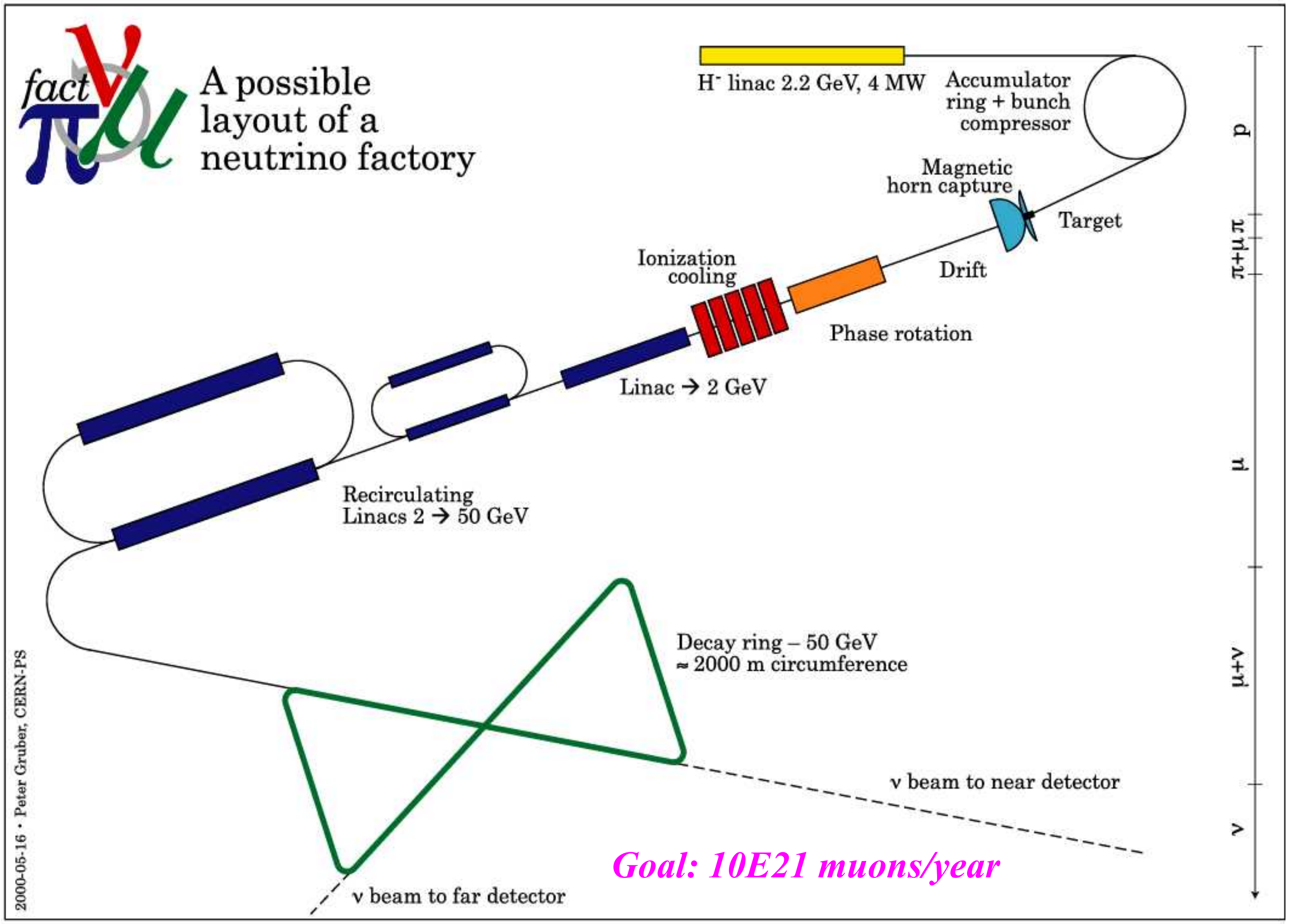
International Activities
(Europe and Japan)

H. Haseroth

for the

Neutrino Factory Working Group at CERN



Goal: 10E21 muons/year

Activities concerning the Proton Driver

(Main CERN Actors with substantial fraction of their time)

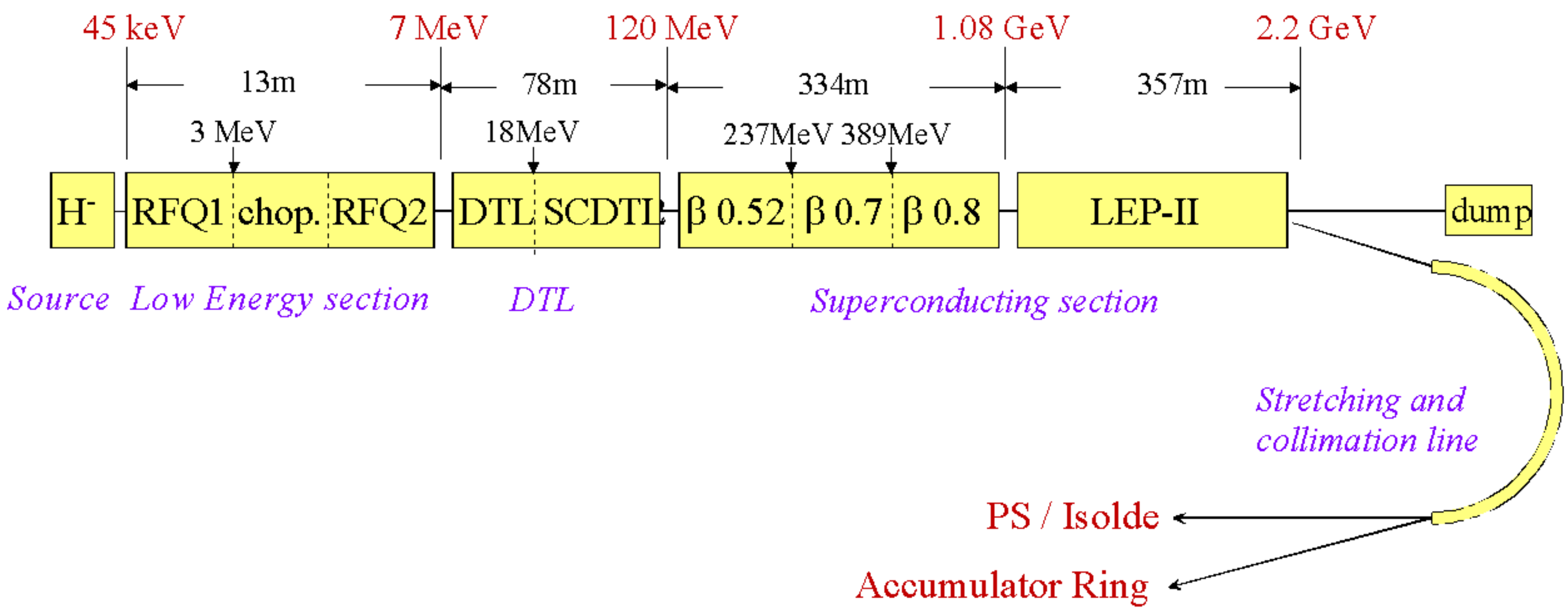
→SPL (Garoby, Lombardi, Vretenar)

→Accumulator Ring (Schonauer, Metral, Cappi)

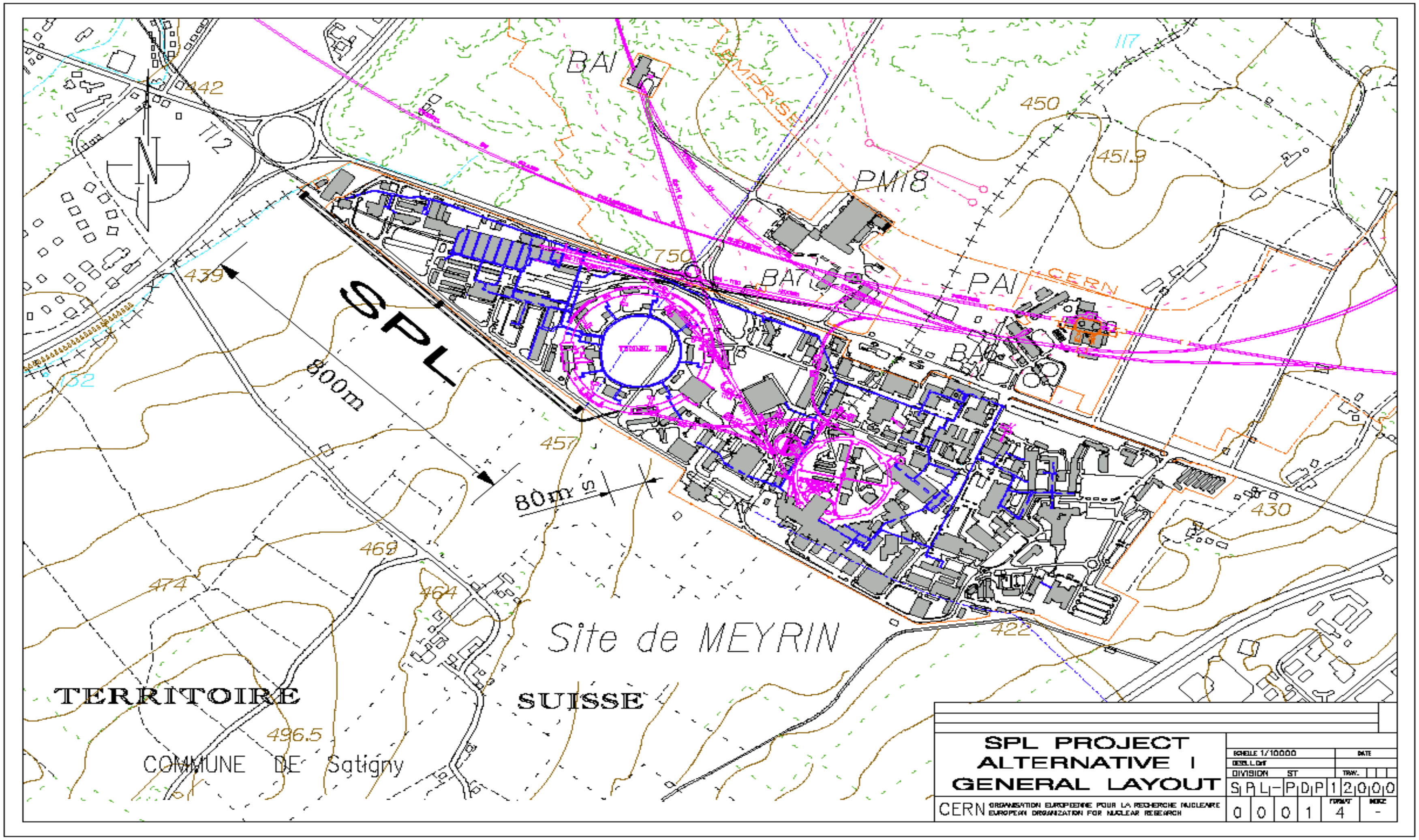
→Compressor Ring (Schonauer, Metral, Cappi)

→Fast cycling Synchrotrons (Schonauer)

Schematic Layout of the SPL (4 MW of Beam Power)

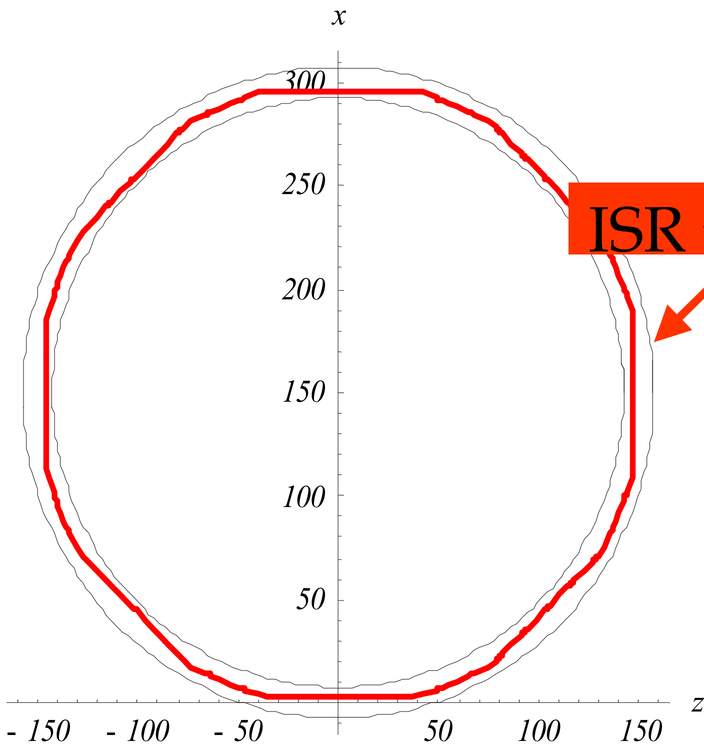


The SPL on the CERN site



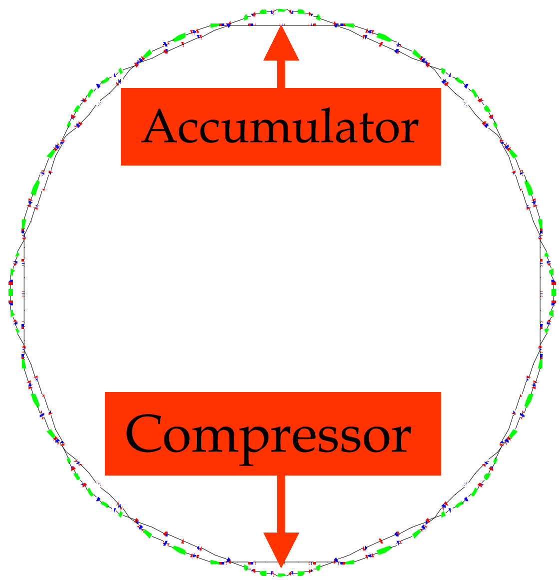
RAL Accumulator (1)

2.2 GeV RAL Accumulator



Mean ring radius=150 m

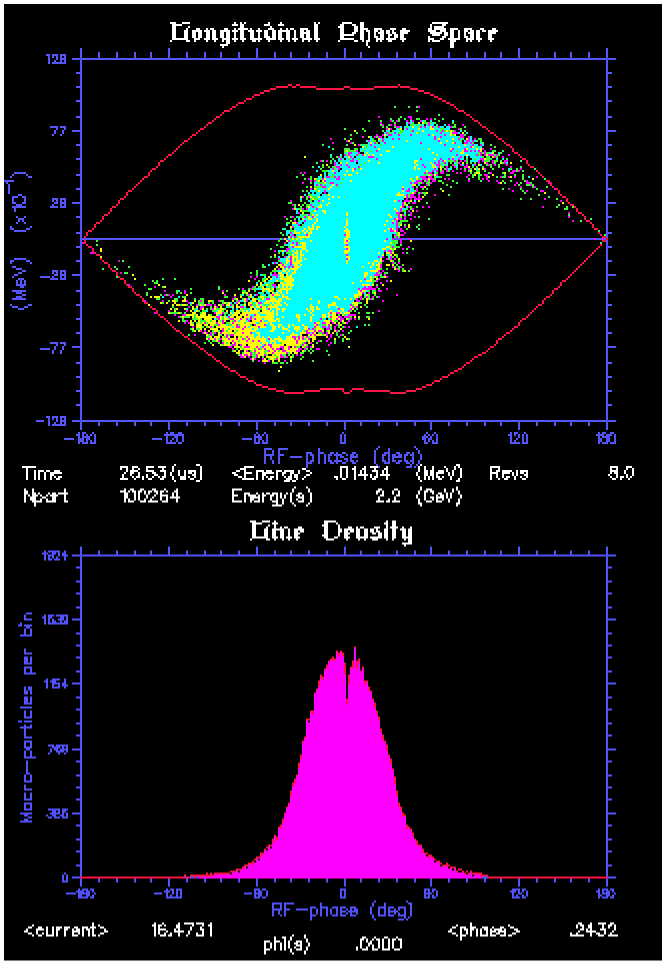
Accumulator & Compressor



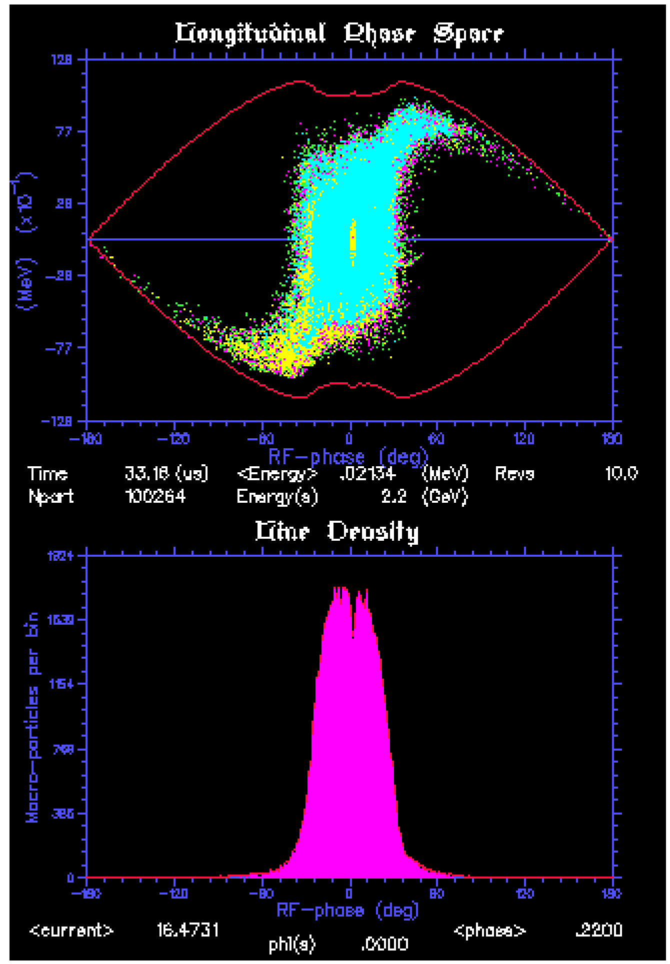
in ISR Tunnel

33 Hz Operation with 3.41 10^{14} p/p :
End of Compression (Phase painting +/- 90 deg)

8 turns



10 turns



Non Proton Driver Activities

(Main CERN Actors with substantial fraction of their time)

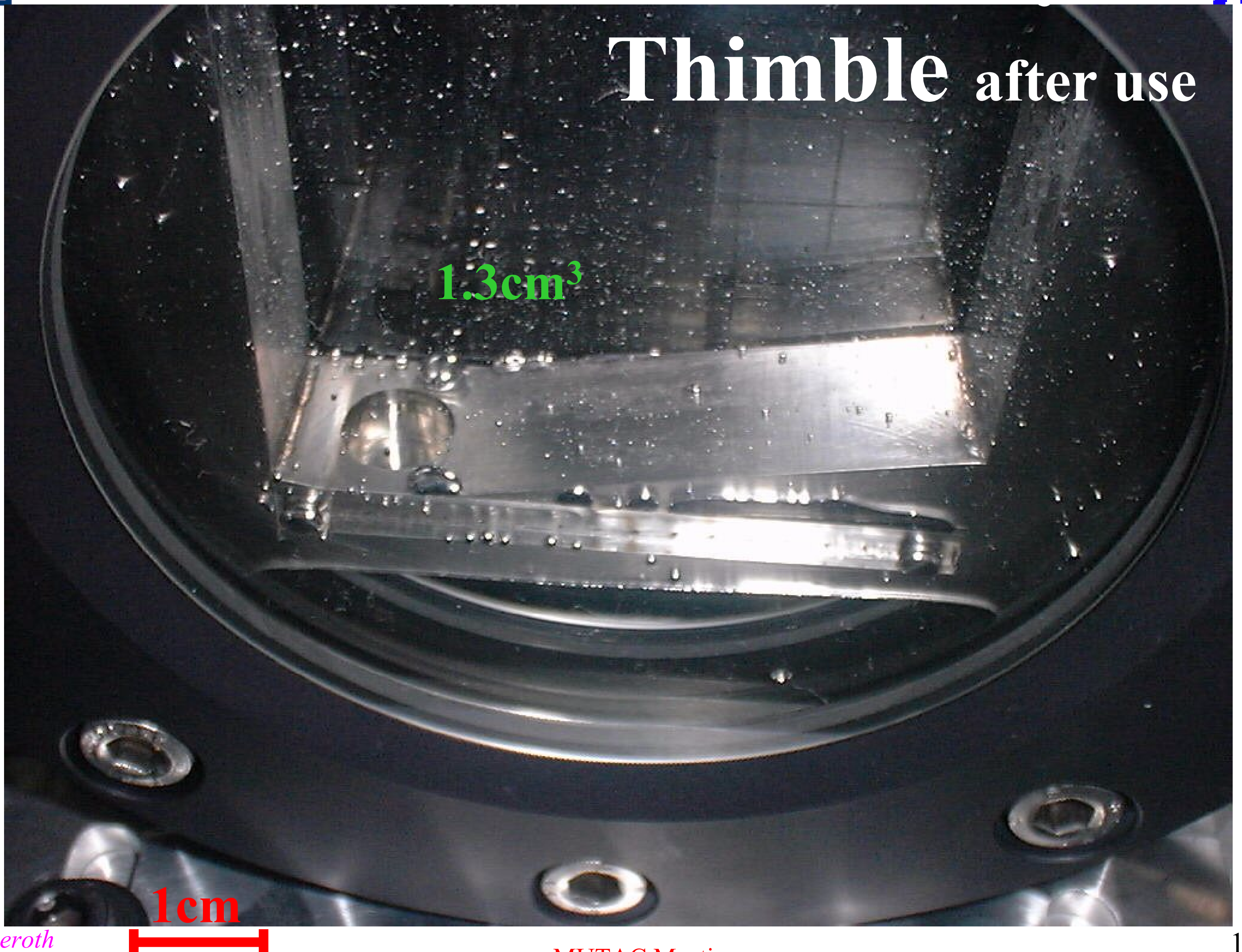
Target and collection (magnetic horn) work, i.e. simulations of pion production, simulations of capture and experimental work on target issues (Ravn, Fabich, Lettry, Volker, Maugain)

Simulation of the phase rotation (energy reduction), of the cooling channel and of the acceleration in the first linac (Lombardi, Hanke, Holzer)

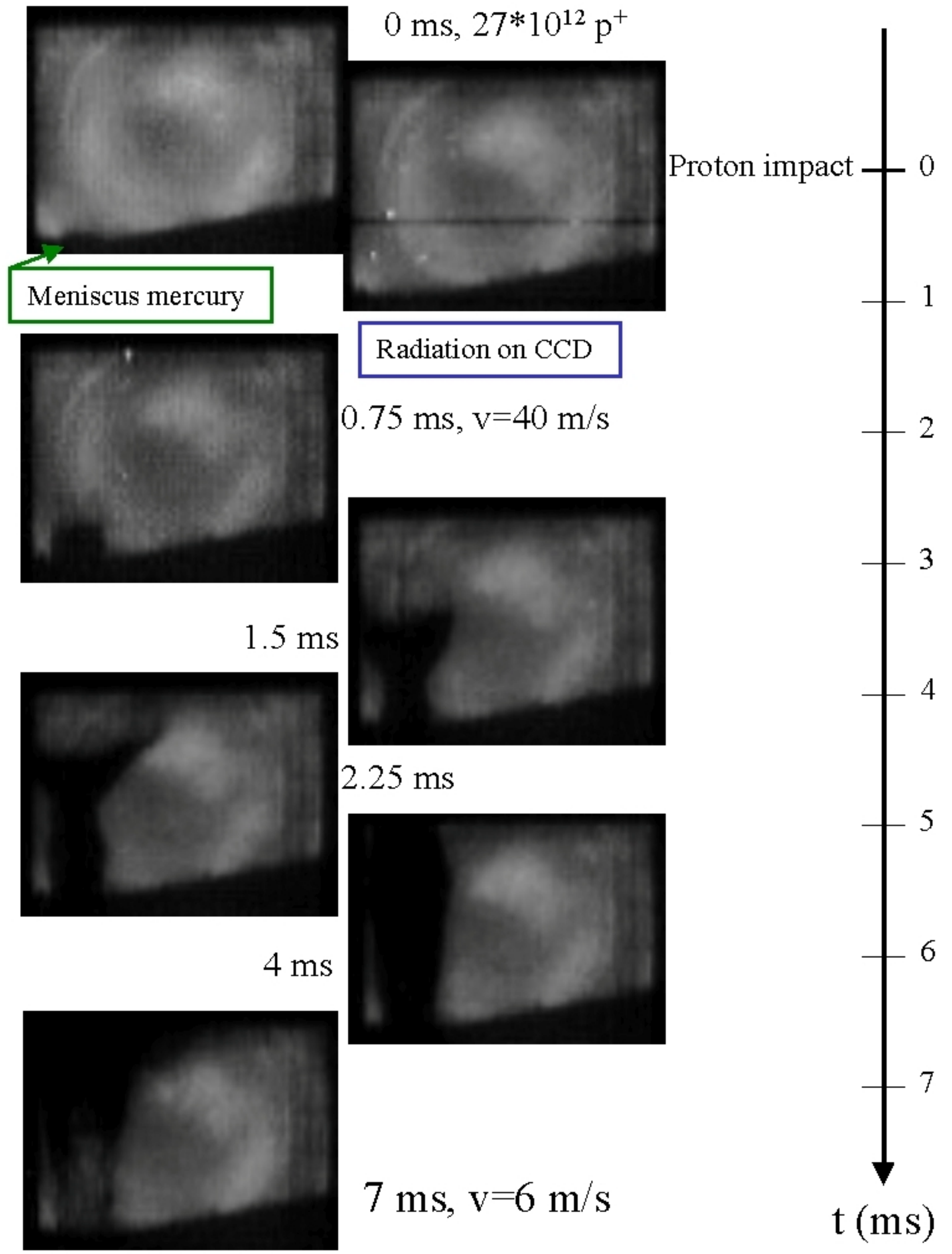
Simulation the RLAs (Recirculating Linear Accelerators) and of the Decay Ring (Keil, Verdier)

Work by ST for layout on the site (Poehler)

Detector locations being investigated (Wenninger)


Thimble after use
1.3cm3
1cm

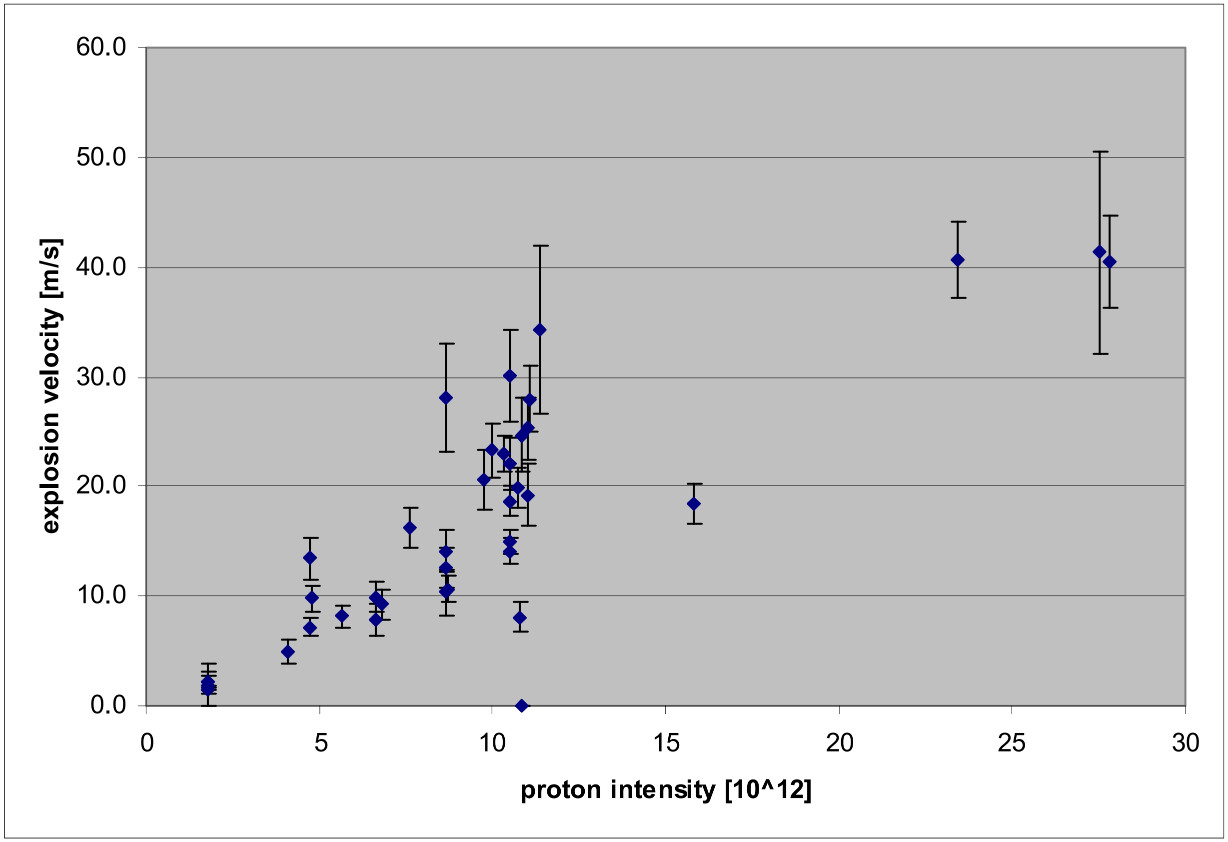
Mercury splash after beam pulse



Protons on Mercury

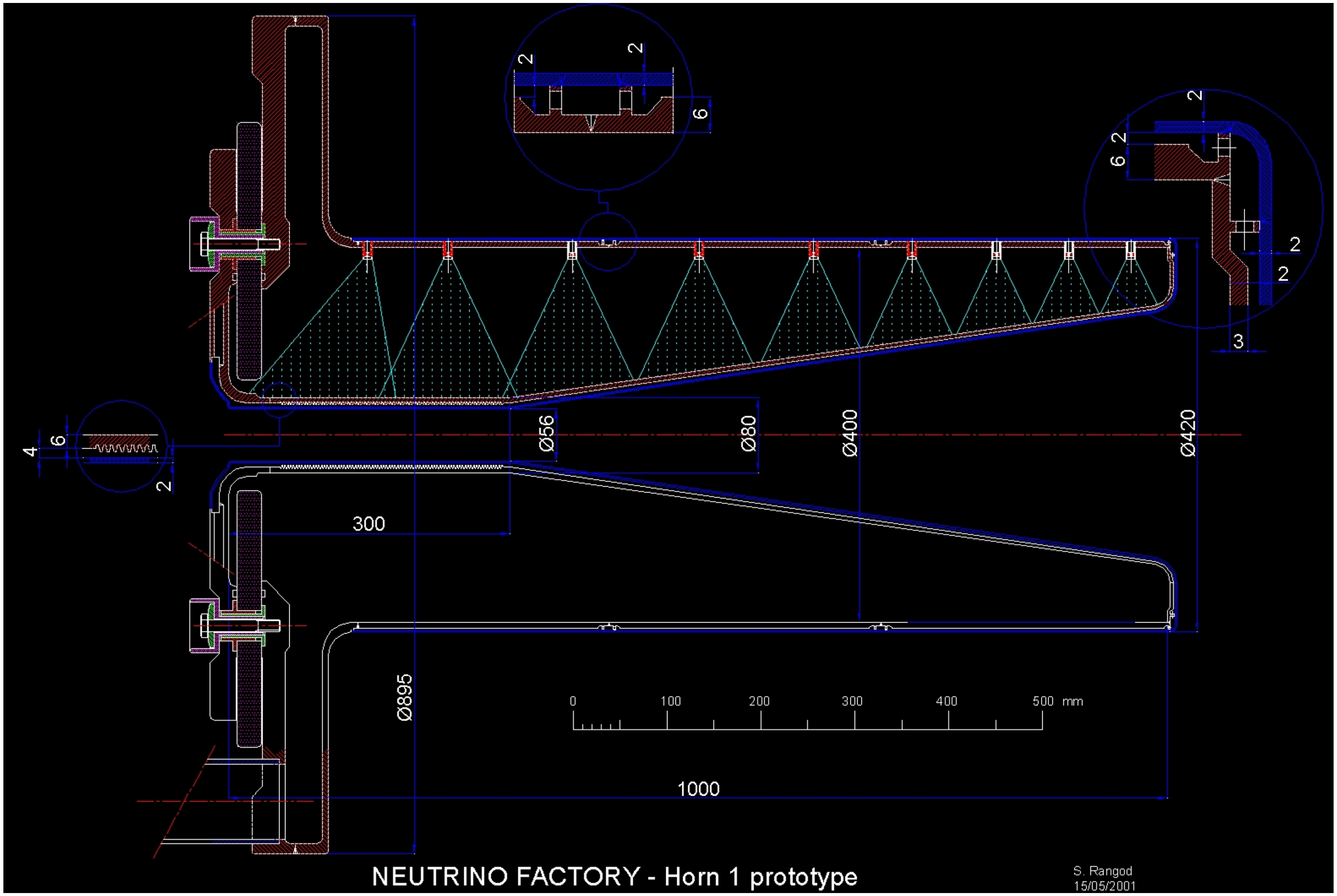
ISOLDE GPS, Aug. 2001

40 single pulse events at 1.4 GeV



PSB (NuFACT CERN)

- pulse intensity
  1-28 10^{12} p^+
  (230 10^{12} p+)
- pulse length
  0.6-8 µs
  (3.2 ms)
- height scan
- p-beam size
  σ=1.2-3.5 mm
  (7.5 mm)
- Beam density
  1.3-8.5 p^+/mm^2
  (1.3 p^+/mm^2)



Ø56
Ø80
Ø400
Ø420
Ø895
300
1000
0 100 200 300 400 500 mm
NEUTRINO FACTORY - Horn 1 prototype
S. Rangod
15/05/2001

Detailed electrical parameter table of Horn H40-400

	Units	**Horn H40-400**
Peak current in horn	kA	300
Duty cycle	Hz	50
Inductance horn	µH	0.41
Inductance additional	µH	0.21
TOTAL inductance	µH	0.62
Resistance horn at 100 °C	µΩ	183
Resistance additional	µΩ	287
TOTAL resistance	µΩ	470
Total capacitance for 1 switching section	µF	1453
Pulse duration (half period)	µs	93
Skin depth	mm	1.25
Charging voltage	V	6280
Energy stored in capacitor section	kJ	29
Efficiency		0.64
Voltage on element	V	4200
r.m.s. current in horn	kA	14.5
Mean power dissipation in horn by current *	kW	39
Water flow needed in l/min with $\delta\theta$ w= 15°C *	l/min	38

* power dissipation due to beam absorption has to be added

TEST PROGRAM

5.1 Construction of a test stand in BA7

to study the vibrational behaviour and the mechanical fatigue due to electrical pulsing

(see Appendix A-electrical table & B-horn test in BA7)

Two branches are under construction

Space in BA7 seems convenient (to be confirmed with final thyristor arrangement)

5.2 Construction of horn prototype

(see Appendix C- horn assembly)

Rigid end plate on neck side of inner conductor

Flexible end plate on the other side

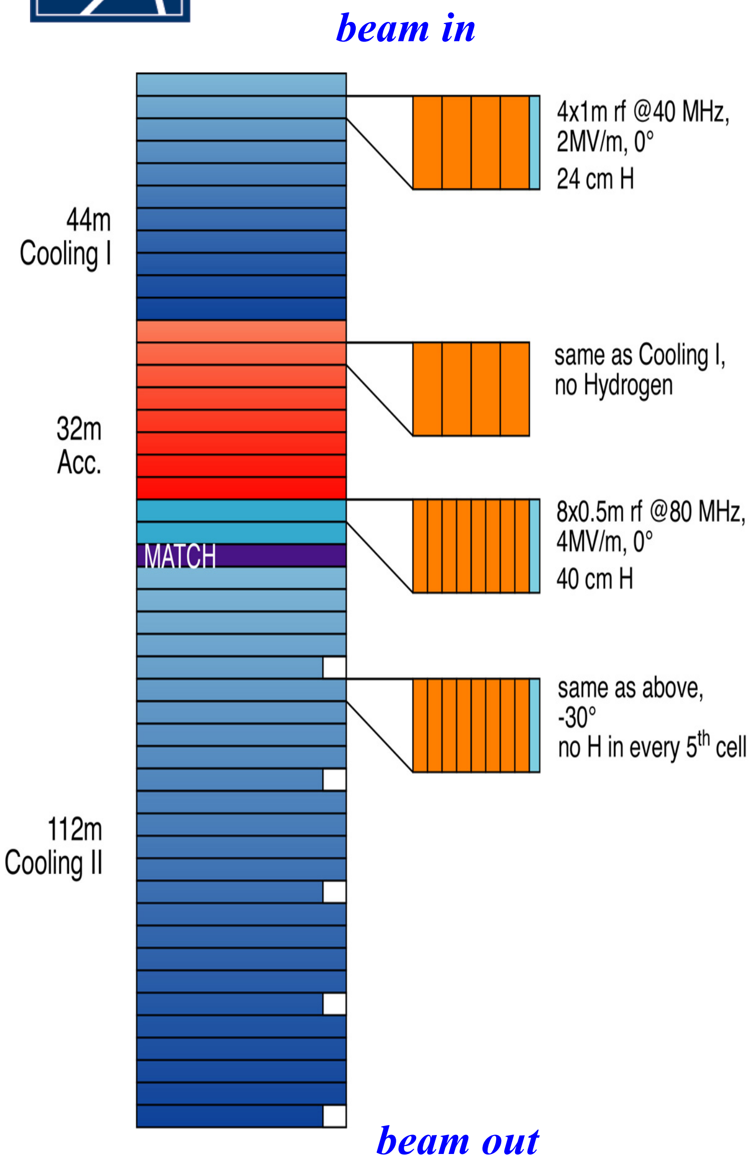
Dual water circuit (inner conductor with double skin)

Horn ordered with central workshop.

Estimated construction time

>> end of February 2002

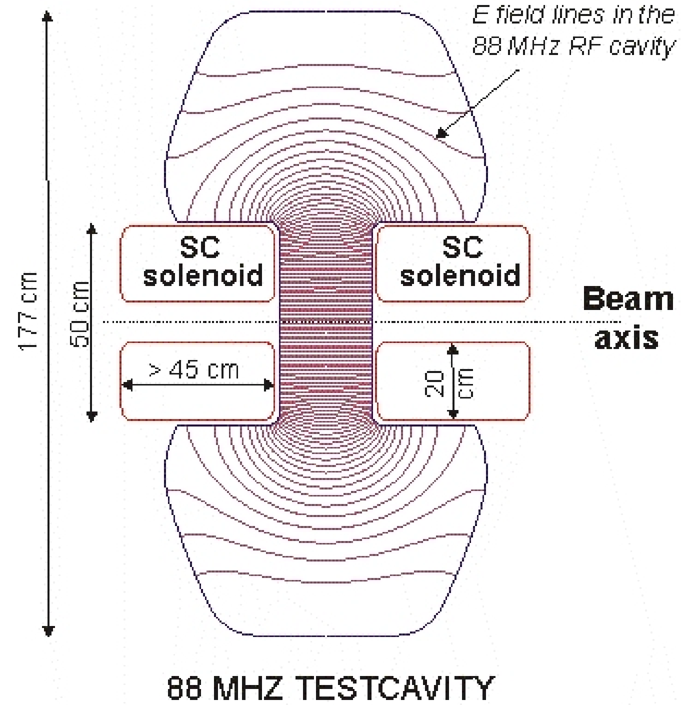
Layout of 40/80 MHz Cooling Channel

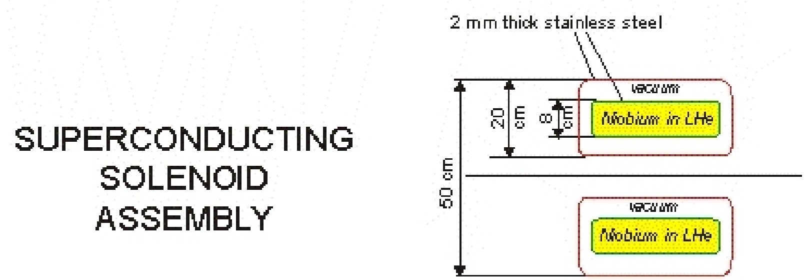


	Decay	Rotation	Cooling-I	Acceleration	Cooling-II	Acceleration
Length, m	30	30	46	32	112	≈450
Diameter, mm	600	600	600	600	300	200
Solenoid field, T	1.8	1.8	2.0	2.0	2.6	2.6
Frequency, MHz		44	44	44	88	88-176
Gradient, MV/m		2	2	2	4	4-10
Energy, MeV		200		280	300	2000

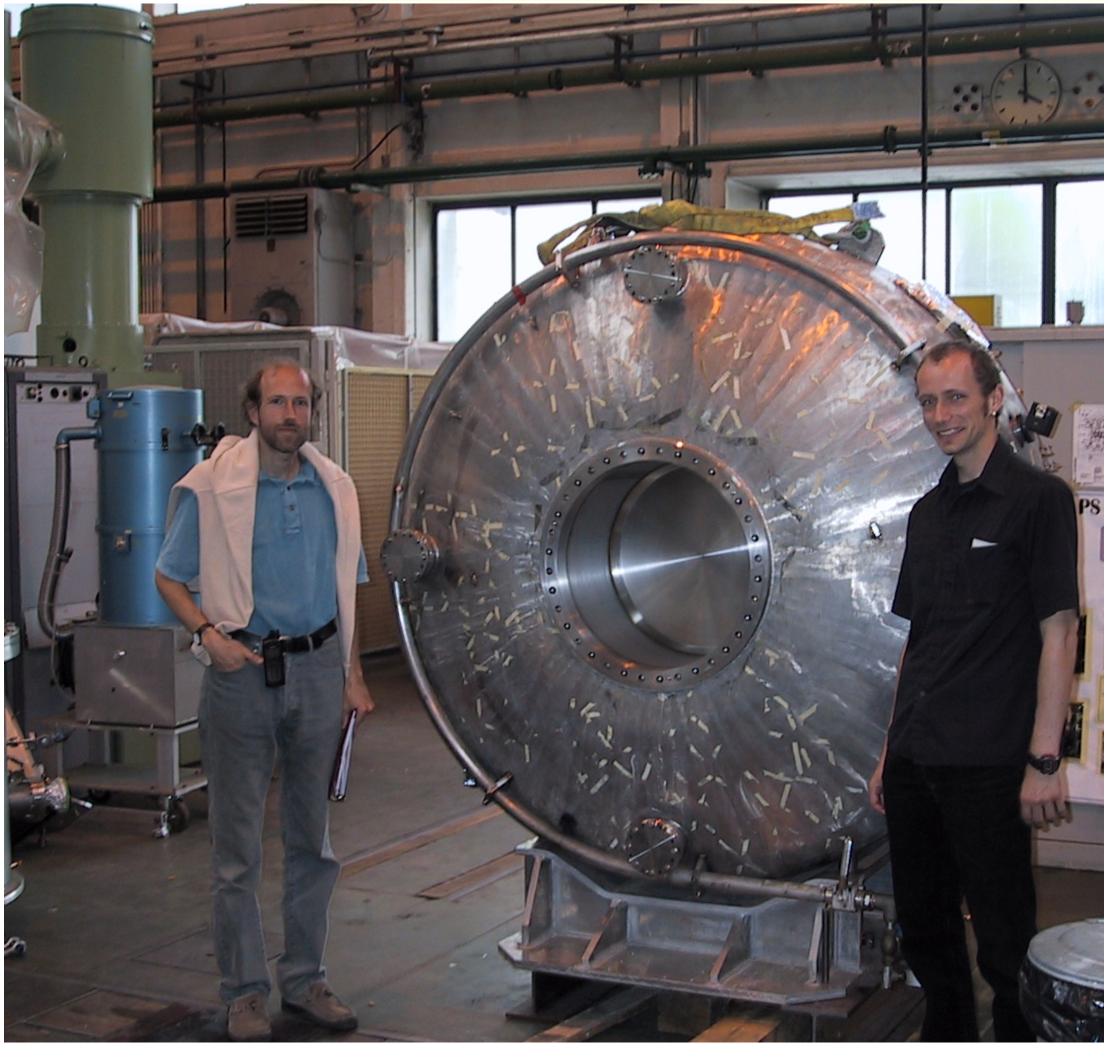
Table 3 Main parameters of the capture, phase rotation, cooling and acceleration section

88 MHz test cavity





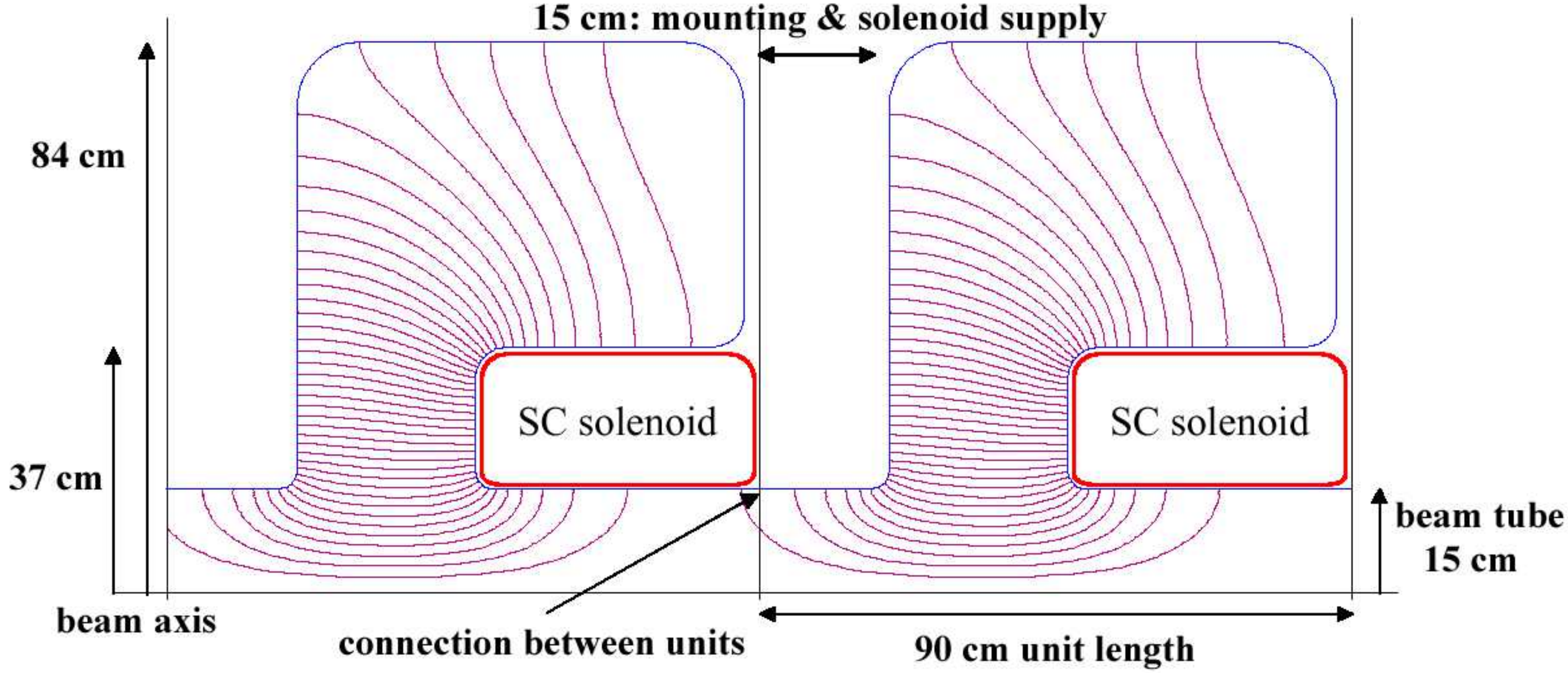
- An 88 MHz test cavity for high gradient is being prepared (2 MW amplifier driving a modified 114 MHz PS cavity)
  - High RF gradient without solenoid: end 2001
  - RF test with solenoid: mid-2002



Cavity with closed gap:

E_0	= 4 MV/m
f_{rep}	= 1 Hz
r/Q	= 113 Ω
τ	= 180 µs
t_{pulse}	= 10.5 ms
P_{peak}	= 1.4 MW
P_{mean}	= 15 kW
Kilp.	= 2.3
gap	= 280 mm
length	= 1 m
diameter	= 1.77 m

Asymmetric 88 MHz cavities



E_0T	= 4 MV/m	τ	= 156 µs	solenoid: 40 x 20 cm
Z_{TT}	= 5 MΩ/m	P_{PEAK}	= 2.19 MW/cavity	Kilpatrick: 2.3
R/Q	= 137 Ω	P_{MEAN}	= 85 kW/m for 75 Hz repetition rate	

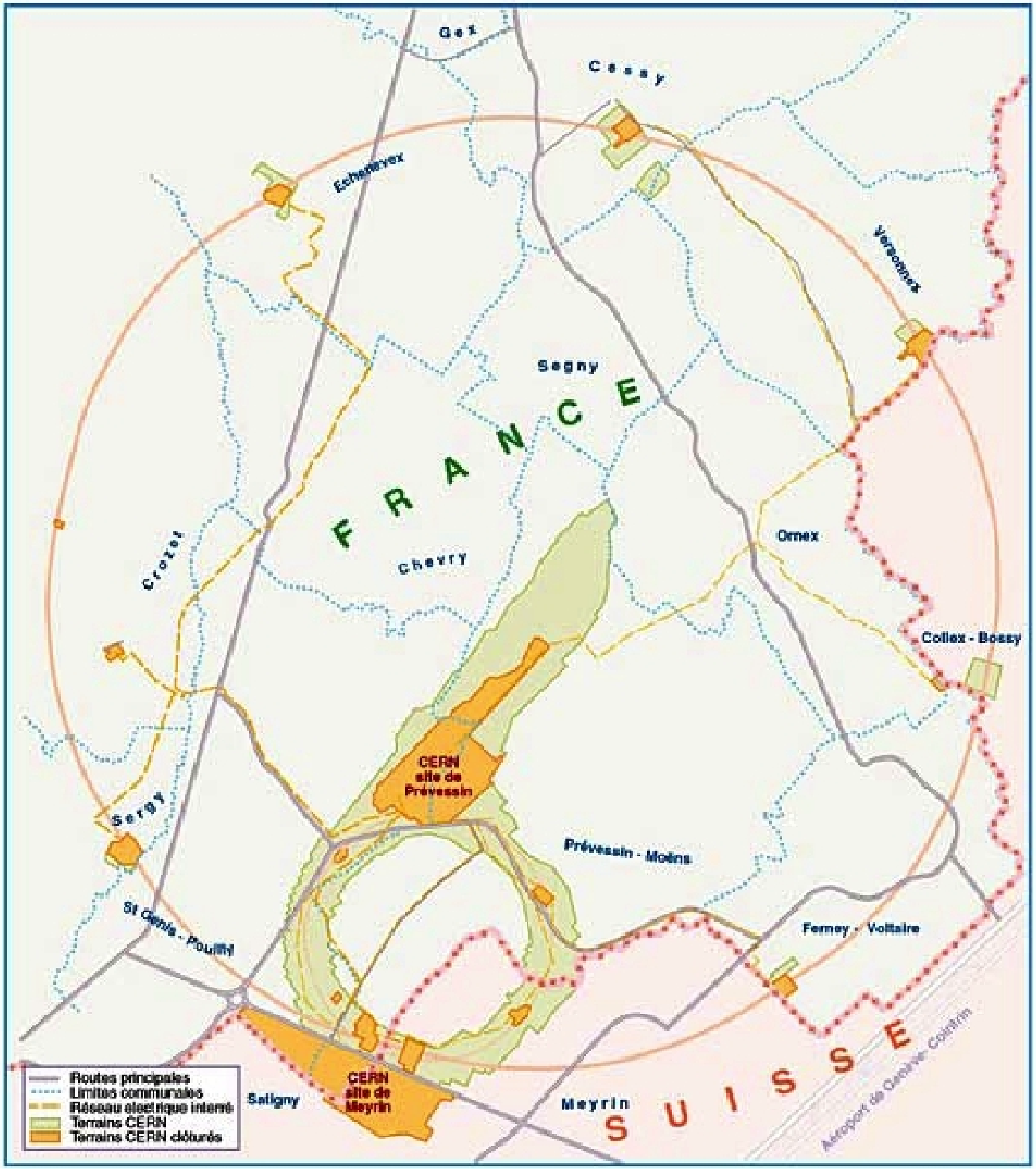
	RLA1	RLA2
Injection energy, GeV	2	10
Extraction energy, GeV	10	50
Number of turns	4	4
Length of linacs (2), m	680	3813
Rf frequency, MHz	352	352
Bending radius in arc, m	5	25
Mean arc radius, m	20	100
Circumference, m	806	4442
Peak voltage gradient per linac, MV/m	7.4	7.4
Normalised admittance, mm rad	16.47	18.80
Normalised rms emittances, mm rad	1.83	2.09

Parameters of Recirculating Linacs (RLAs)

Design momentum, GeV	50
Muon fluence, s^{-1}	10^{14}
Configuration	Triangular
Normalised beam divergence in SS at σ_ε, mrad	0.1
Normalised beam emittance (σ_ε), mm rad	1.67
Aperture limit	3 σ_ε
Relative rms momentum spread	0.005
Bunch spacing, mm	851
Dipole field, T	6
Total length of straight sections, m	1500
Average radius in the arcs, m	46
Circumference, m	2075

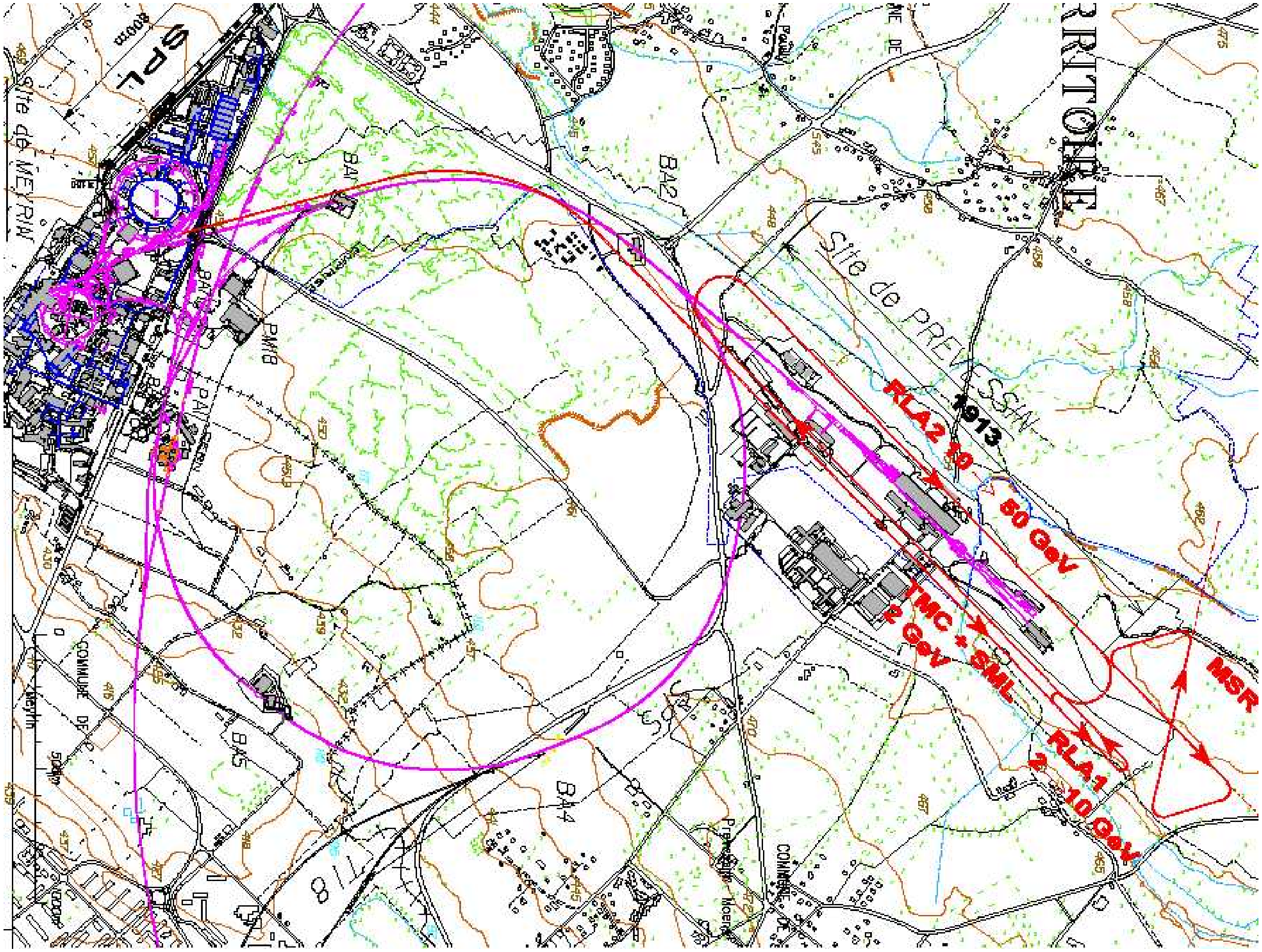
Parameters of Decay Ring

CERN Site



Gex
Cessy
Echenevex
Versonnex
Segny
FRANCE
Crozet
Chevry
Ornex
Collex - Bossy
CERN
site de
Prévessin
Sergy
Prévessin - Moëns
St Genis - Pouilly
Ferney - Voltaire
Satigny
CERN
site de
Meyrin
Meyrin
SUISSE
Aéroport de Genève- Cointrin
Routes principales
Limites communales
Réseau électrique interne
Terrains CERN
Terrains CERN clôturés

Preliminary Layout of Neutrino Factory



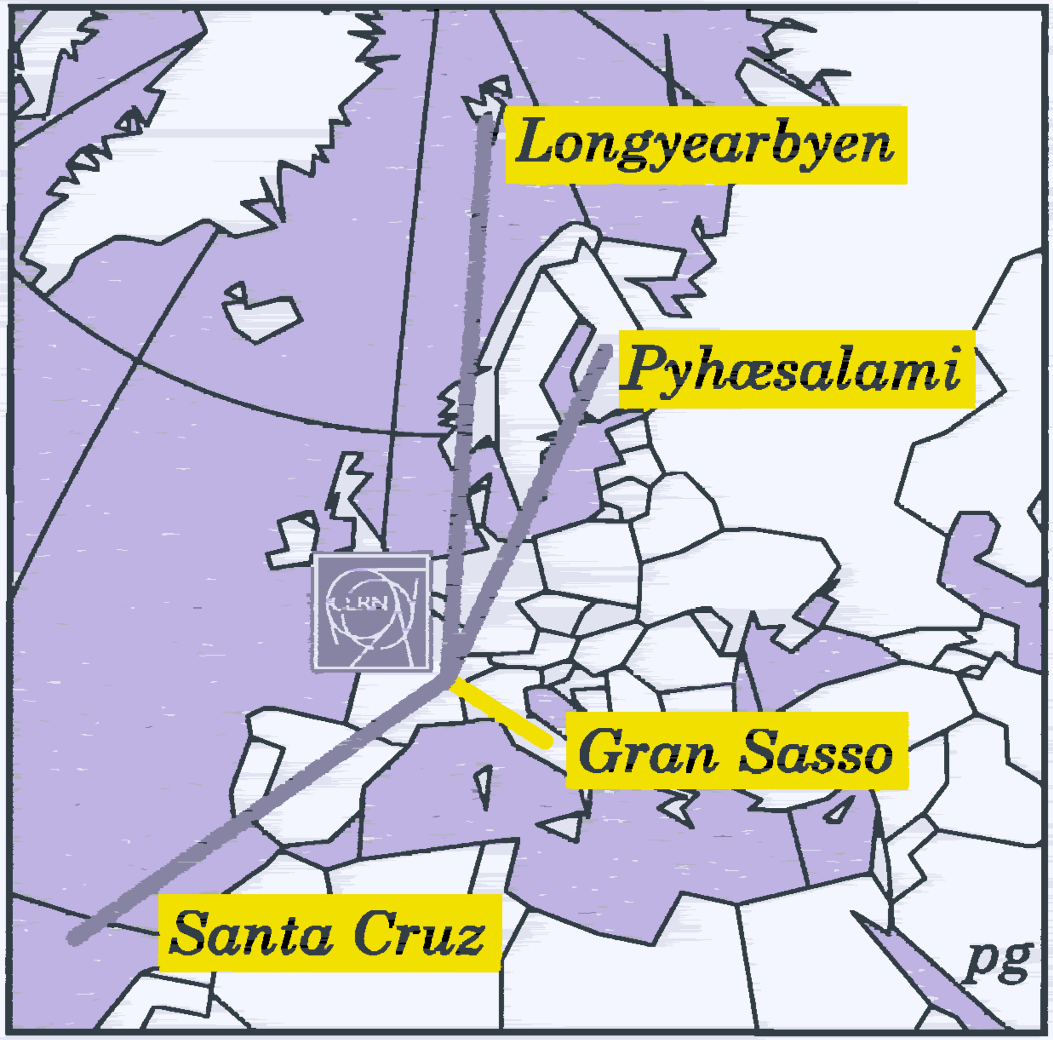


Figure 1: Overview of the detector positions currently under investigation.

Arguments for an International Muon Cooling Experimental Demonstration

There are quite different opinions about the necessity to do a cooling experiment, however, the majority believes strongly that there is a need to demonstrate that ionisation cooling is indeed technically feasible. Some people feel that even the relevant programs need checking by experiments. One remark to answer criticism like "we know Moliere scattering and Maxwell's laws" is that in spite of knowing Maxwell's laws and the properties of superconducting cable one has built not only one but several magnet prototypes for the LHC. Muon ionisation cooling is by no means more trivial.

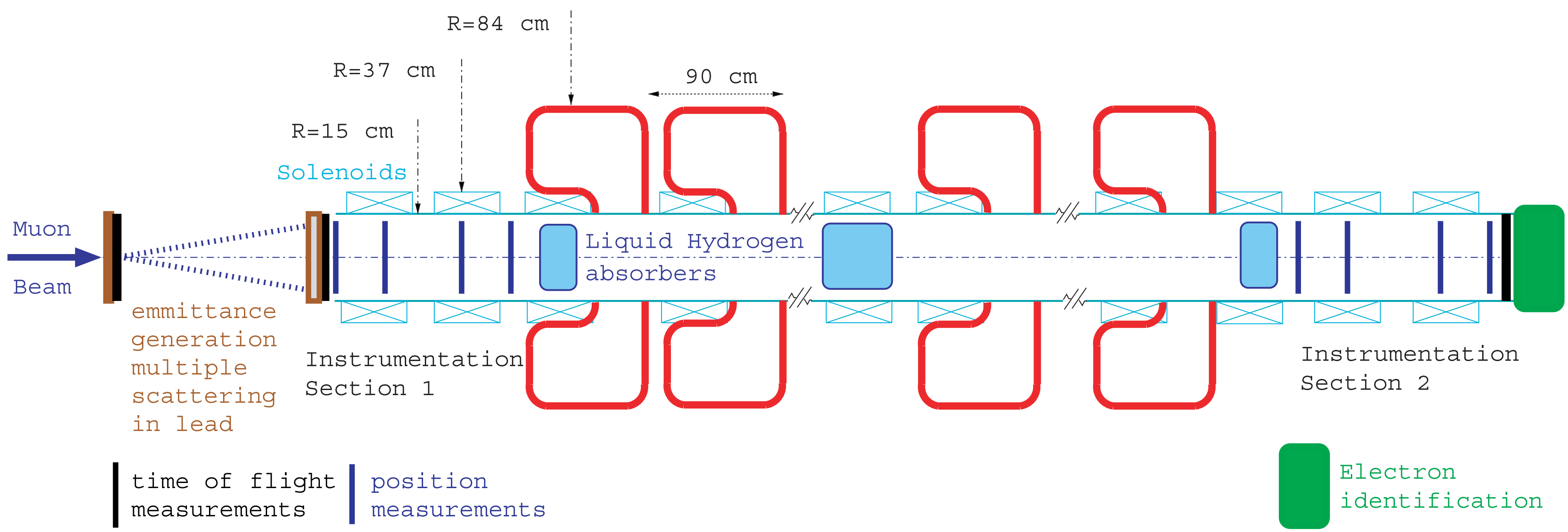
As a by-product of the discussions in the context of the cooling experiment several new ideas came already up, which were the result of stimulating exchange of ideas, not limited to the SPL and the target:

- The idea of "Beta - beams", i.e production of neutrino beams by decay of radioactive isotopes
- Very important findings about the H_2 absorber heat load due to electron beams from the cavities.

A possible (poor man's) Muon Cooling Experiment

The main hardware is composed of the following items:

- ⇒ RF cavities
- ⇒ RF transmitters, modulators and charging supplies
- ⇒ Cavity sc solenoids
- ⇒ Hydrogen absorbers
- ⇒ Measuring lines at input and output including sc solenoids and data acquisition


R=84 cm
R=37 cm
90 cm
R=15 cm
Solenoids
Muon
Beam
Liquid Hydrogen
absorbers
emmittance
generation
multiple
scattering
in lead
Instrumentation
Section 1
Instrumentation
Section 2
time of flight
measurements
position
measurements
Electron
identification

To minimise the cost, the following distribution of hardware contributions is envisaged (very personal and provisional!):

1) One 4 cell cavity from the US collaboration (LBNL)

2) CERN (One rf transmitter refurbished with pieces from Linac1, one spare borrowed. Upgrading of power with special tube (old 516) needed. Russian manpower is sought to help)

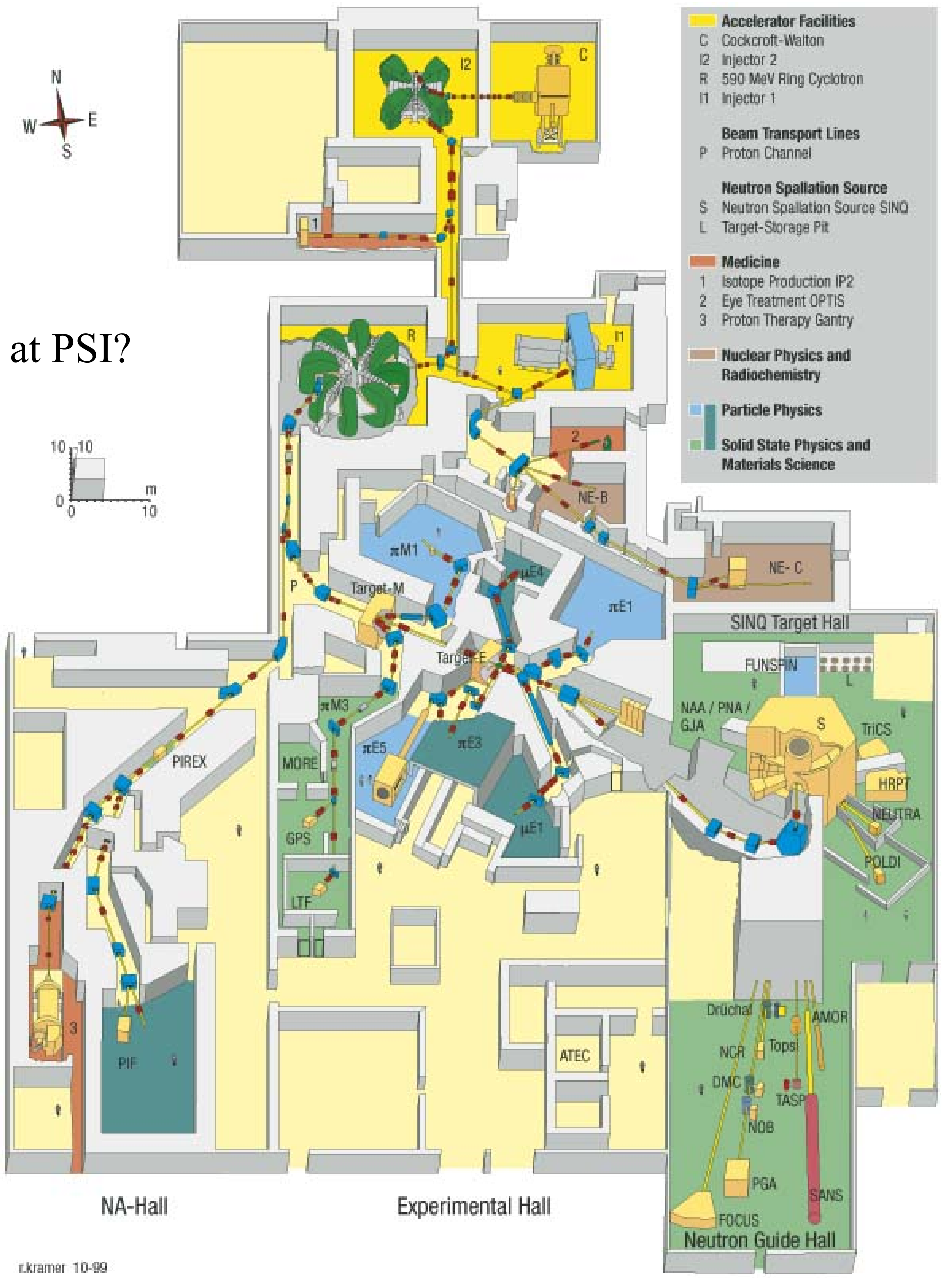
3) Swiss confederation, RAL, EU money?

4) American / Japanese collaboration (IIT et al.)

5) Collaboration of different physics institutes (V. Palladino)

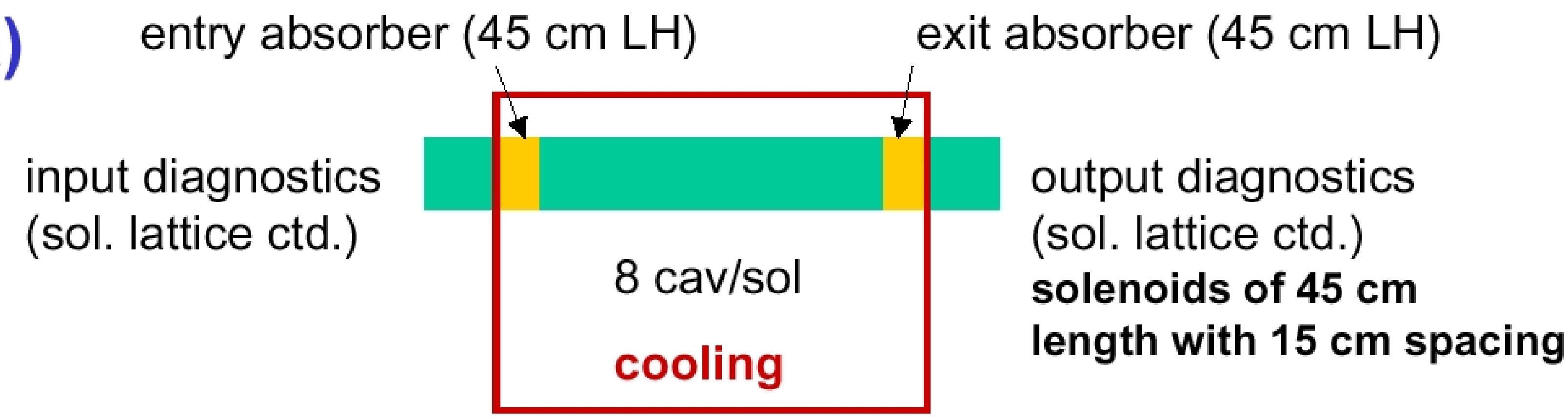
+ a Muon Beam (PSI or RAL)

Cooling experiment at PSI?

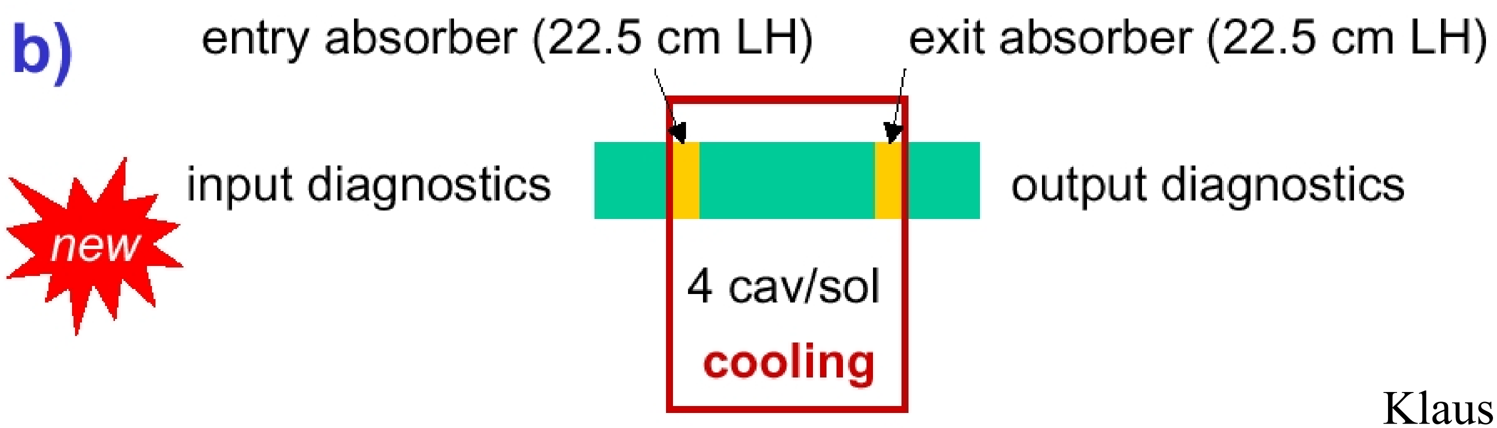


88 MHz Option: Lay-Out

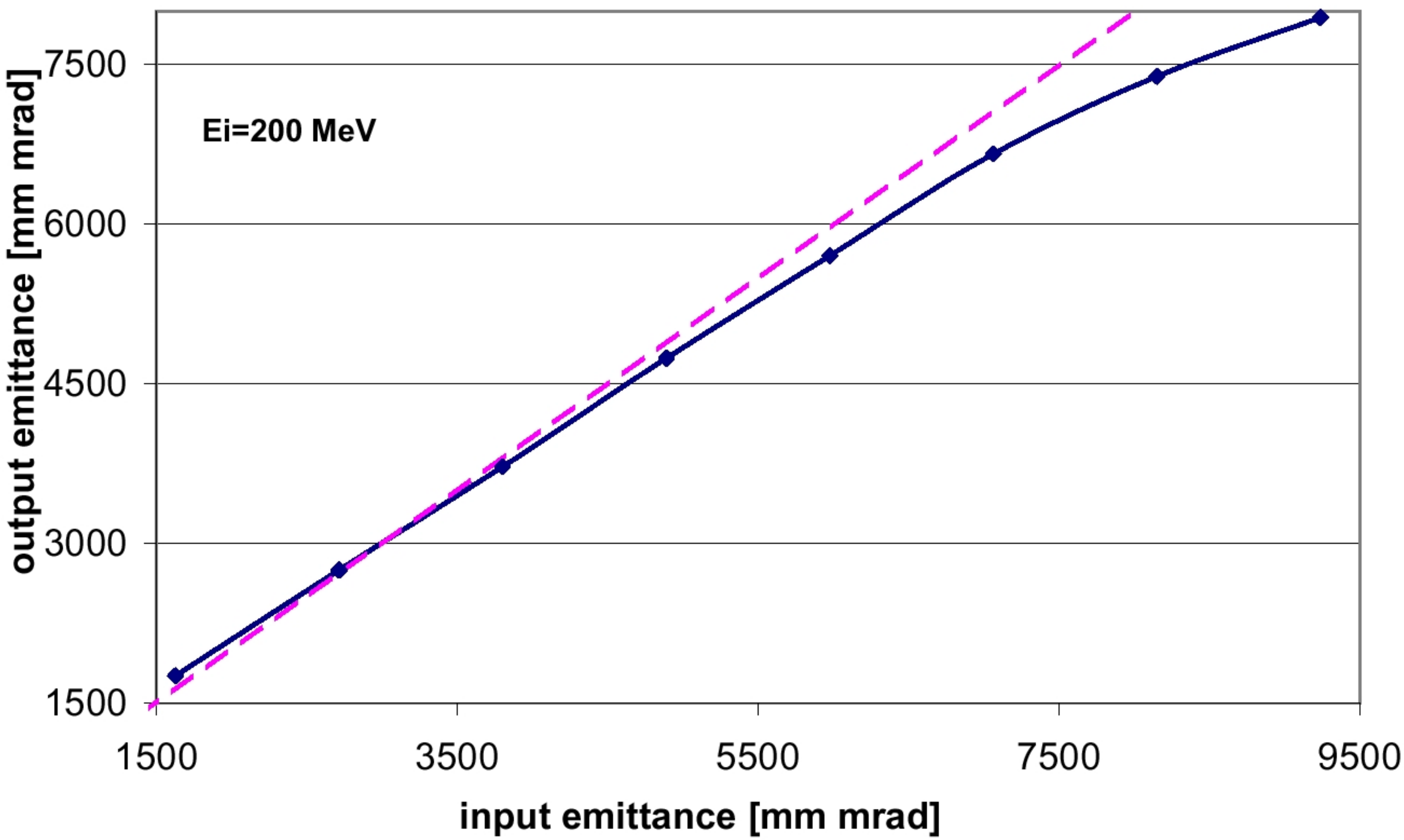
a)

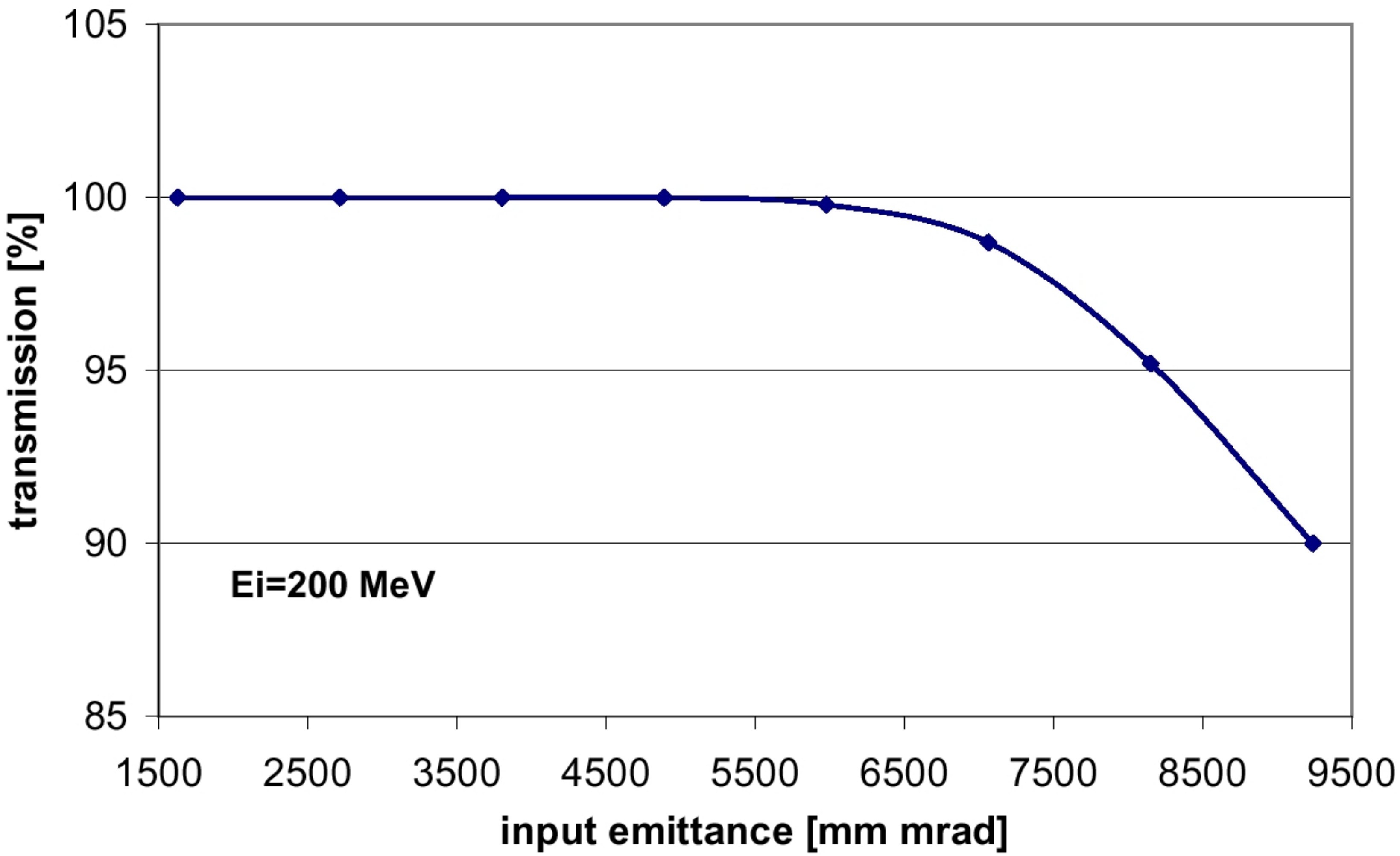


b)

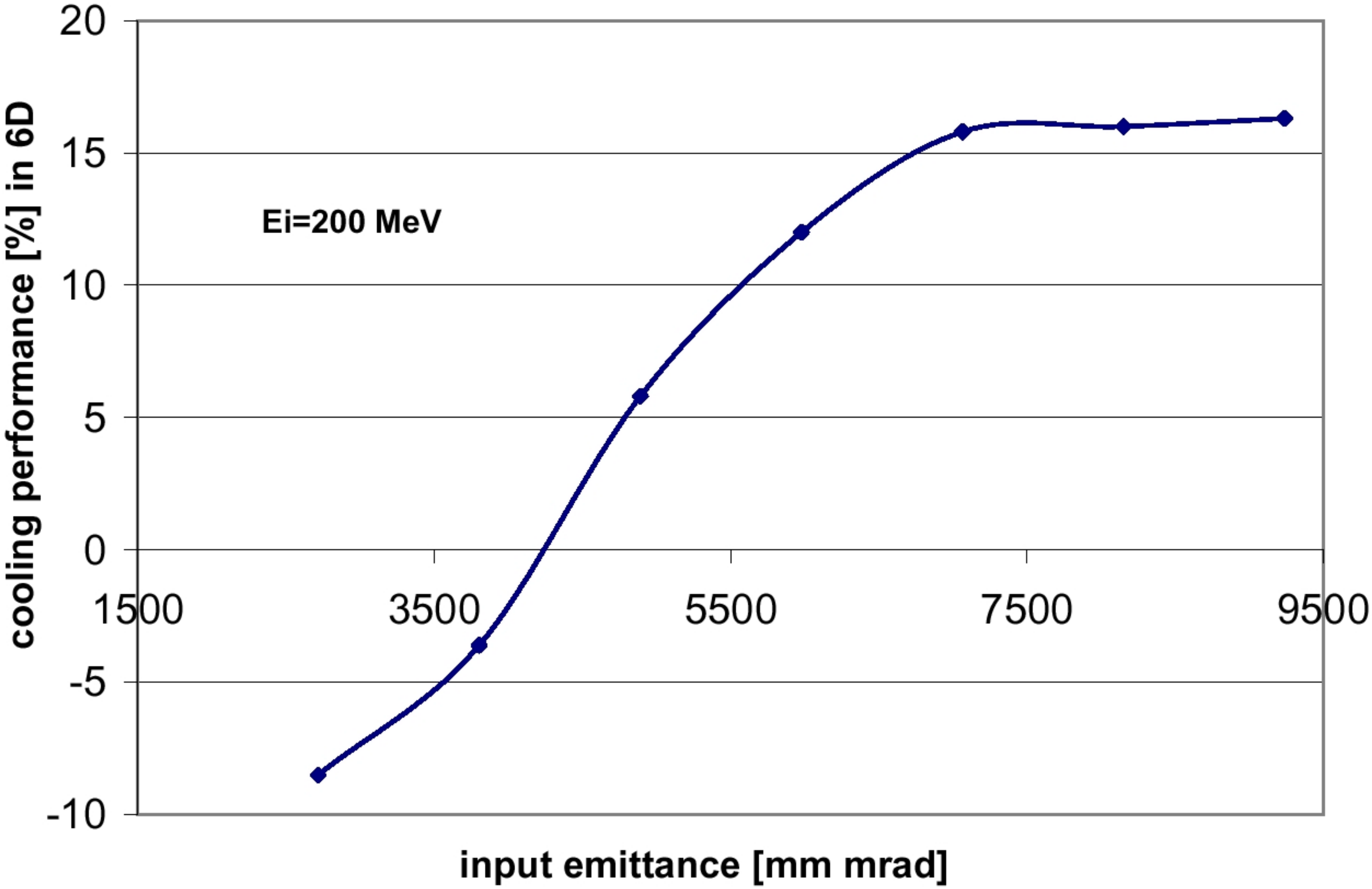


Klaus Hanke

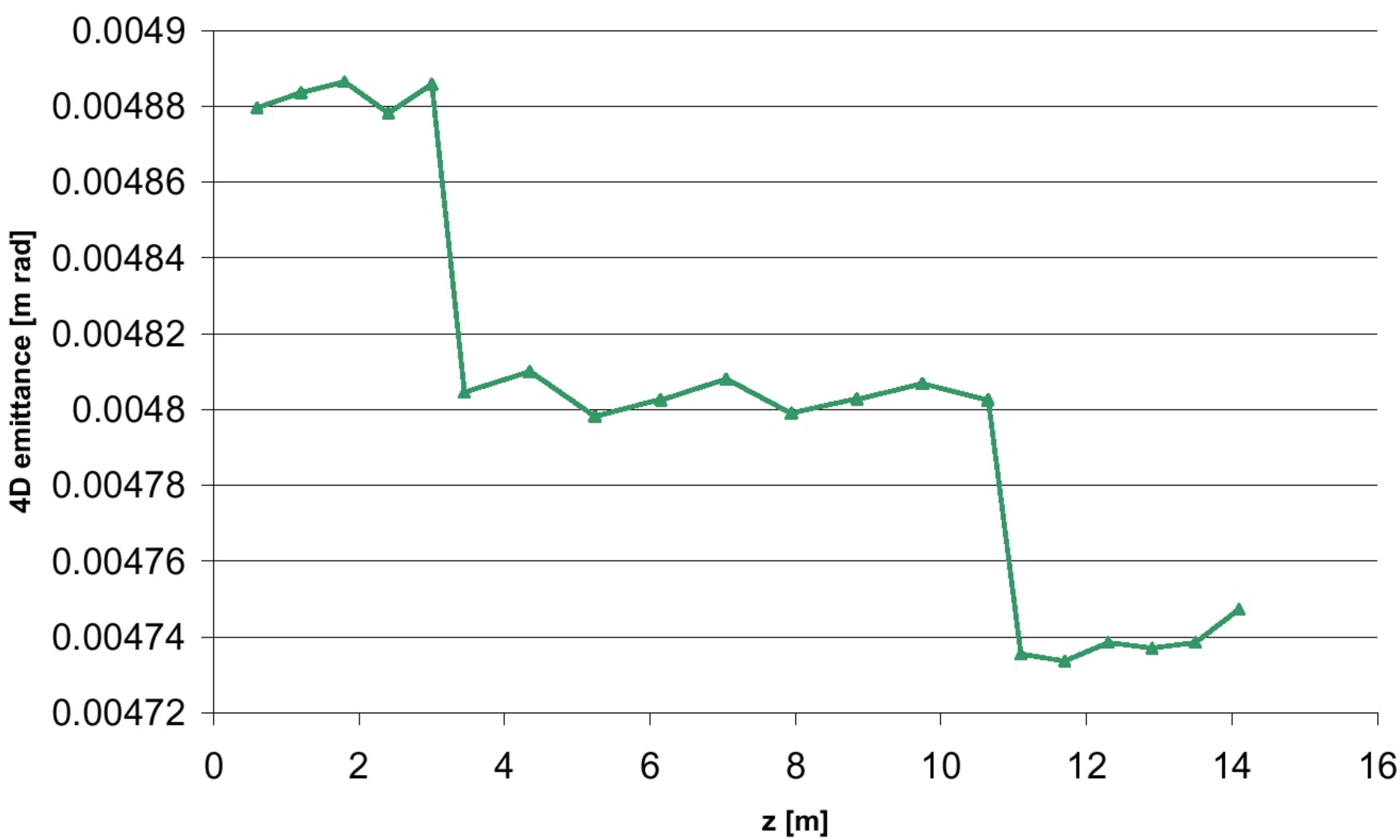

Ei=200 MeV
output emittance [mm mrad]
7500
6000
4500
3000
1500
1500
3500
5500
7500
9500
input emittance [mm mrad]



105
100
95
90
85
transmission [%]
Ei=200 MeV
1500
2500
3500
4500
5500
6500
7500
8500
9500
input emittance [mm mrad]



cooling performance [%] in 6D
20
15
10
5
0
-5
-10
1500
3500
5500
7500
9500
Ei=200 MeV
input emittance [mm mrad]


0.0049
0.00488
0.00486
0.00484
0.00482
0.0048
0.00478
0.00476
0.00474
0.00472
4D emittance [m rad]
0
2
4
6
8
10
12
14
16
z [m]

Conclusion

a cooling experiment, which is a subsection of the CERN 88 MHz cooling channel, has been simulated with *PATH* based on engineering designs for cavities and solenoids

the cooling performance is about 3.7 % in transverse (rms) emittance reduction and about 9.1 % in gain of muons inside a given acceptance; the performance of a system of only 4 cavities goes down in proportion

the results have been confirmed with a second code (*ICOOL*) and with high statistics

a detailed parameter scan has been performed to evaluate the performance of the channel for various input beams, settings etc. (E.-S.Kim, K.Hanke, to be published)

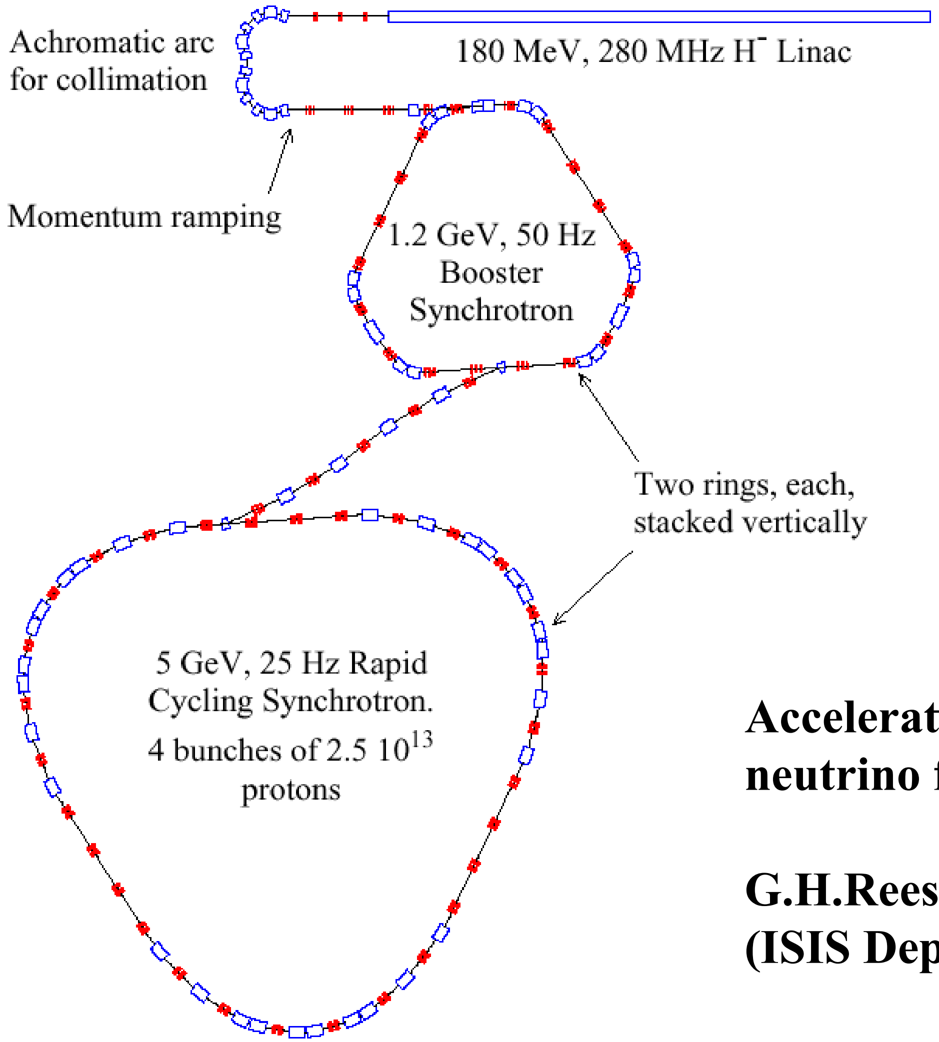
simulation of a 200 MHz option under way

Klaus Hanke

Activities in the UK

The 'Particle Accelerators for Particle Physics' initiative has been jointly funded by PPARC and CLRC over the past two years. The main objective is to re-establish within the UK the tradition of research and development into accelerator technology for particle physics applications, either at the high energy or the high luminosity frontier.

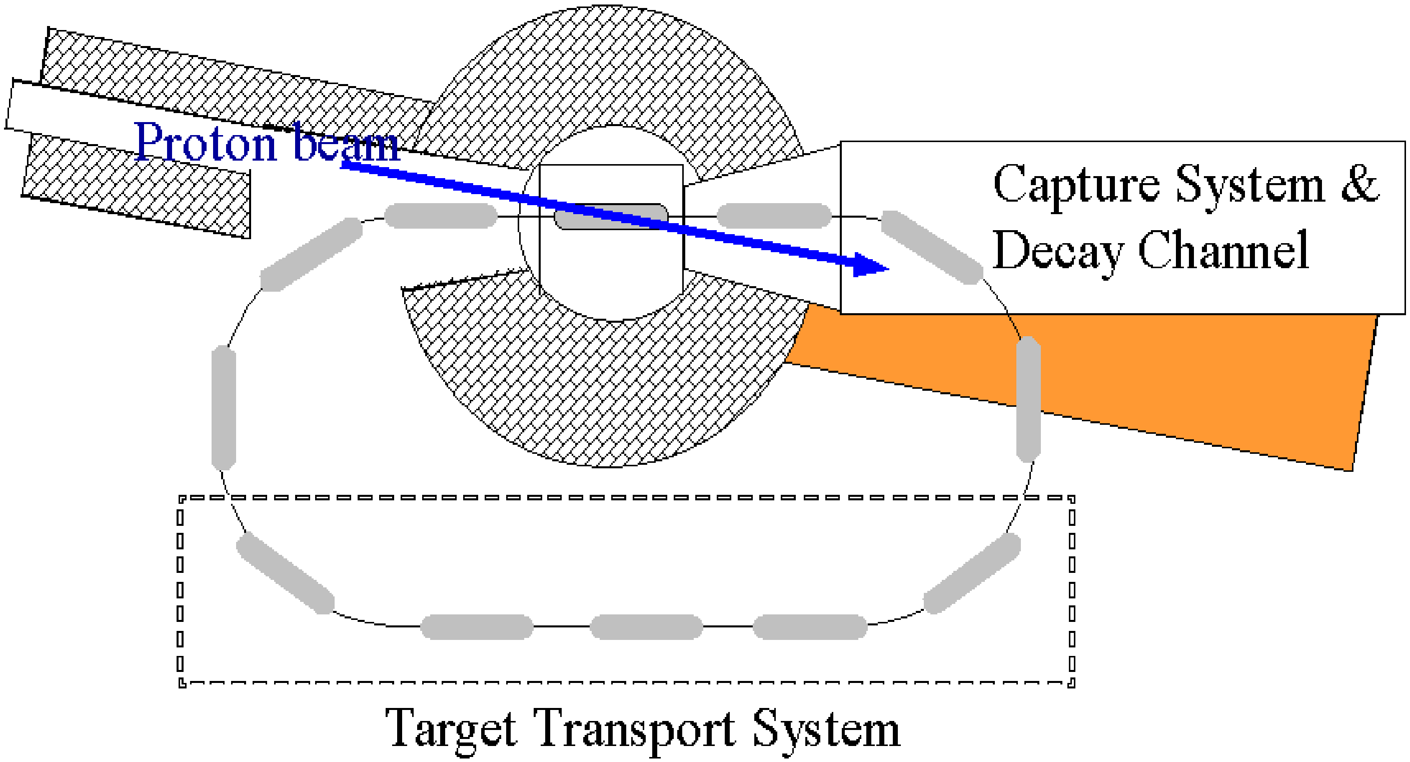
This would enable the UK to evaluate for itself how it would wish to contribute to future international particle physics facilities, with the option of making the contribution to the machine 'in kind' (as is done with the detectors)



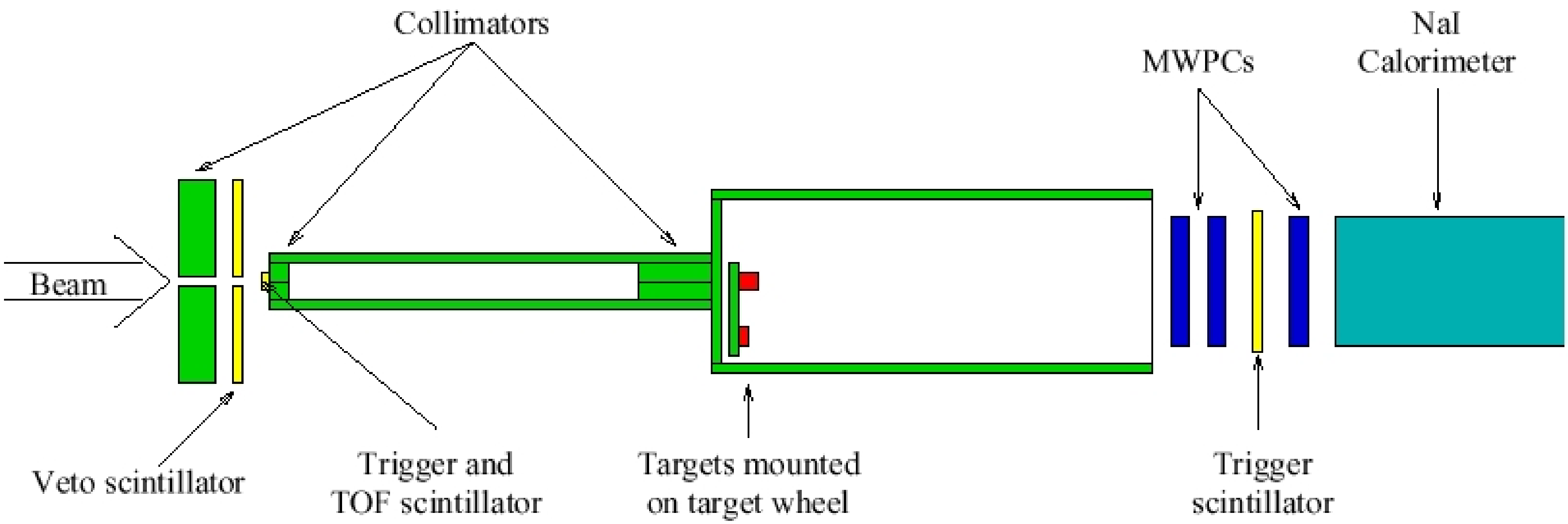
Accelerator studies for a neutrino factory Proton driver design

G.H.Rees and C.R.Prior
(ISIS Dept, CLRC RAL)

Schematic of the 5 GeV, 50 Hz RCS Design



High power target studies
P.V.Drumm and J.R.J.Bennett (ISIS Dept, CLRC RAL) and C.J.Densham (Engineering Dept.,CLRC RAL)



The MuScat experiment

J.Wilson and T.McMahon (Birmingham), E.McKigney and K.Long (ICSTM), T.R.Edgecock, M.Ellis, W.Murray and P. Norton (RAL PPD), J Lidbury (RAL ED), together with international collaborators

Japanese Study of High Intensity Muon Source with Phase Rotation and Muon Cooling

The purpose of this program is an R&D study on a high intensity muon source for PRISM, a neutrino factory and a muon collider. In particular, we are studying the techniques of phase rotation and muon ionization cooling. Phase rotation is to accelerate slow muons and decelerate fast muons by applying an RF field in order to produce a muon beam with narrow beam-energy spread.

(1) Development of liquid Hydrogen Absorber

(2) Development of a low-frequency RF cavity

Yoshitaka Kuno
Osaka University

Introduction

Why Neutrino Factory in Japan?

1 Neutrino Physics in Japan

Super-KAIMIOKANDE(atomospheric neutrino)

Long Base-line (KEK 12-GeV PS to KAMIOKA) K2K

2 High Intensity Proton Accelerator Project

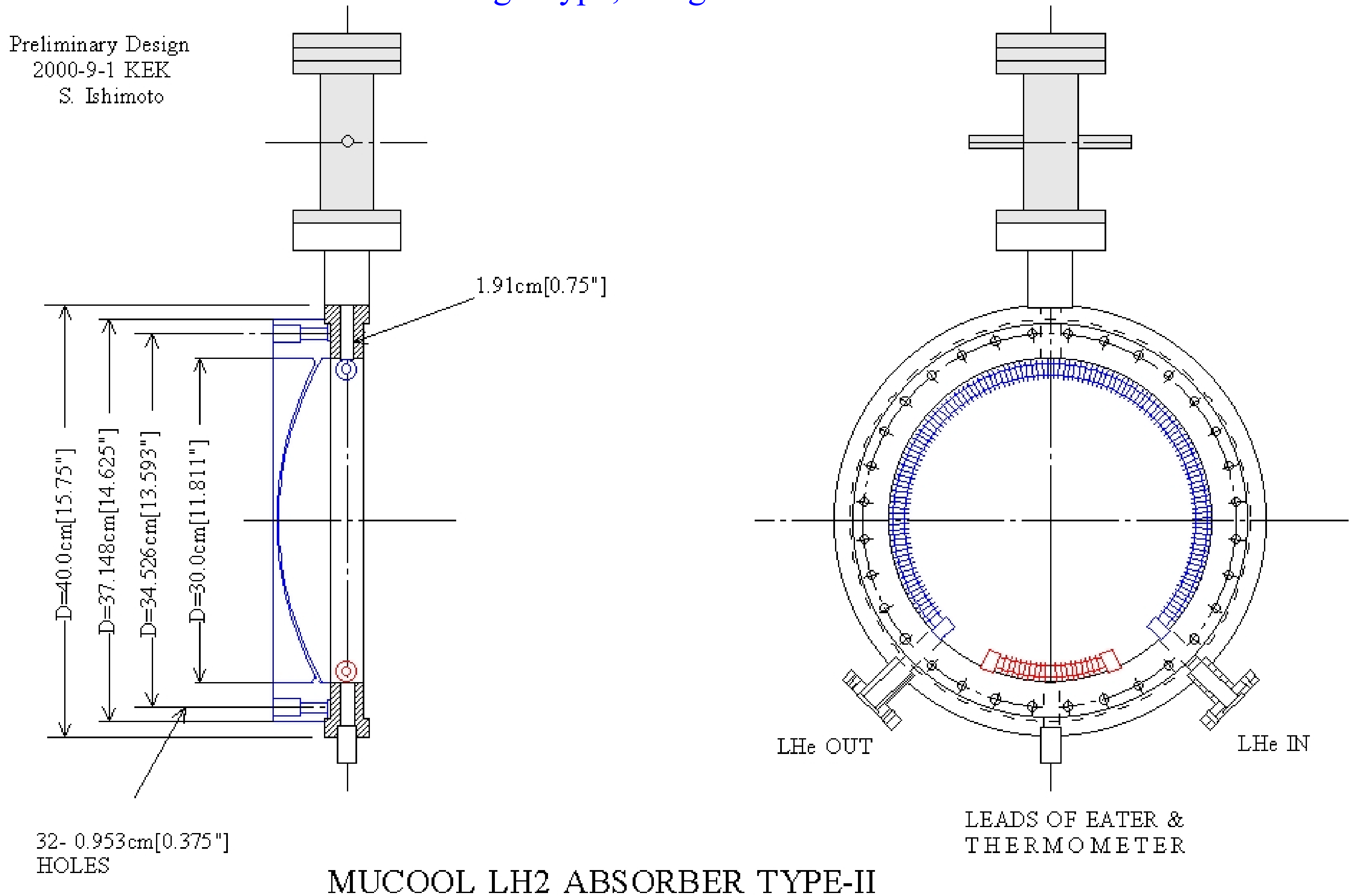
Proton Driver beam power > 1 MW

50-GeV PS Joint Project KEK/JAERI

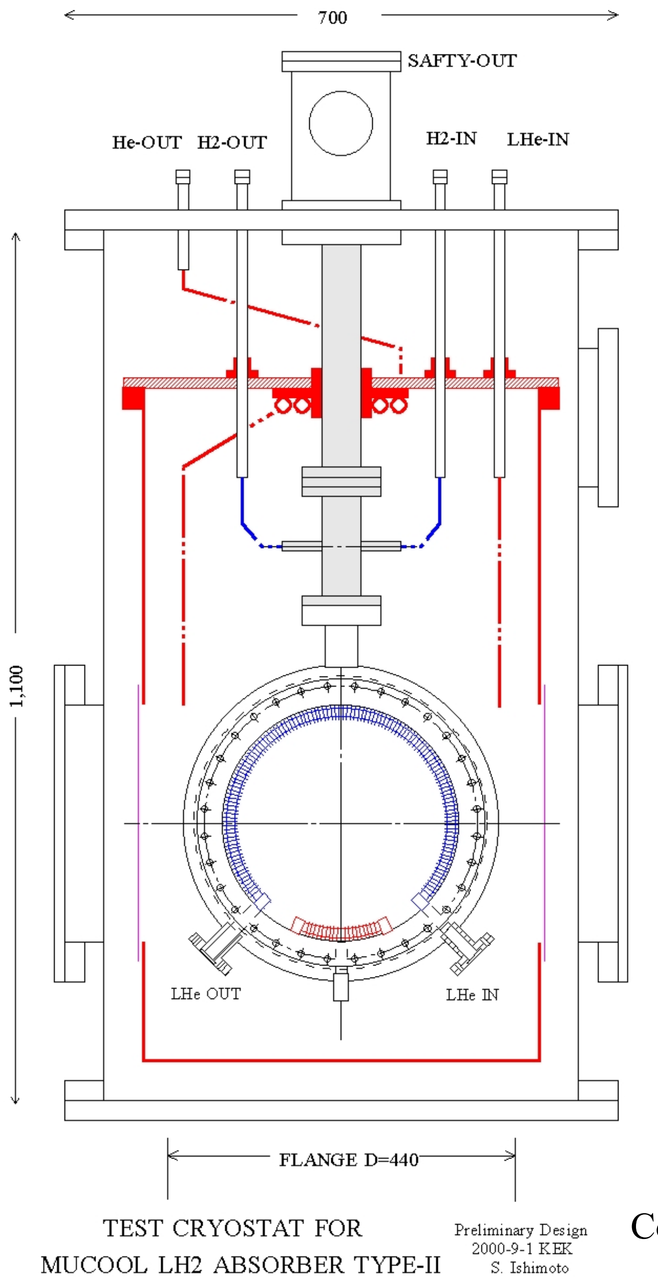
Yoshitaka Kuno
Osaka University

(2) Development of liquid Hydrogen Absorber

Drawing of a prototype of absorber of internal exchanger type, designed at KEK



Courtesy of Y. Kuno (Osaka)



Layout of a prototype absorber in a large cryostat

Courtesy of Y. Kuno (Osaka)

Accelerator Scenario - FFAG Option

FFAG(Fixed-Field Alternating Gradient) Accelerator

(1) Large Momentum Acceptance

$\Delta p/p$ ~ +- 50% or more

(2) Large Aperture

A ~ 0.01-0.02 πm.rad

(3) Scaling

$p/p_0 \sim (r/r_0)^{k+1}$: tunes=const., $\xi=0$, $\alpha=1/(k+1)$:no higher orders

(4) Non-scaling

linear system

Yoshitaka Kuno
Osaka University

Yoshitaka Kuno
Osaka University

CYCLOTRON CONFERNECE, May 12-17,2001, MSU, Lansing

Magnetic Alloy

A high-permeability soft magnetic alloy, such as FINEMET and METGLAS has become available for applying the RF cavity, recently.

Characteristics of MA:

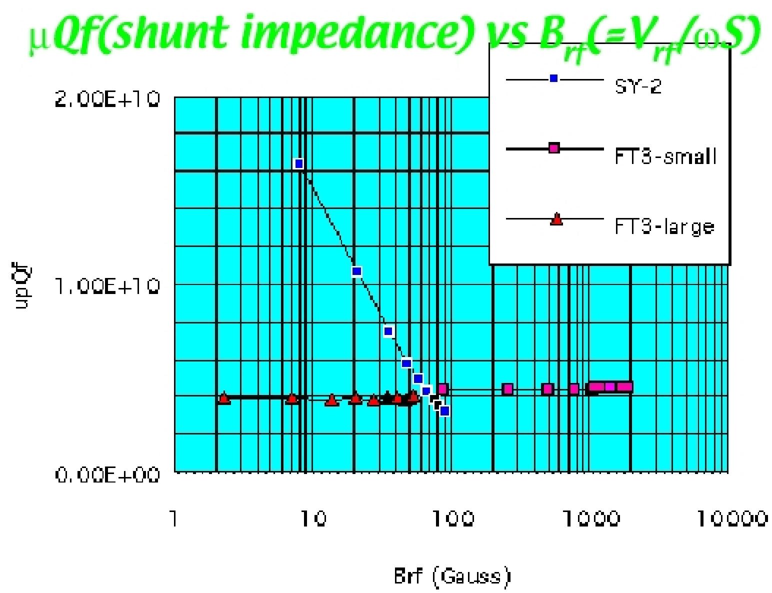
(1) The μQf-value remains constant at a high RF magnetic field (Brf) of more than 2 kG.

(2) A high Curie temperature, typically 570°C for FINEMET.

(3) The intrinsic Q-value is small. No frequency tuning loop is necessary in the cavity control system because of its low Q-value (Q~1). This substantially widens the stable operating region of the cavity loading phase angle under heavy beam loading. The longitudinal coupled-bunch instability may be reduced

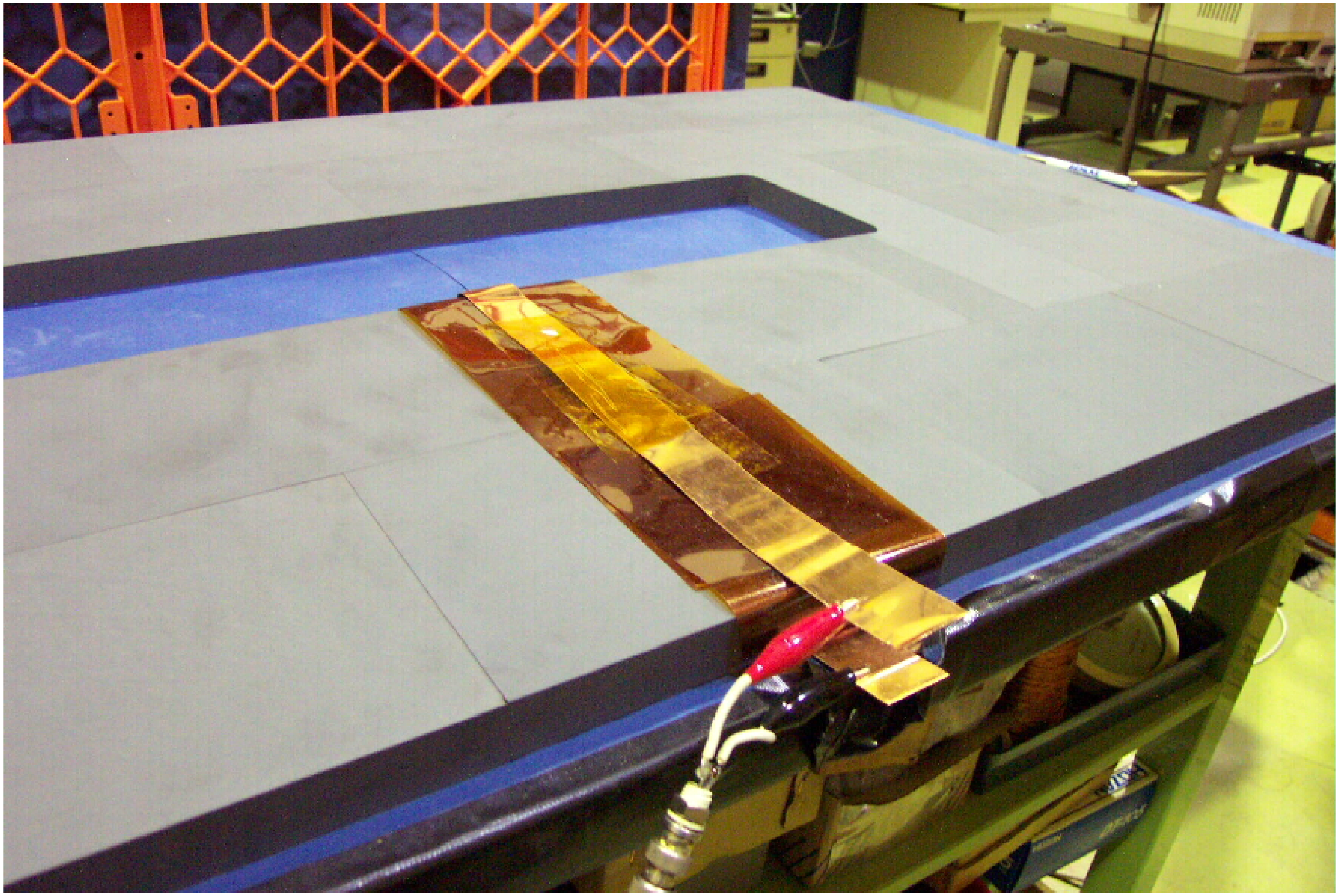
(4) The Q-value can be increased up to more than 10(Q>10) by a radial gap with cut-core configuration.

(5) Fabrication of a large core is possible because the core is formed by winding the very thin tapes.



Typical characteristics of Ni-Zn ferrite and Magnetic Alloy(FINEMET).

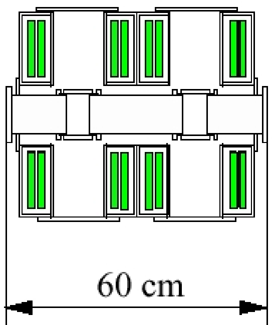
Courtesy of Y. Kuno (Osaka)



Yoshitaka Kuno
Osaka University

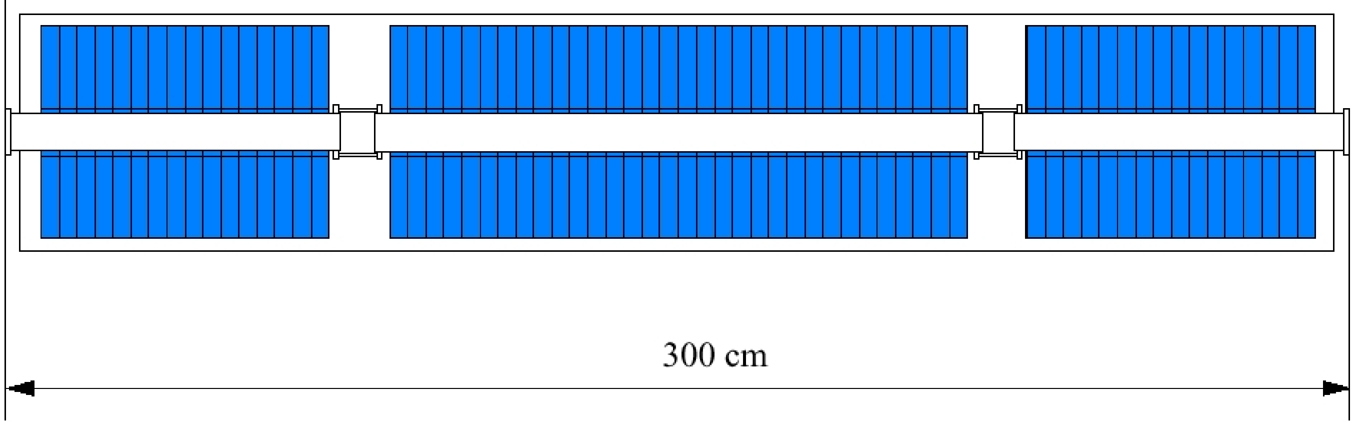
MA vs. ferrite

MA-loaded Cavity



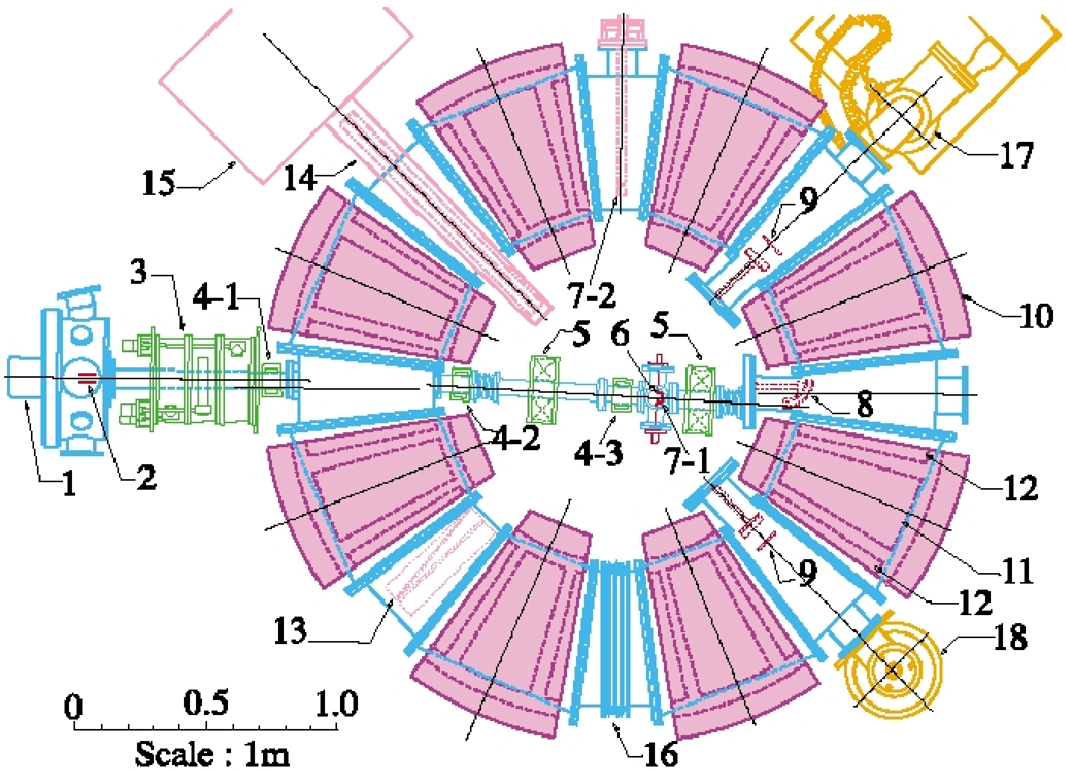
	MA	Ferrite
RF Voltage	~40kV	~40kV
No. of Cores	12	68
Total length	0.6m	3m

Ferrite-loaded Cavity



Yoshitaka Kuno
Osaka University

PoP proton FFAG accelerator



1: ion source
2: chopper electrode
3: triplet-quadrupole magnet
4: steering magnet
5: solenoid magnet
6: beam slit
7: Faraday cup
8: septum electrode
9: bump electrode
10: sector magnet
11: F-magnet pole
12: D-magnet pole
13: beam position monitior
14: RF cavity
15: RF amplifier
16: vacuum bellows
17: turbo molecular pump
18: cryopump

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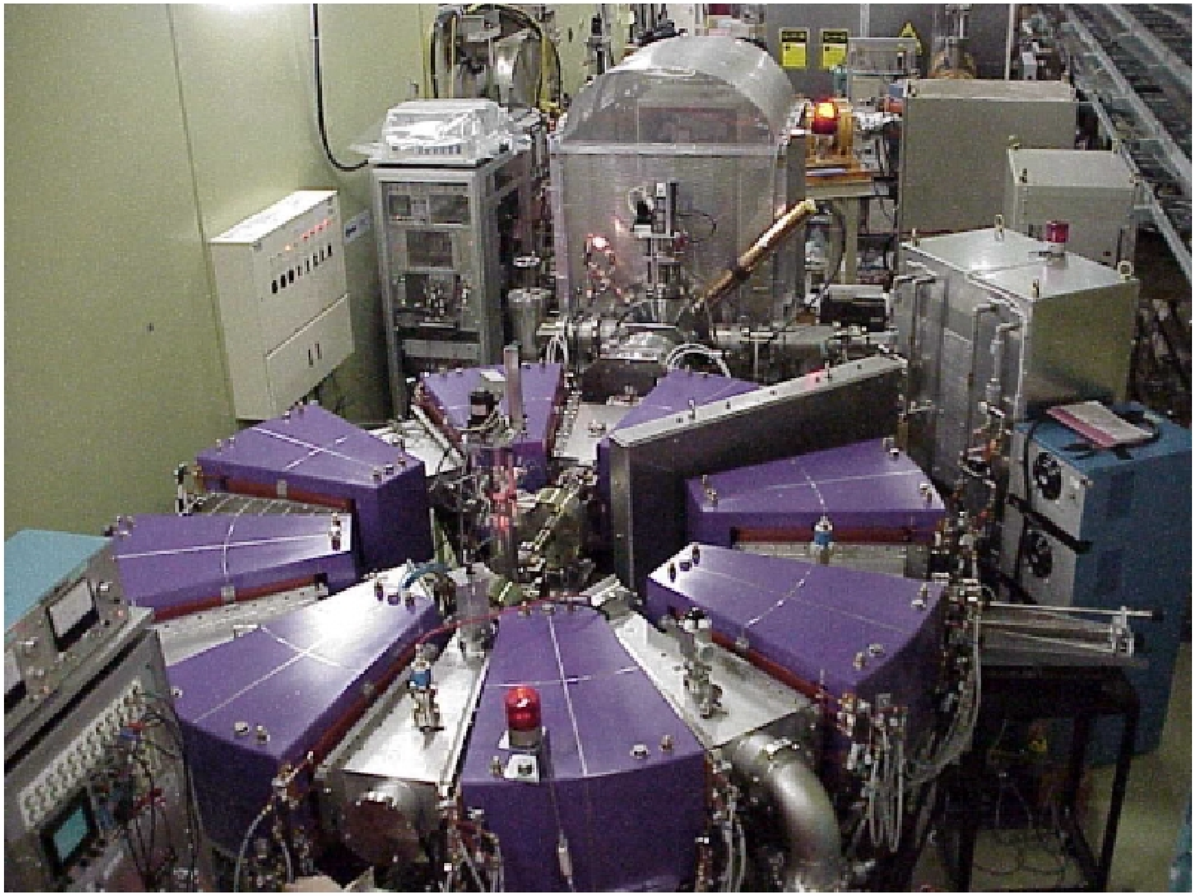
PoP proton FFAG model



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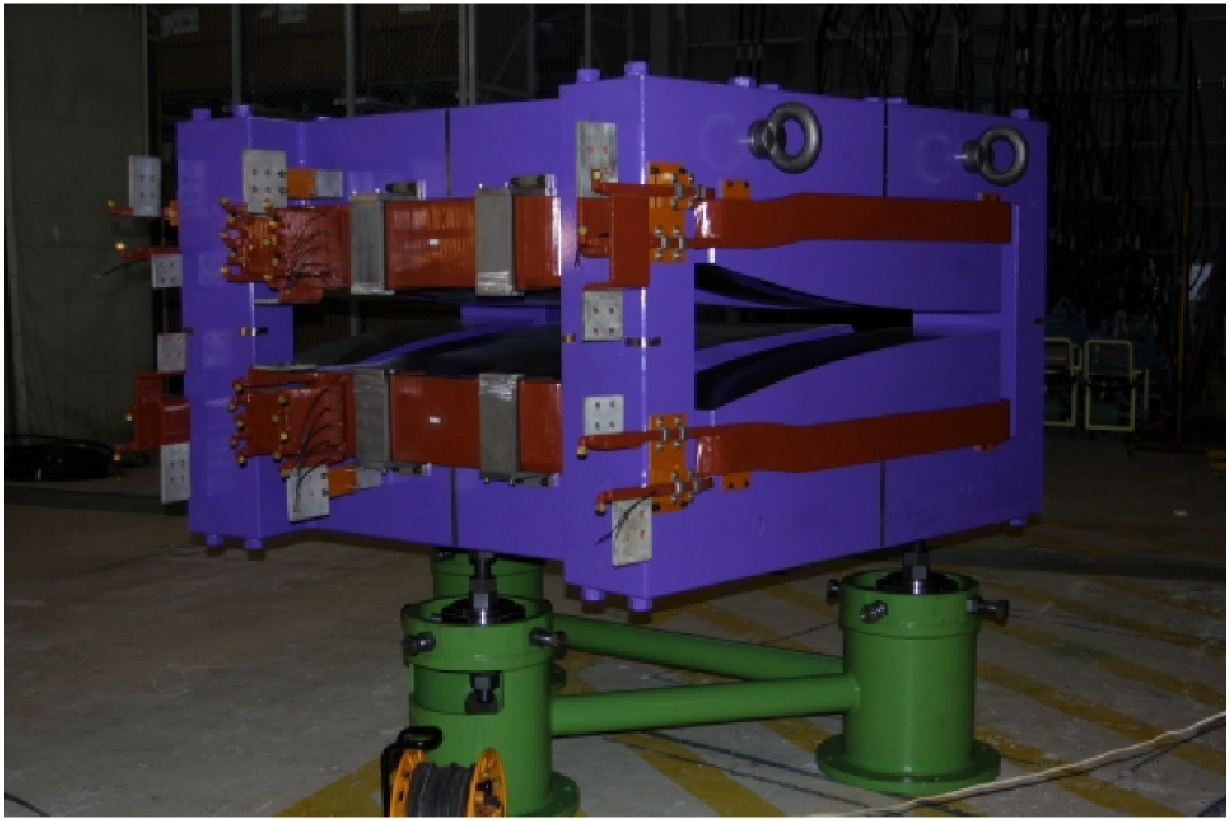
Magnet of 150-MeV proton FFAG



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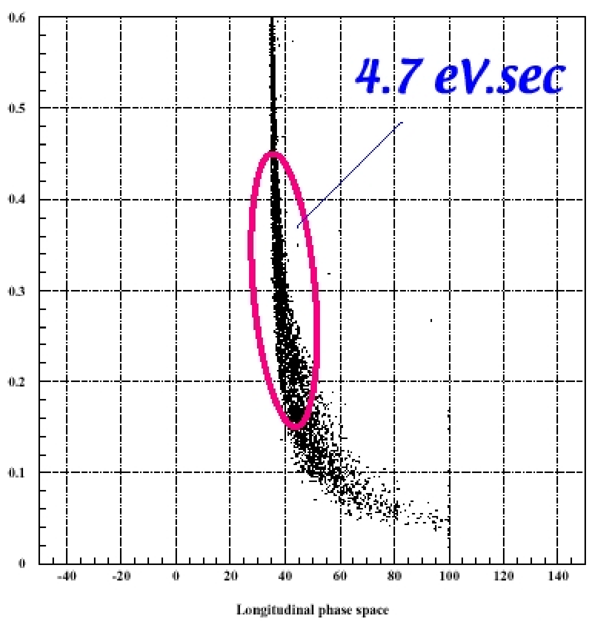
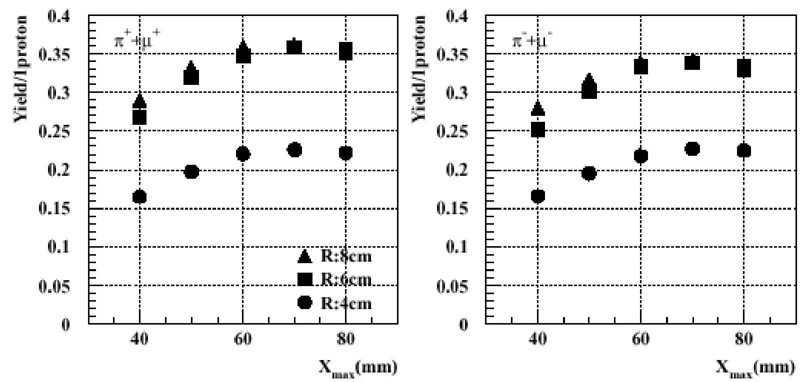
Accelerator Scenario - FFAG Option

Direct Acceleration by Low Frequency RF
No Phase Rotation, No Cooling





$\Delta p/p = +-50\%$@300MeV/c, A=0.01-0.02πm.rad

~ 0.3muons / proton @ 50-GeV PS

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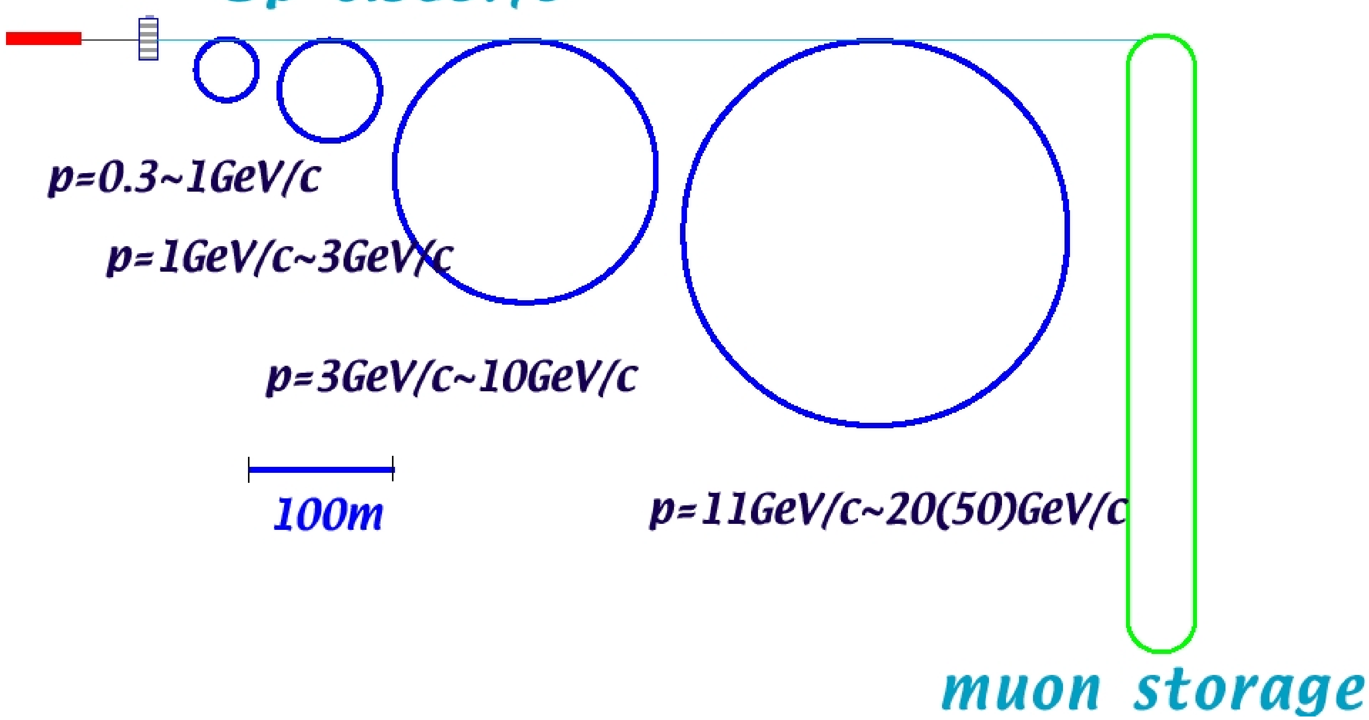
Accelerator Scenario - FFAG Option

(1)Low Freq.(~MHz) & High Gradient RF E> 1MV/m

(2)Acceptance : Trans.:0.01-0.02πm.rad, Long.ΔP/P~+-50% @p=0.3GeV/c



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Parameters

Conventional

based on PJK scheme

proton driver	50GeV(1-4MW)
phase rotation	80MeV/c
cooling	100m
acceleration	
linac	2GeV
FFAG	2-11GeV
RCL	11-20(50)GeV
storage ring	C~1000m

Intensity

phase 1	10^{20} muon/y (1MW)
phase 2	4×10^{20} muon/y (4MW)

New Scheme

no phase rotation,no cooling

proton driver	50GeV(1-4MW)
Accelerator	
FFAG-0(PRISM)	0.3-1GeV
FFAG-1	1-3 GeV
FFAG-2	3-10 GeV
FFAG-3	10-20 GeV
storage ring	C~800m

Intensity

phase 1	3×10^{20} muon/y(1MW)
phase 2	1.2×10^{21} muon/y(4MW)

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FFAG Parameters

momentum(GeV/c)	0.3~1	1~3	3~10	10~20
number of sector	16	32	64	120
k number	15	63	220	280
average radius(m)	10	30	90	200
max. B field(T)	2.8	3.6	5.4	6.0
tune	5.826	13.704	27.911	22.333
	4.590	4.048	4.089	6.333
drift length(m)	2.120	3.299	5.046	5.668
BF length(m)	1.065	1.575	2.169	2.685
BD length(m)	0.367	0.544	0.813	1.062
orbit excursion(m)	0.77	0.52	0.813	0.49
transition γ	4	8	14.9	16.8

Summary

FFAG is wonderful !

3rd Wordshop FFAG02 : Feb. 2002 at KEK

http://hadron.kek.jp/FFAG