}$ ions per pulse

BEARS project (1998)

11 MeV PET-cyclotron
(Biomedical Isotope facility)

+

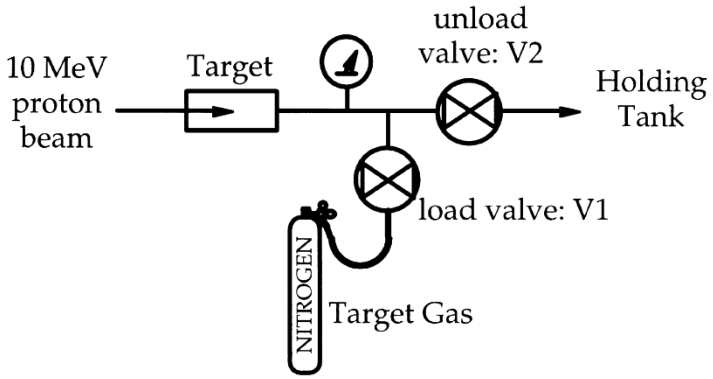
88” cyclotron
(Nuclear Science Division)

350 m transfer line

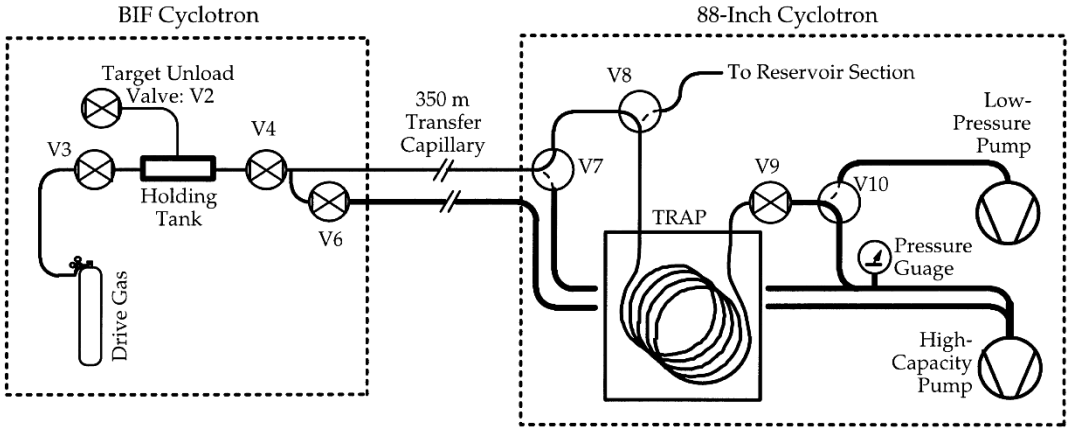
^{11}C beam production

N_2 gas targets; cryogenic separation; ECR ion source

Machine Parameters	
Primary beam	Protons
Targets	N_2 gas target (13 ml, 22 atm, 0.2 %O_2)
Energy	10 MeV
Intensity	~30 μA
Irradiation time	5 min
Molecular sideband	$^{11}CO_2$
Ion source	AECR-u (14+10 GHz): 3^+:4 %, 4^+:11 %, 5^+:4 %, 6^+:2 %
Results	
^{11}C Energy	120 MeV/u
Charge state	6^+
Intensity	$1 \cdot 10^8$ ions/s



^{11}C production system



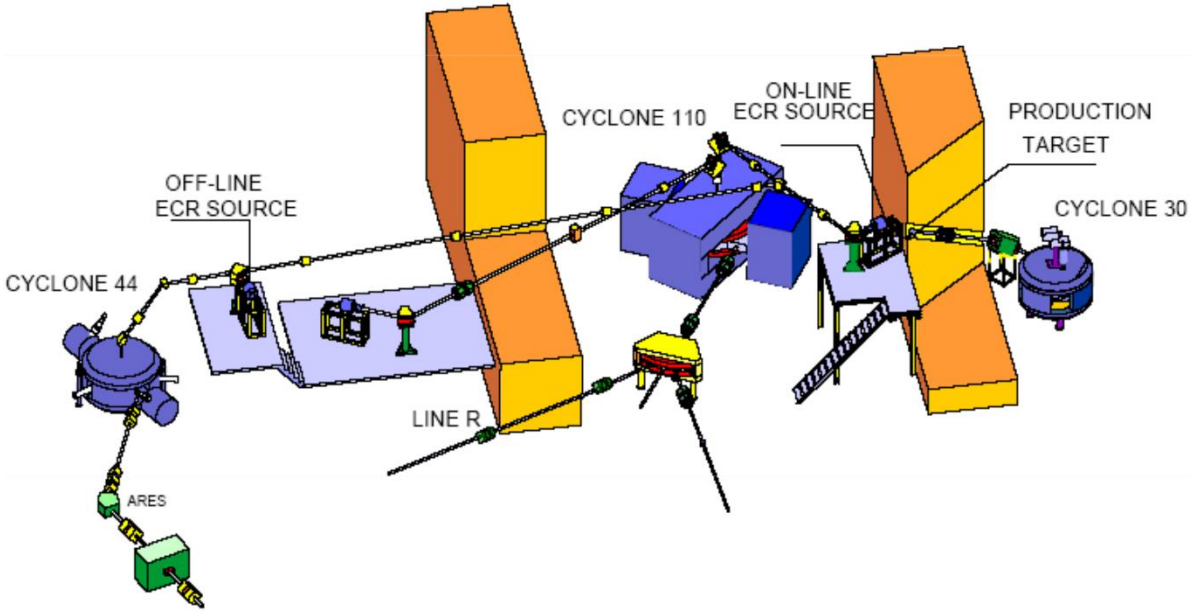
Transport system

- Fully automatized control system handling target loading, irradiation, unloading
- Cryogenic trap crucial feature for ECR ion source performance!

Centre de Recherche du Cyclotron (CRC)

Louvain-la-Neuve, Belgium

CRC – RIB facility (1989-2009)



3 accelerators:
CYCLONE30: 30 MeV, 300 μA

CYCLONE110: K = 110
CYCLONE40: K = 40

1st post-accelerated RIB from ISOL-type production system

Production: CYCLONE30; Post-acceleration: CYCLONE110 & CYCLONE40

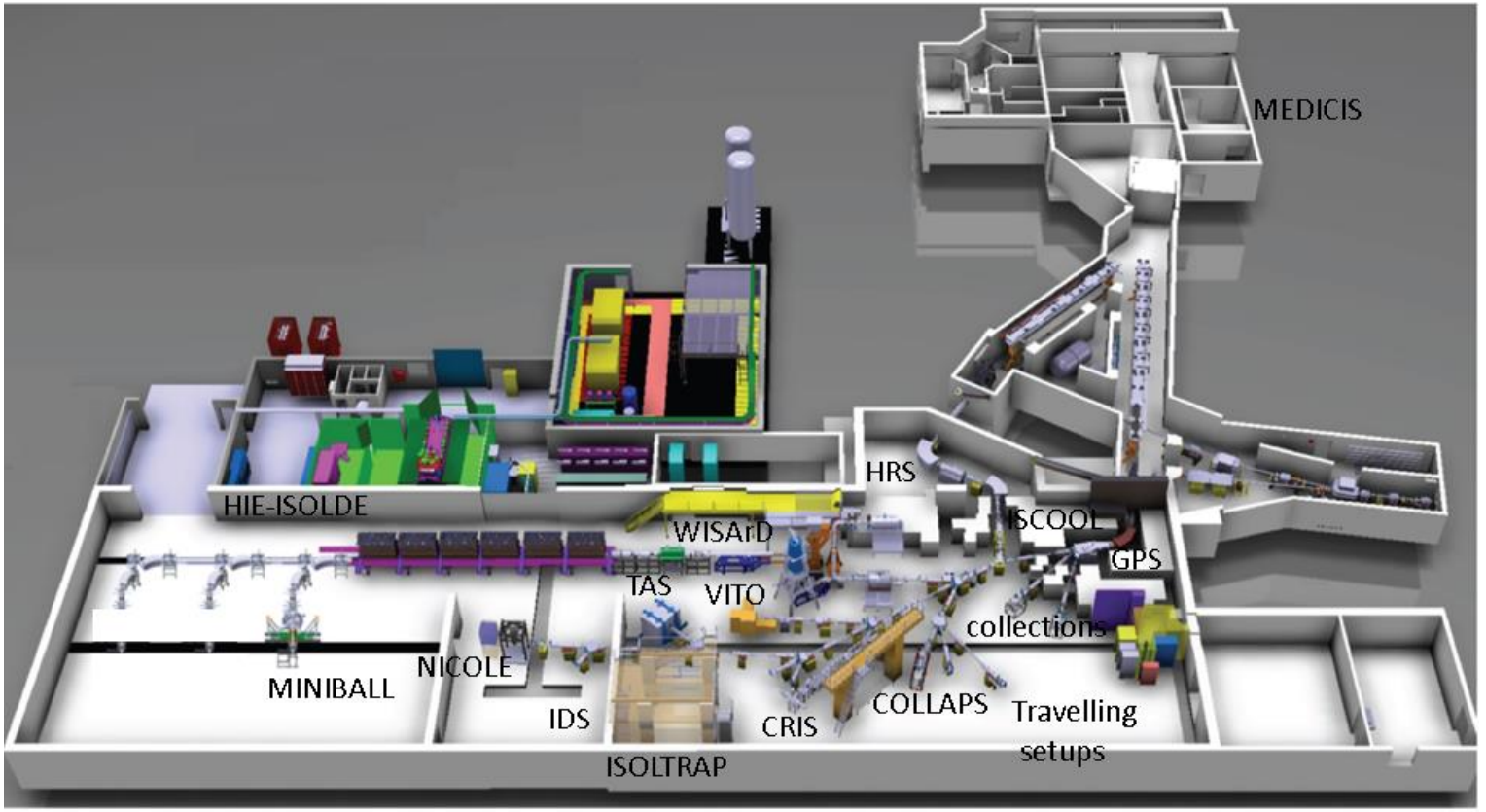
^{11}C beam production

Isotope Separation On-Line (ISOL)

Machine Parameters	
Primary beam	Protons
Targets	BN and B_2O_3 powders
Energy	30 MeV
Release efficiency	10 % at 1000 °C (BN)
Molecular sideband	$^{11}CO_x$
Ion source	ECR: $^{12}C^+$: 15 % (10^{-5} mbar in-source pressure; CO_2-leak; He-carrier gas)
Results	
^{11}C Energy	Max. 10 MeV
Charge state	1^+
Intensity	$1 \cdot 10^7$ ions/s (BN target; 0.1 cm^3/h O_2-leak)

CERN ISOLDE

Geneva, Switzerland



1.4 GeV protons, max. 2 μA

Two target stations: GPS: 1 bending magnet
HRS: 2 bending magnets (> 5000 resolving power)

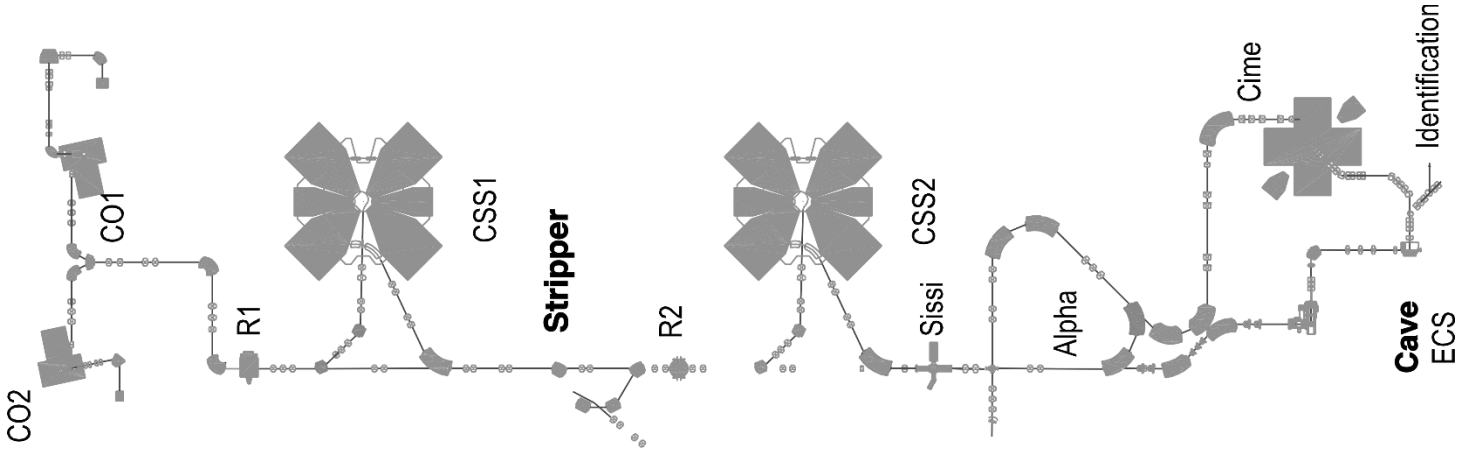
Ion sources: Surface ion sources
Plasma ion sources
Laser ion sources

Target	Yield [1/µC]	Ion source	Molecular sideband
HfO_2	$4.4 \cdot 10^4$	Plasma-Helicon	
TiO_x	$6.2 \cdot 10^6$	Plasma-Cold-MK7	$^{11}C^{16}O^+$
NaF:LiF salt	$7.7 \cdot 10^8$	Plasma-Cold-VD7	$^{11}C^{16}O^+$
MgO	$2.1 \cdot 10^5$	Plasma-Cold-MK7	$^{11}C^{16}O^+$
CeO_x fibers	$4.8 \cdot 10^6$	Plasma-Cols-MK7	$^{11}C^{16}O^+$
CaO nanostructured powder	$2.7 \cdot 10^6$	Plasma-Helicon	$^{11}C^{16}O^+$

- Adsorption enthalpies of SiO_2 and Al_2O_3 as coating materials (wrt retention times)
- Diffusion faster in fiber pellets than in powder pellets
- Limitations on extraction & transport: shortage of O_2 supply
  losses on hot Ta surfaces (> 1000 °C)
  retention on Mo (in ion source)

SPIRAL1/GANIL

Caen, France



5 cyclotrons

Nanogan-3 ECR ion source

250 resolving power magnet

No ^{11}C beams produced at SPIRAL1

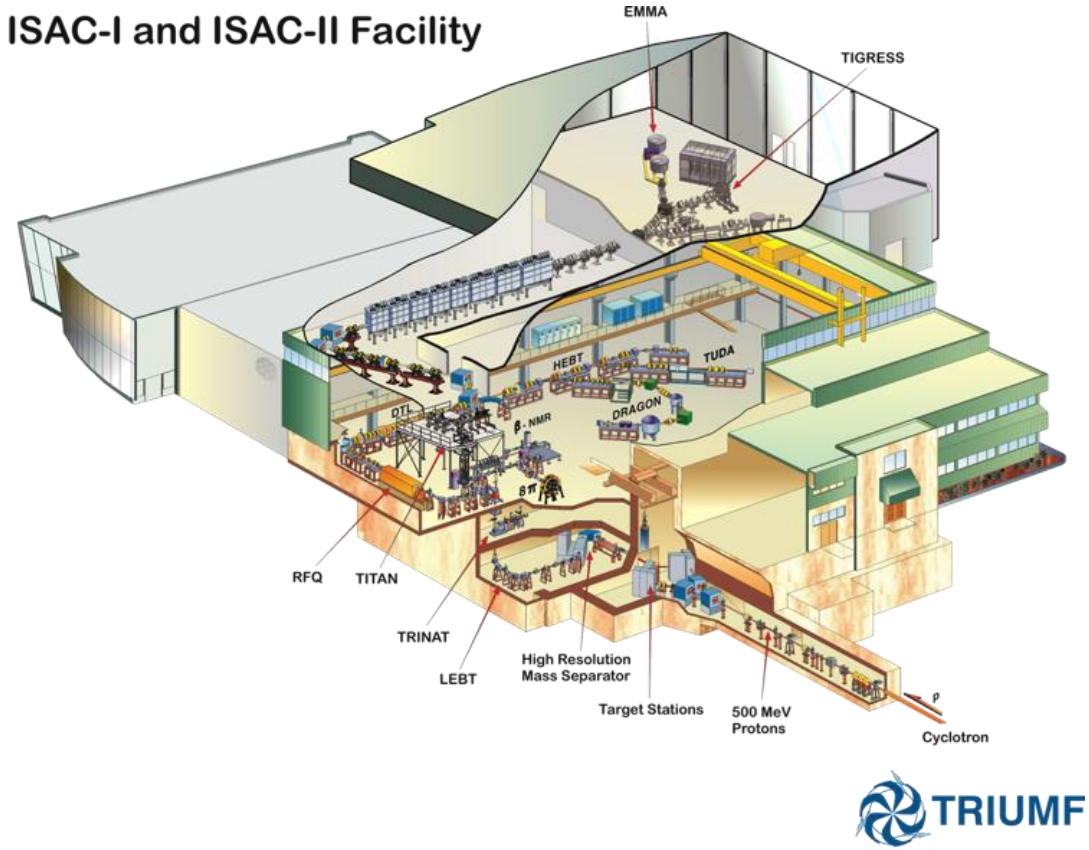
Studies on CO, CO_2 ionization and charge breeding efficiencies

Developed with PANTECHNIK 2.45 GHz ECR ion source for 1^+ ionization (MONO1000)

Off-line study with compact version at ISOLDE: 14 % CO^+

ISAC/TRIUMF

Vancouver, Canada



Main accelerator:

Sector-focused H^- cyclotron

4 independent extraction lines

Beam current: 100 μA (ISAC)

Energy: 500 MeV (ISAC)

Two magnet separator

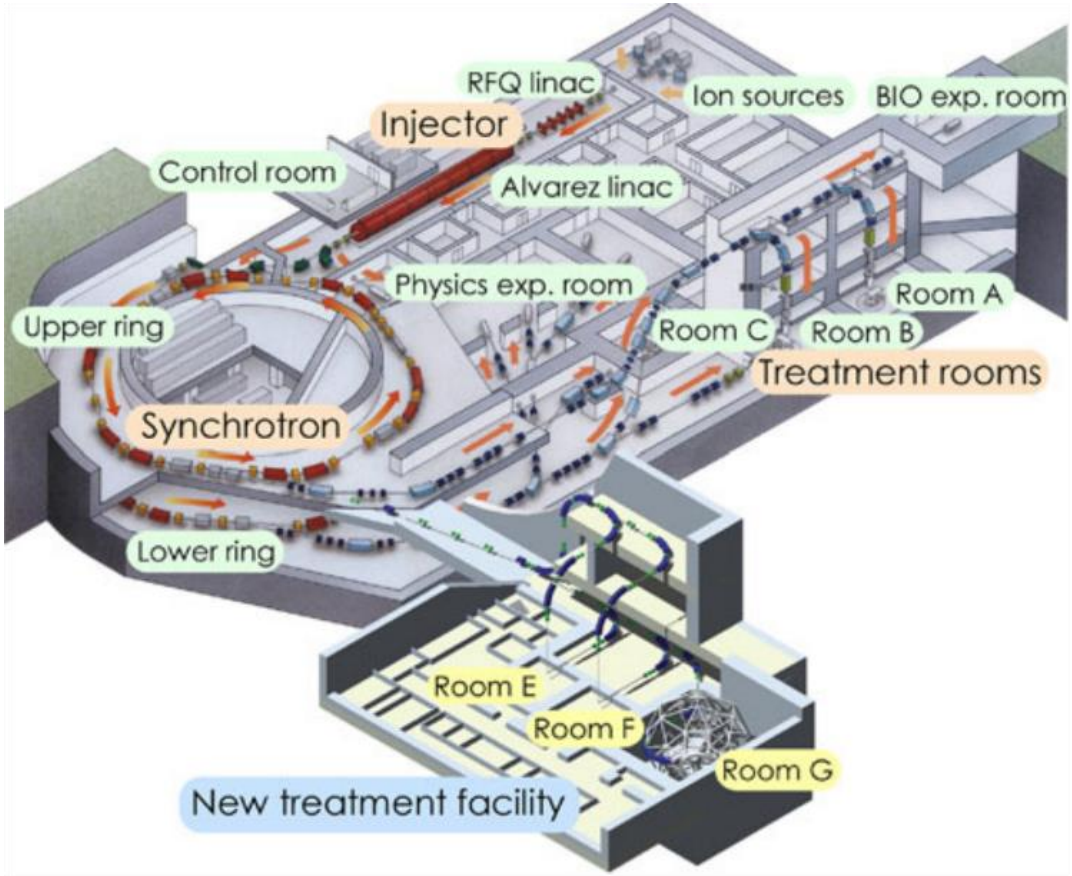
1 Target station with 3 ion sources: surface, laser, plasma (FEBIAD)

^{11}C beam production

NiO/Ni target at 1100 °C, 500 MeV 16 μA protons: max. yield 10^7 ^{11}CO [1/s]

HIMAC/NIRS

Chiba, Japan



Heavy Ion Medical Accelerator

(RFQ Linac, Alvarex type Drift-Tube Linac, synchrotron rings)

Accelerate heavy ions from protons to Xe up to 800 MeV/u

>10000 patients treated with ^{12}C

Since 2010 SC rotating-gantry

^{11}C beam production

Projectile fragmentation

Machine Parameters	
Primary beam	^{12}C
Target	Be
Energy	430 MeV/u
Intensity	$1.8 \cdot 10^{9}$ pps
Separator	3 quadrupole magnets
Results	
^{11}C Energy	355 MeV/u
Purity	93 % (contaminations of ^{12}C, and ^{7}Be)
Momentum spread	3.5 % (FWHM)
Intensity	$7.22 \cdot 10^{6}$ pps (in spot scanning mode)

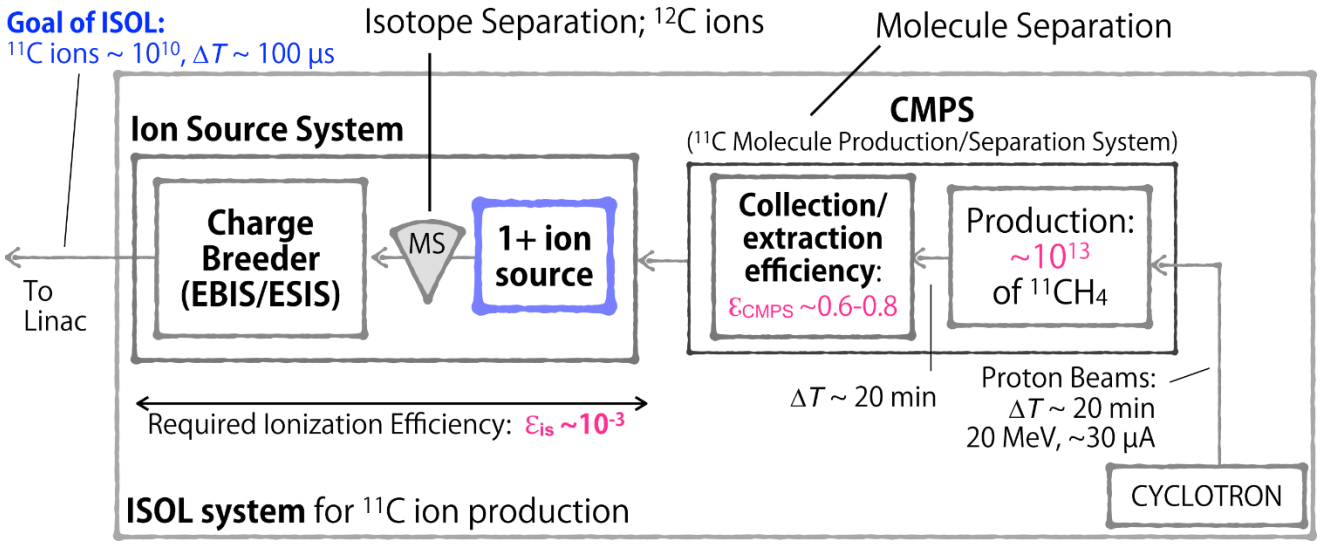
^{11}C beam production

N_2 gas targets; gas separation

Machine Parameters	
Primary beam	Protons
Targets	N_2 gas target (100 ml, 15 bar, 2% O_2)
Energy	18 MeV
Intensity	~20 μA
Irradiation time	20 min
Molecular sideband	$^{11}CO_2$
Ion source	ECR : 4^+: 1%
Results	Theoretical estimation
Charge state	6^+
Intensity	~1 $\cdot 10^8$ ions per pulse
Impurities	N_2 ~10^{22} for 100 ml target

^{11}C beam production

Isotope Separation On-Line (ISOL); cryogenic separation



^{11}C beam production

Isotope Separation On-Line (ISOL); cryogenic separation

Parameters	
Primary beam	Protons
Targets	$NaBH_4$, B_2O_3, B
Energy	18 MeV
Intensity	~30 μA
Irradiation time	20 min
Released fraction	29.3 %, 76 % (but as CO_2), 0.2 %
Molecular sideband	$^{11}CH_4$
Yield	~10^{13} $^{11}CH_4$ ($NaBH_4$)
Collection/extraction eff.	60-80 %
Ion source	1^+ ion source; ESIS charge breeder: Requirement: 1% total efficiency

Thank you.
Questions, comments?

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Backup

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