Present Status of Neutrino Factory Studies as seen by CERN

H. Haseroth

for the

Neutrino Factory Working Group at CERN

A Basic Concept for a Neutrino Factory

⇒Proton driver

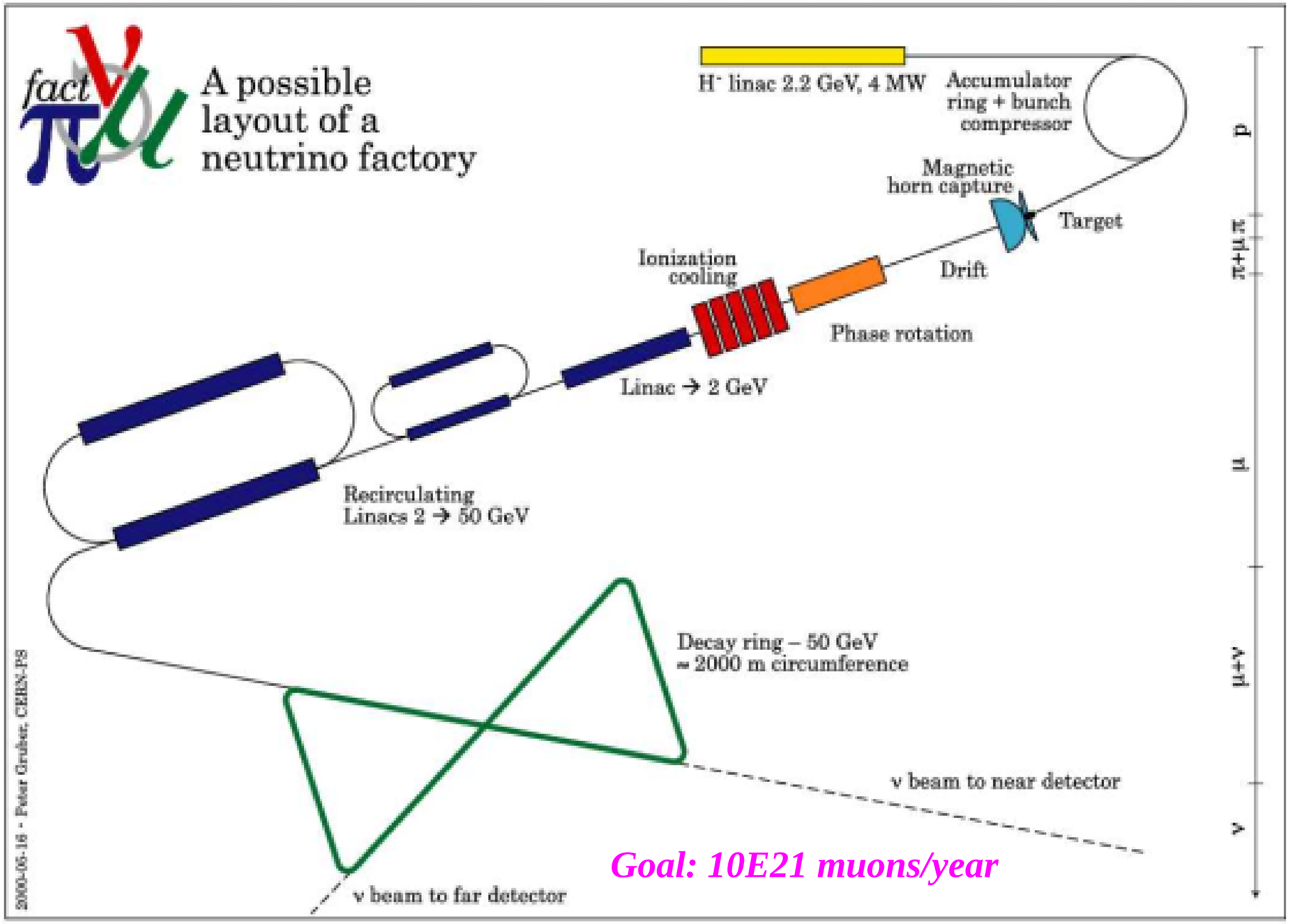
⇒High-power proton beam onto a target

⇒System for collection of the produced pions and their decay products, the muons.

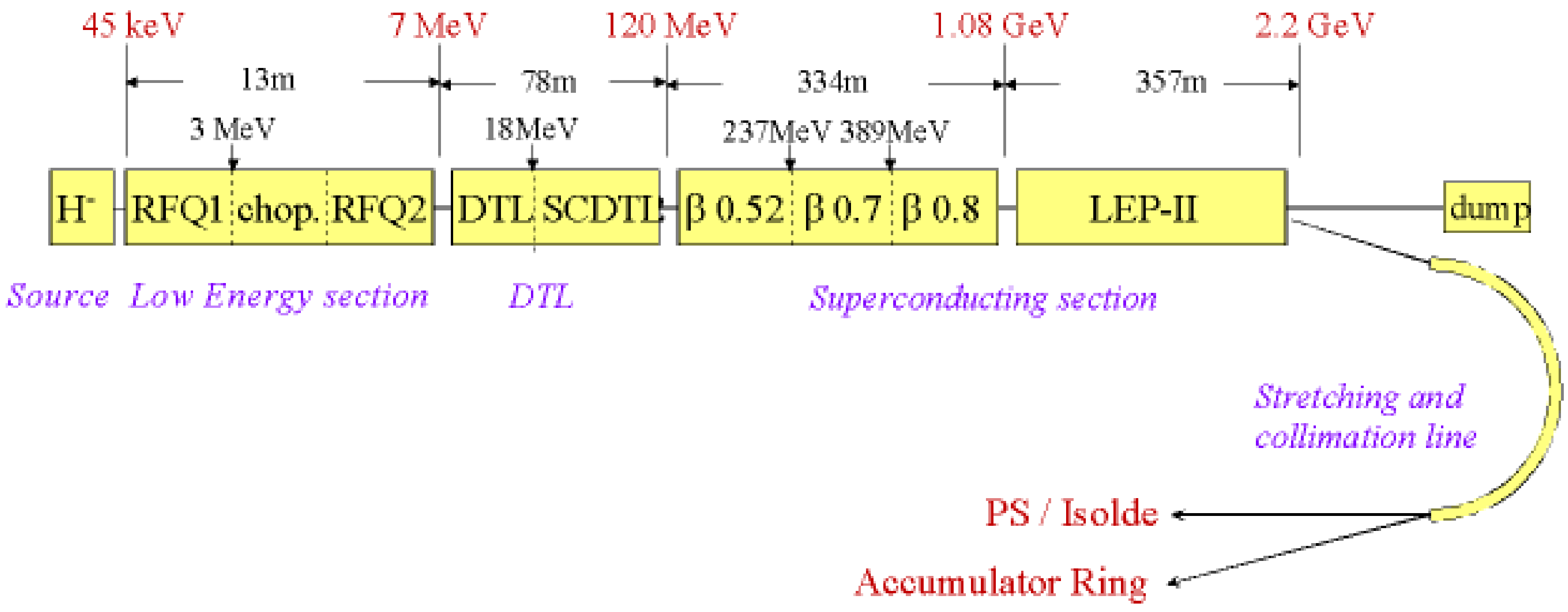
⇒Energy spread and transverse emittance may have to be reduced: “phase rotation” and ionisation cooling

⇒(Fast) acceleration of the muon beam with a linac and “RLAs” (Recirculating Linear Accelerators) or FFAGs (?)

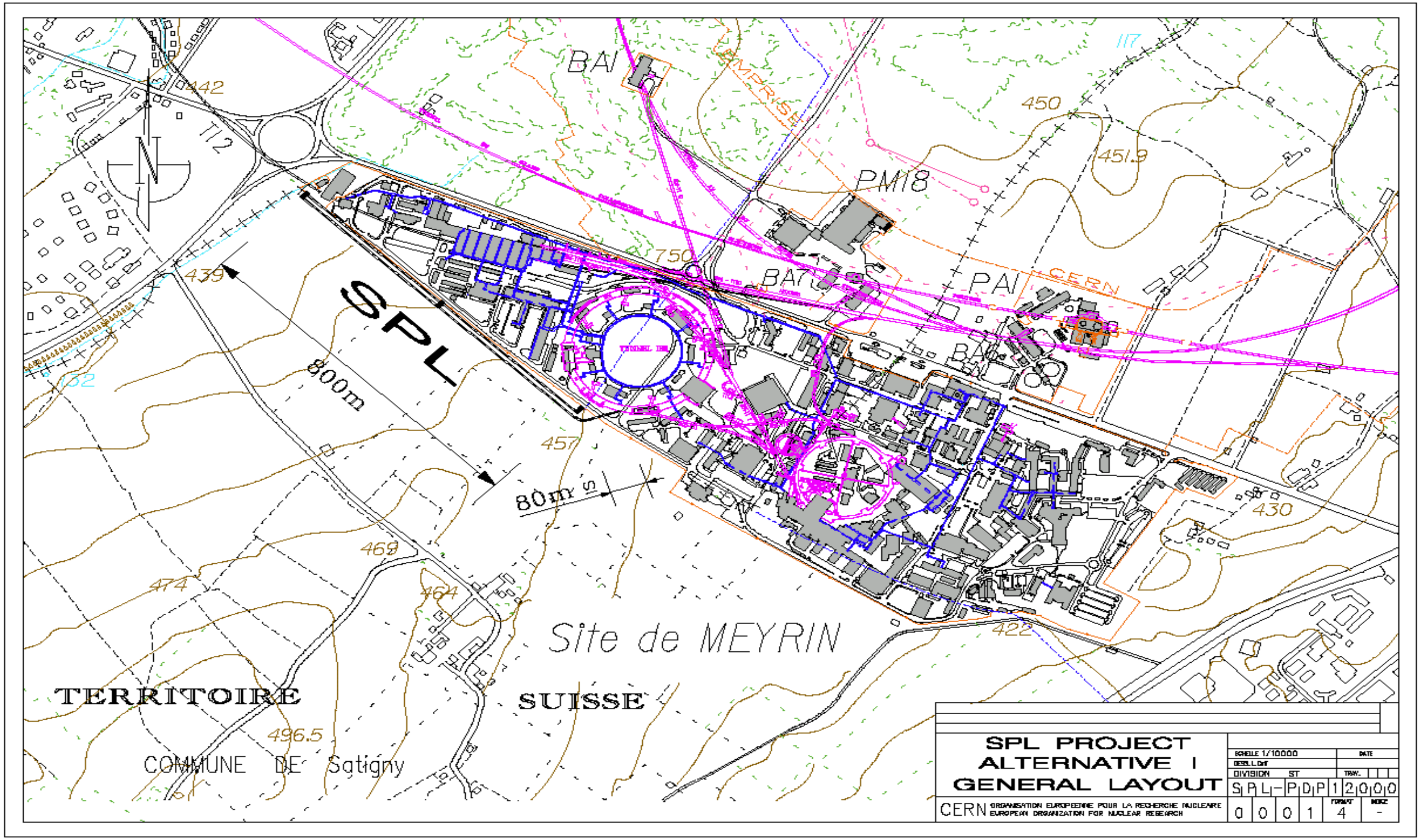
⇒Muons are injected into a storage ring (decay ring), where they decay in long straight sections in order to deliver the desired neutrino beams.


A possible
layout of a
neutrino factory
H⁻ linac 2.2 GeV, 4 MW
Accumulator
ring + bunch
compressor
Magnetic
horn capture
Target
Drift
Ionization
cooling
Phase rotation
Linac → 2 GeV
Recirculating
Linacs 2 → 50 GeV
Decay ring – 50 GeV
≈ 2000 m circumference
ν beam to near detector
ν beam to far detector
Goal: 10E21 muons/year
p
π+μ
μ
μ+ν
ν
2000-05-16 - Peter Gruber, CERN-PS

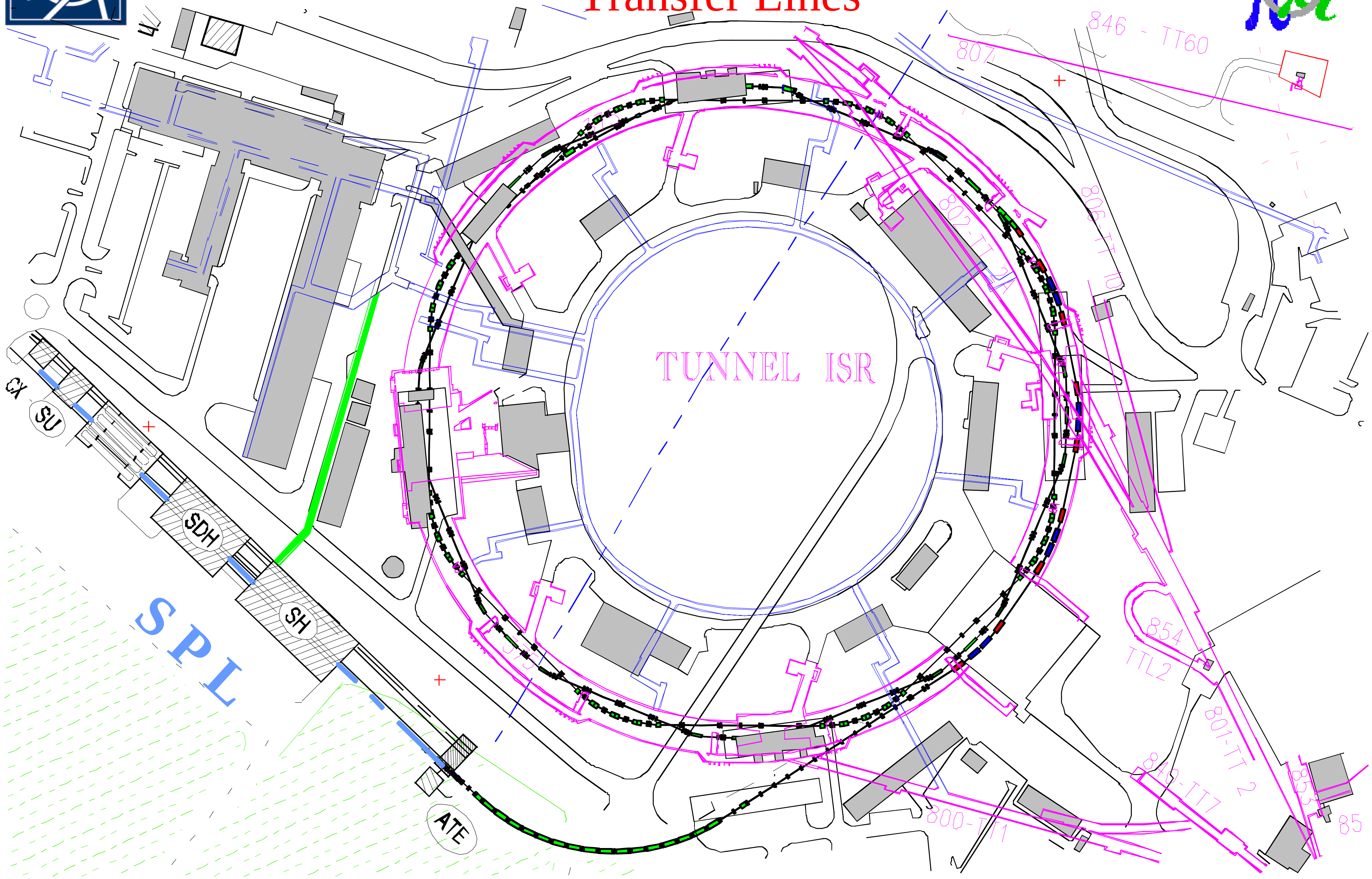
Schematic Layout of the SPL (4 MW of Beam Power)



The SPL on the CERN site



Complete Layout of Proton Driver Rings and Transfer Lines



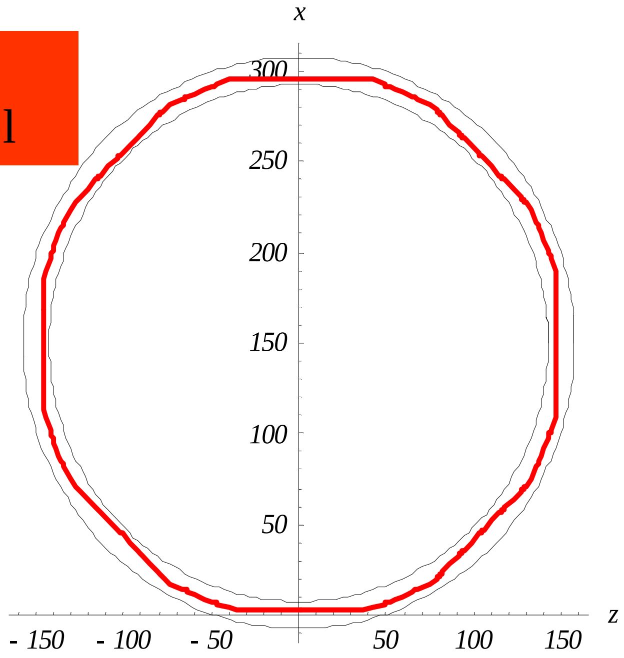
H. Haseroth for the NFWG at CERN

Thursday, April 18, 2002

MCOC Meeting at CERN

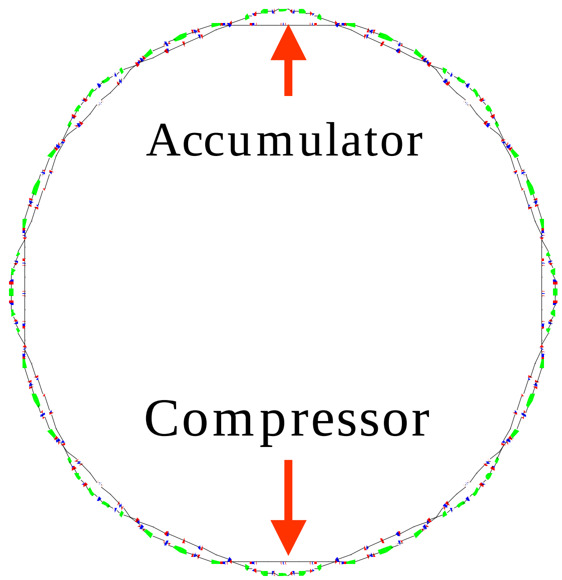
2.2 GeV RAL Accumulator

ISR tunnel



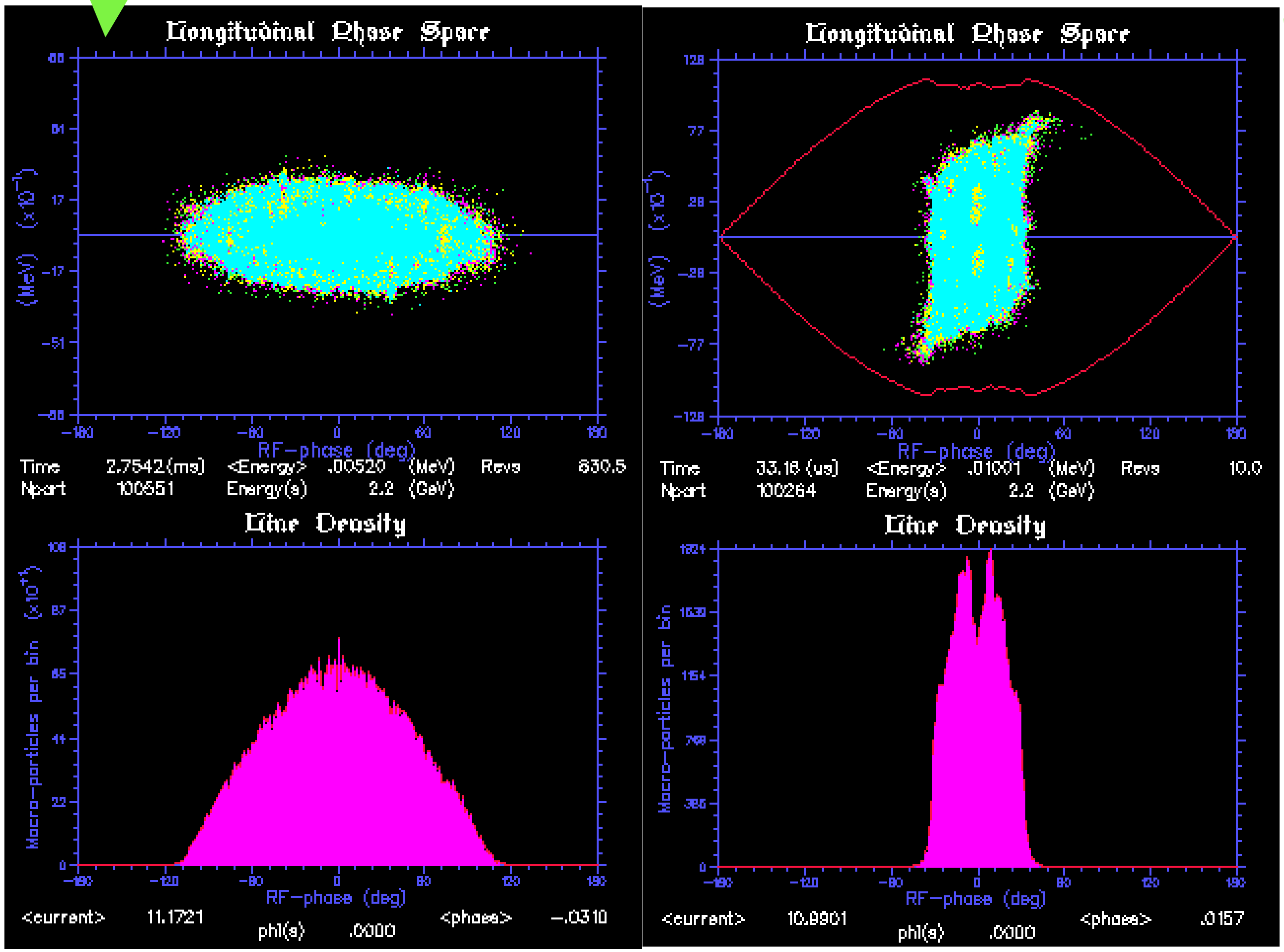
Mean ring radius=150 m

RAL Accumulator & CERN Compressor



in ISR Tunnel

Accumulation & Compression: No Major Problems with 2.27×10^{14} ppp



Non Proton Driver Activities

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

Simulation of the phase rotation (energy reduction), of the cooling channel and of the acceleration in the first linac. Concept of cooling experiment and simulations: Muon International Cooling Experiment (MICE).

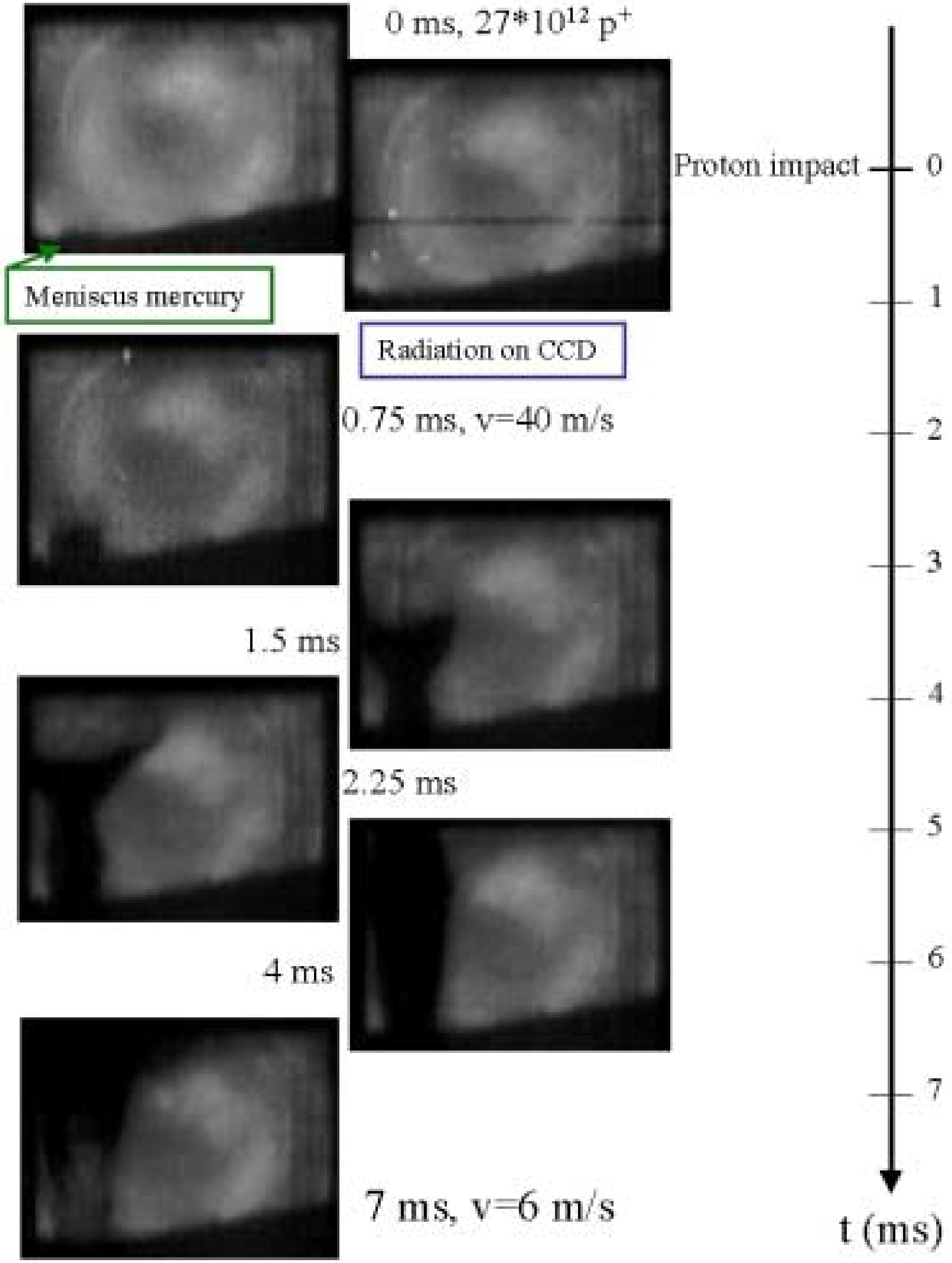
Simulation the RLAs (Recirculating Linear Accelerators) and of the Decay Ring

Work by ST for layout on the site

Detector locations being investigated

Thimble after use

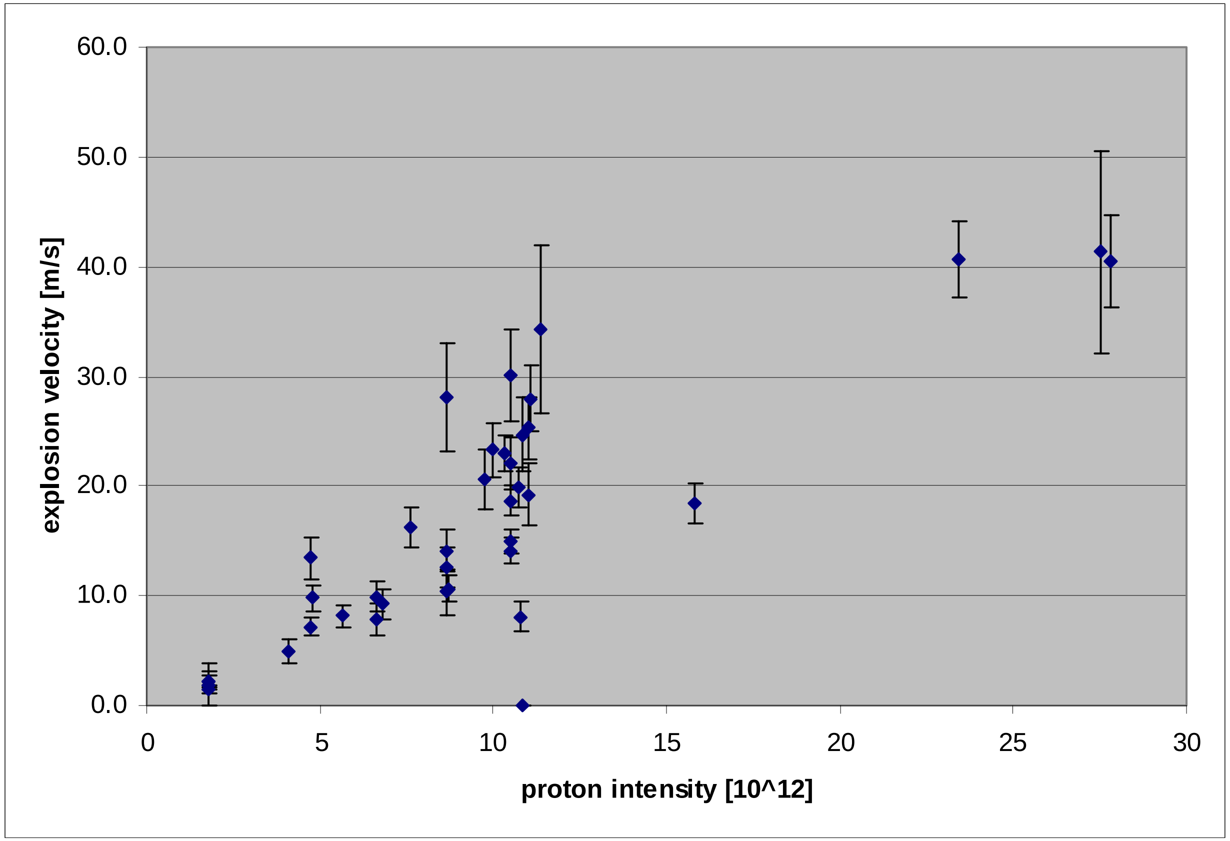
Mercury splash after beam pulse



Protons on Mercury

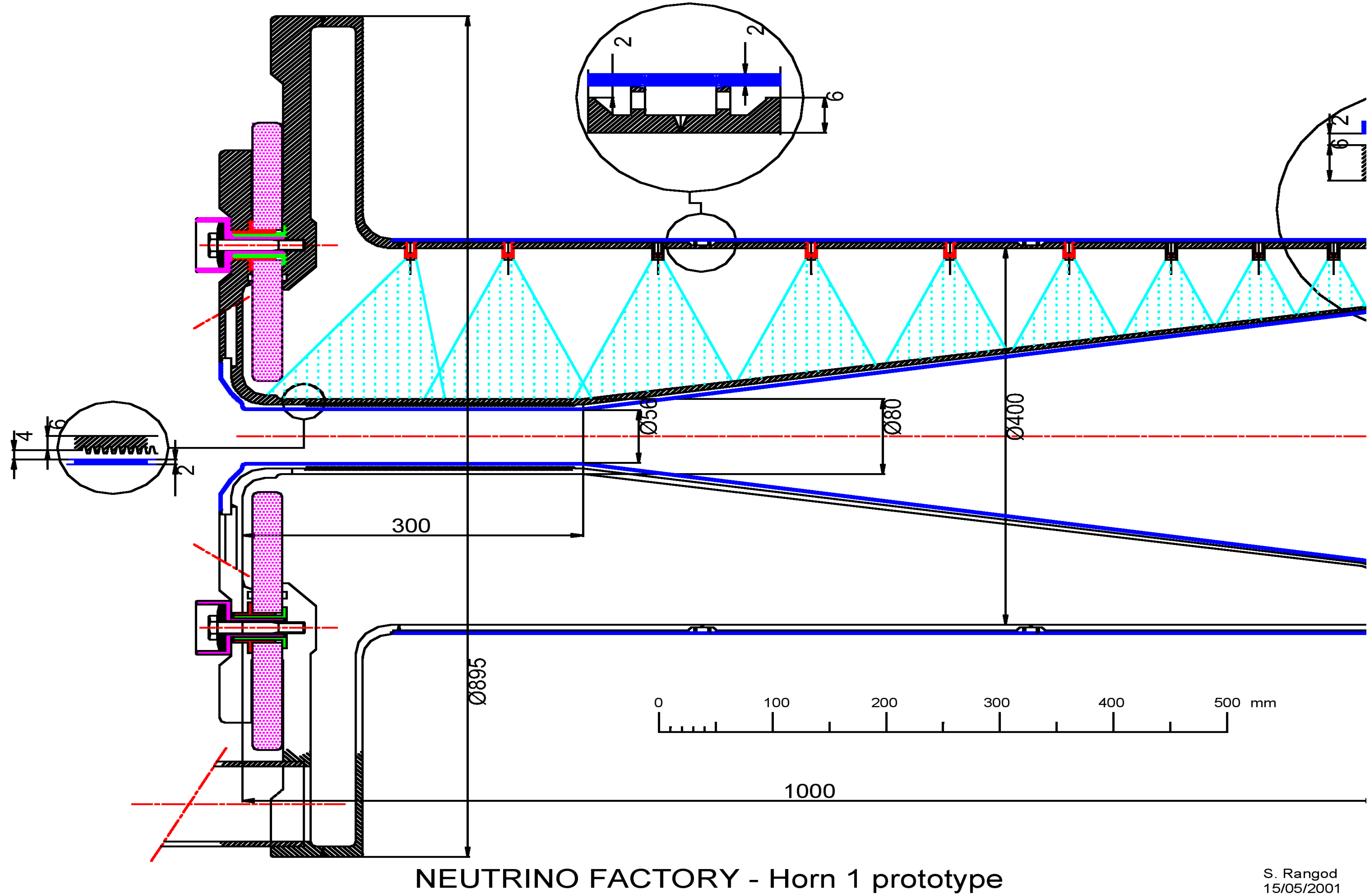
ISOLDE GPS, Aug. 2001

40 single pulse events at 1.4 GeV



PSB (NuFACT CERN)

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



2
2
6
6
2
6
4
6
2
Ø56
Ø80
Ø400
300
Ø895
0
100
200
300
400
500 mm
1000
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

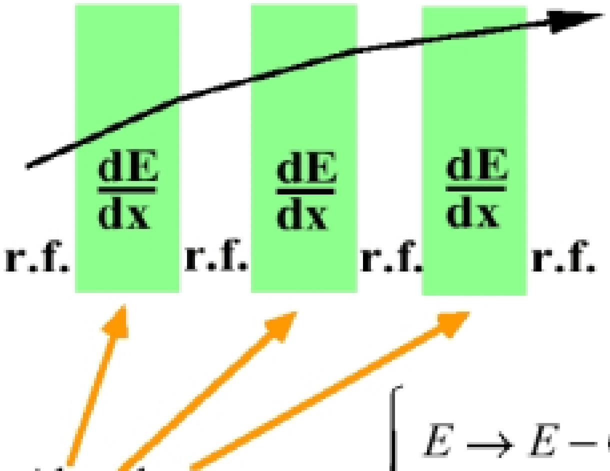
Dual water circuit (inner conductor with double skin)

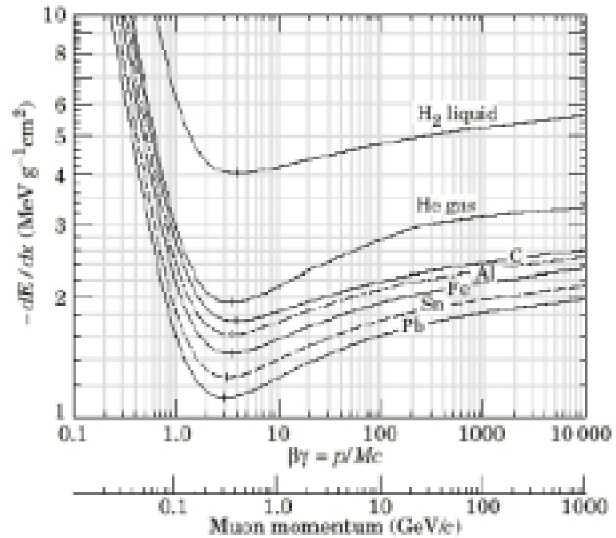
Horn ordered with central workshop.

Estimated construction time

>> end of February 2002

Ionization Cooling: Background





- Absorbers: $\begin{cases} E \to E - \left\langle \dfrac{dE}{dx} \right\rangle \Delta s \\ \theta \to \theta + \theta^{rms}_{space} \end{cases}$
- RF cavities between absorbers replace ΔE
- Net effect: reduction in $p_\perp$ w.r.t. $p_{\|}$, i.e., transverse cooling:

$$\frac{d\epsilon_N}{ds} = -\frac{1}{\beta^2}\left\langle\frac{dE_\mu}{ds}\right\rangle\frac{\epsilon_N}{E_\mu} + \frac{\beta_\perp (0.014\ \text{GeV})^2}{2\beta^3 E_\mu m_\mu X_0}$$

$\Rightarrow$ want strong focusing, large X_0, and low E_μ

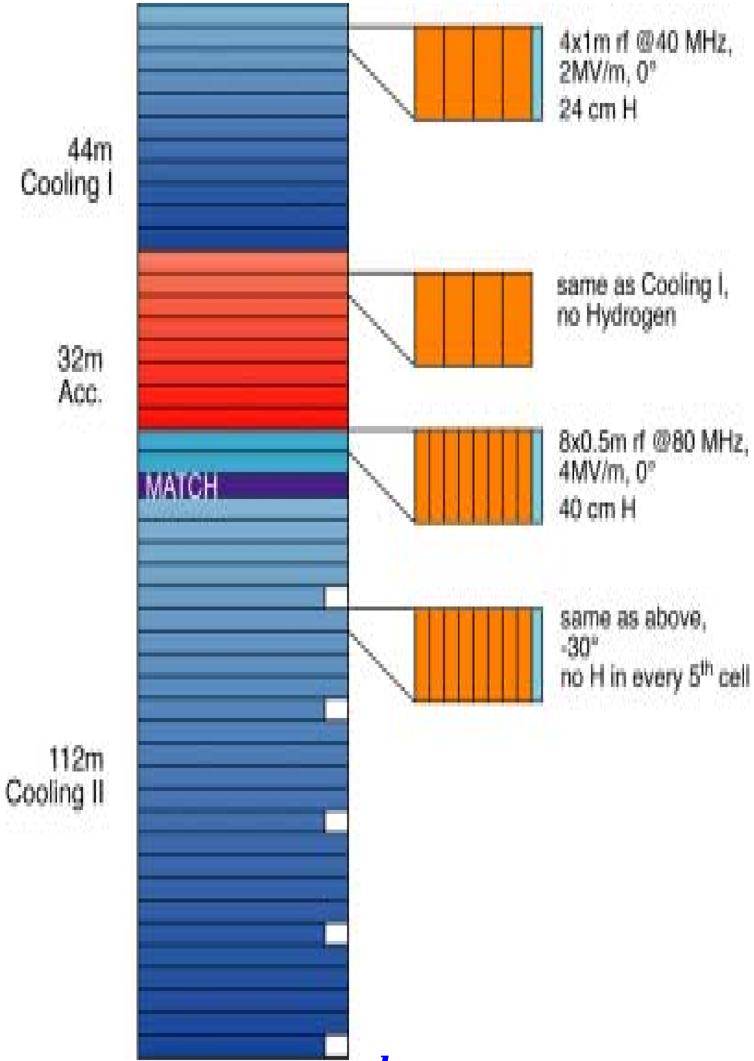
Note: The **physics** is not in doubt

$\Rightarrow$ in principle, ionization cooling **has** to work!

... but in practice it is subtle and complicated so a test is important

Layout of 40/80 MHz Cooling Channel

beam in

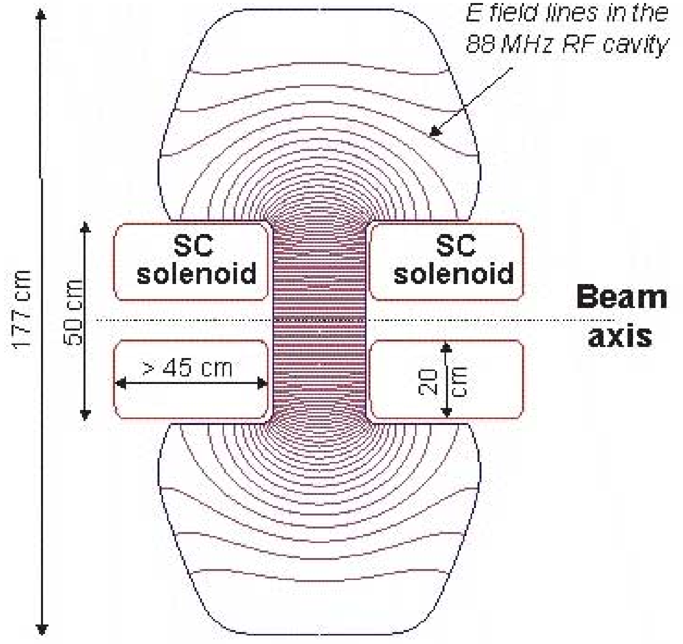


beam out

	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

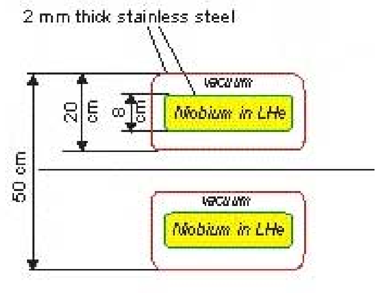
Table 3 Main parameters of the capture, phase rotation, cooling and acceleration section

88 MHz test cavity



88 MHZ TESTCAVITY

SUPERCONDUCTING
SOLENOID
ASSEMBLY

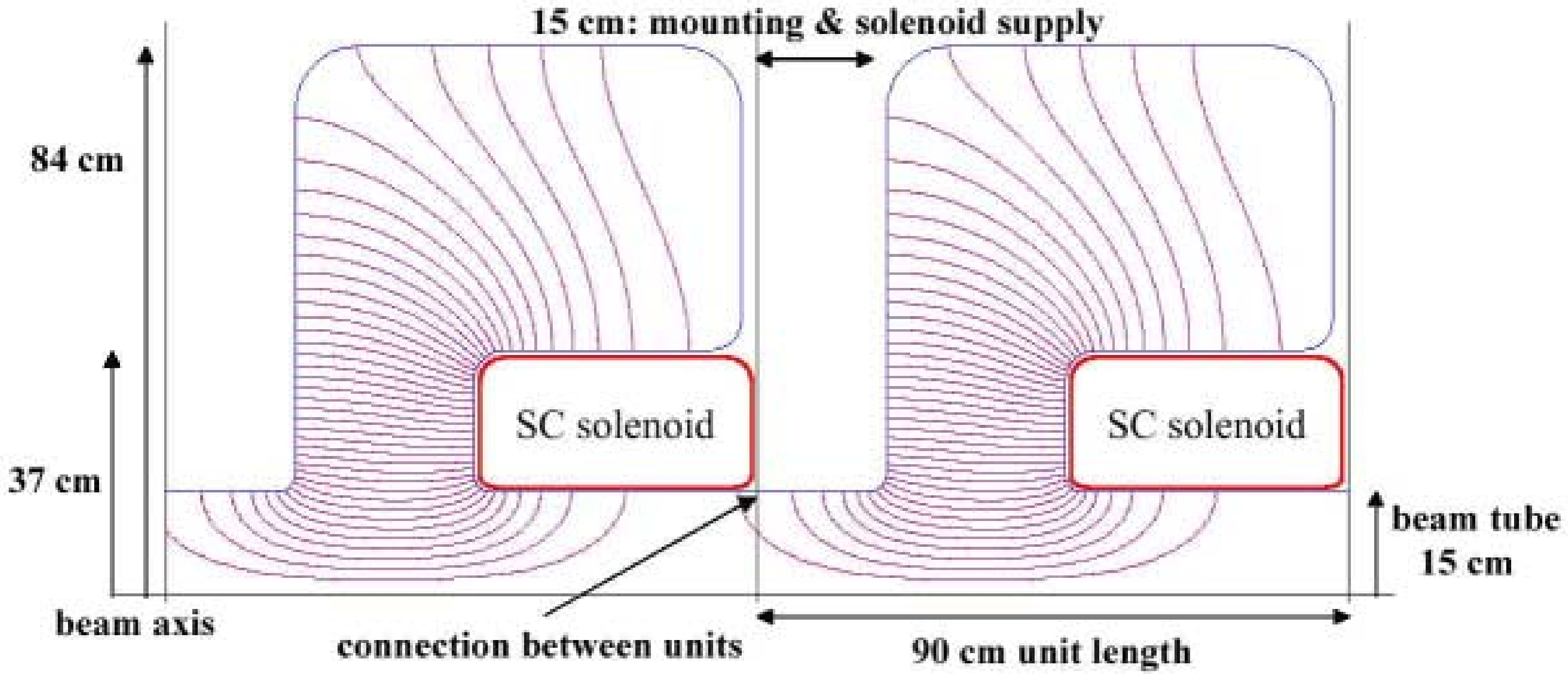


- An 88 MHz test cavity for high gradient is being prepared (2 MW amplifier driving a modified 114 MHz PS cavity)
  - High RF gradient without solenoid: end 2001
  - RF test with solenoid: mid-2002

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	

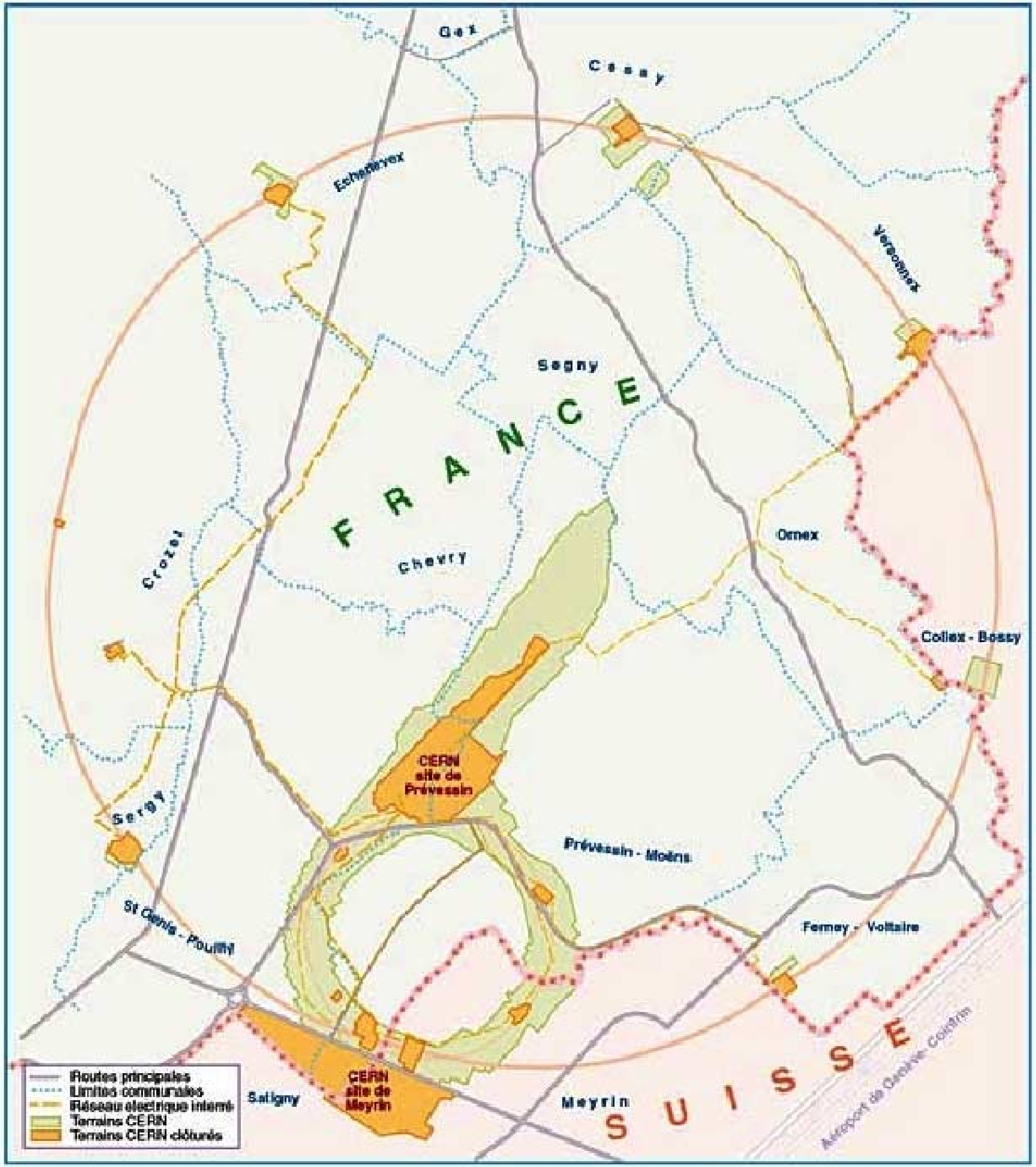
	RLA1	RLA2
Injection energy, GeV	2	10
Extraction energy, GeV	10	50
Number of turns	4	4
Length of linacs (2), m	680	3813
Rf frequency, MHz	352	352
Bending radius in arc, m	5	25
Mean arc radius, m	20	100
Circumference, m	806	4442
Peak voltage gradient per linac, MV/m	7.4	7.4
Normalised admittance, mm rad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

Parameters of Recirculating Linacs (RLAs)

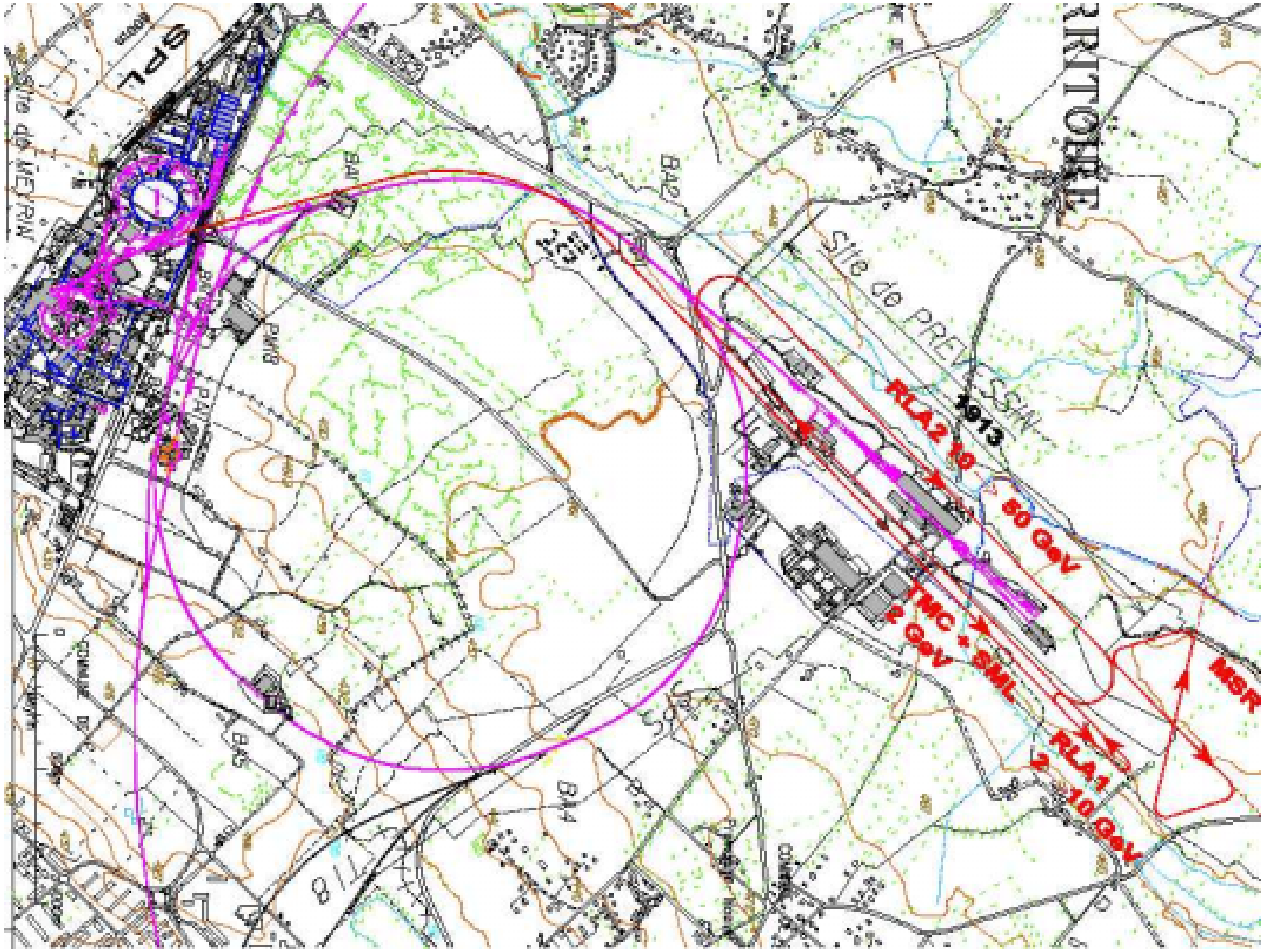
Design momentum, GeV	50
Muon fluence, s^{-1}	10^{14}
Configuration	Triangular
Normalised beam divergence in SS at σ_ε, mrad	0.1
Normalised beam emittance (σ_ε), mm rad	1.67
Aperture limit	3 σ_ε
Relative rms momentum spread	0.005
Bunch spacing, mm	851
Dipole field, T	6
Total length of straight sections,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

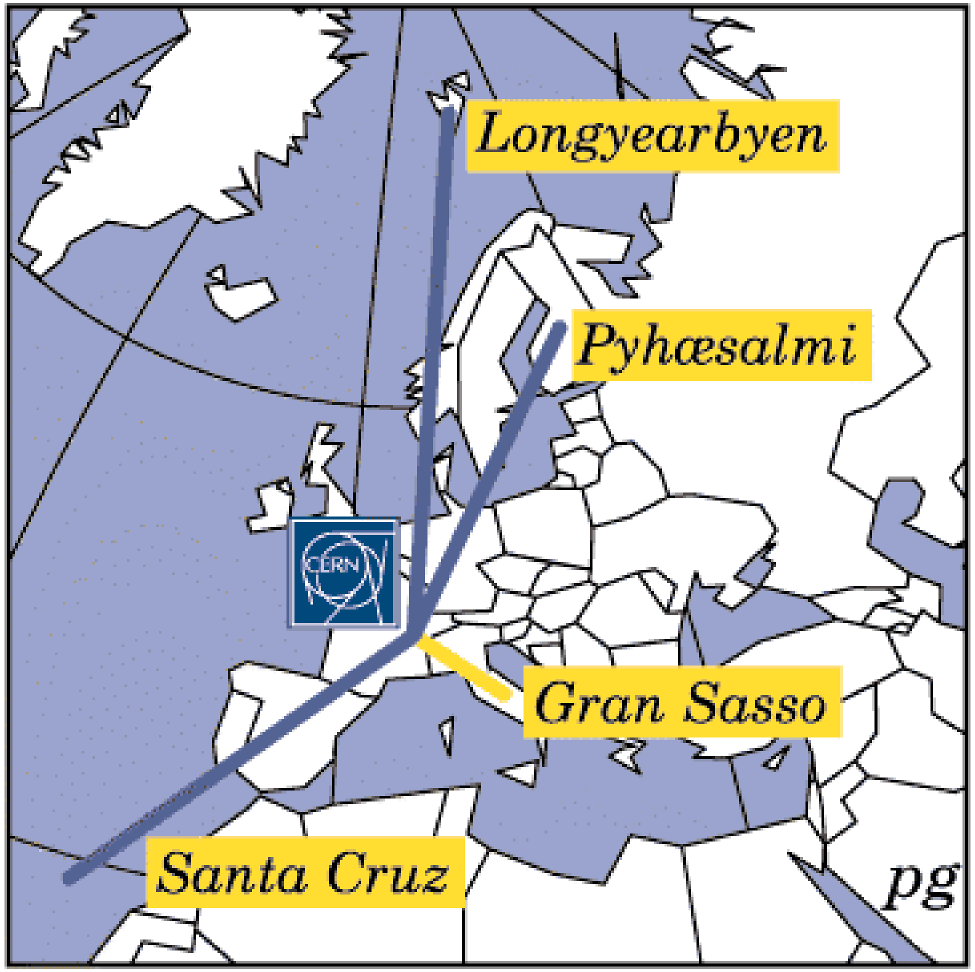
Parameters of Decay Ring

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
Routes principales
Limites communales
Réseau électrique interne
Terrains CERN
Terrains CERN clôturés
Satigny
CERN site de Meyrin
Meyrin
SUISSE
Aéroport de Genève Cointrin

Preliminary Layout of Neutrino Factory




Longyearbyen
Pyhæsalmi
Gran Sasso
Santa Cruz
pg

U.S. νFac Feasibility Studies

Have established (with detailed conceptual engineering)

- that a Neutrino Factory is technically feasible
- likely performance, cost, cost drivers, needed R&D

Study	FS I	FS II
Requestor	Fermilab	Brookhaven
Duration	6 months	12 months
Finished	June, 2000	June, 2001
Target	C	Hg jet
Phase rotation	"distorting"	"nondistorting"
# Induction linacs	1	3
Cooling lattices (baseline)	FOFO	SFOFO
(alternate)	Single-Flip	Double-Flip
Storage-ring energy	50 GeV	20 GeV
# RLAs	2	1
ν_e / 10^7 s / straight / MW	2×10^{19}	1.2×10^{20}

(partial FS II author list)

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Indicative (not definitive!) FS II cost estimate

System	Sum ($M)	Others[a] ($M)	Total ($M)
Proton Driver	167.6	16.8	184.4
Target Systems	91.6	9.2	100.8
Decay Channel	4.6	0.5	5.1
Induction Linacs	319.1	31.9	351.0
Bunching	68.6	6.9	75.5
Cooling Channel	317.0	31.7	348.7
Pre-accel. linac	188.9	18.9	207.8
RLA	355.5	35.5	391.0
Storage Ring	107.4	10.7	118.1
Site Utilities	126.9	12.7	139.6
Totals	1,747.2	174.8	1,922.0

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, safety issues, LiH option
- Reduction of cost due to better adjustment of absorbers
- Experimenters and accelerator physicists working together

A possible Muon Cooling Experiment

The main hardware is composed of the following items:

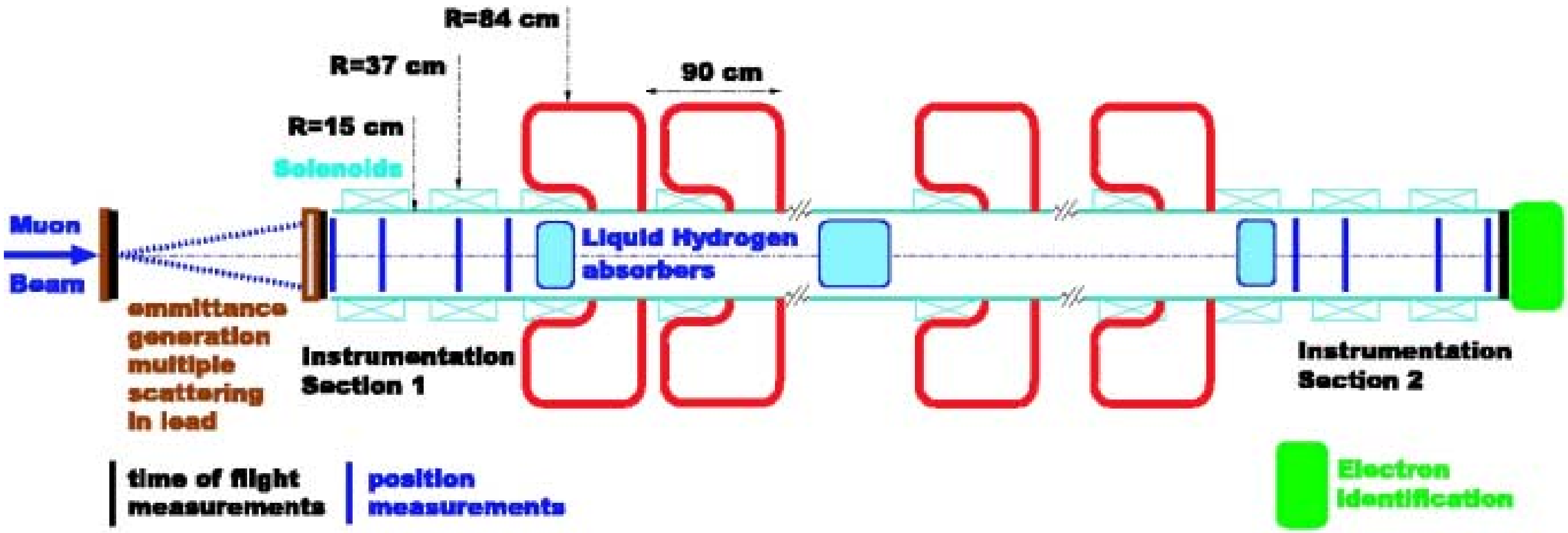
⇒ RF cavities

⇒ RF transmitters, modulators and charging supplies

⇒ Cavity sc solenoids

⇒ Hydrogen absorbers

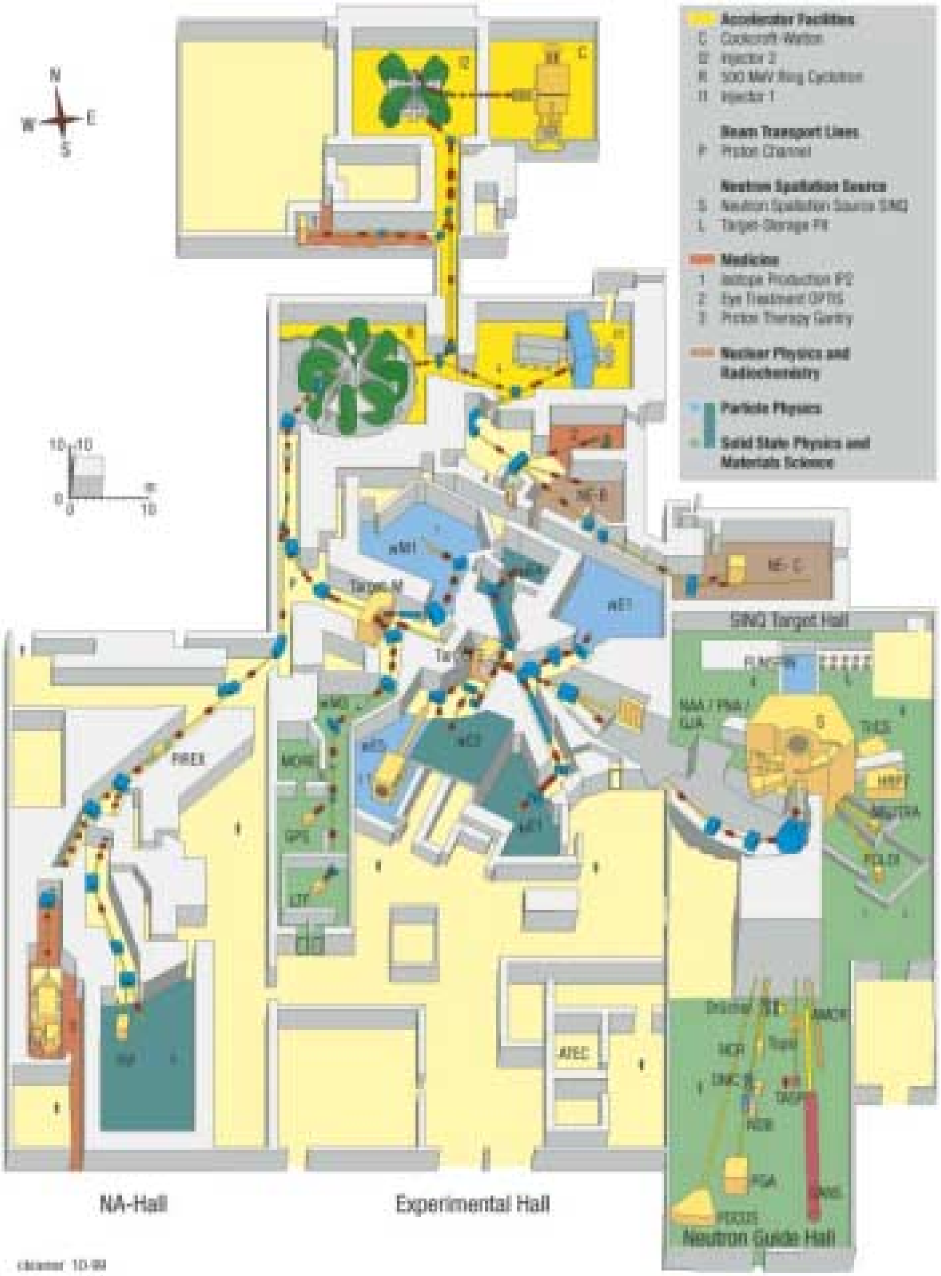
⇒ Measuring lines at input and output including sc solenoids and data acquisition



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

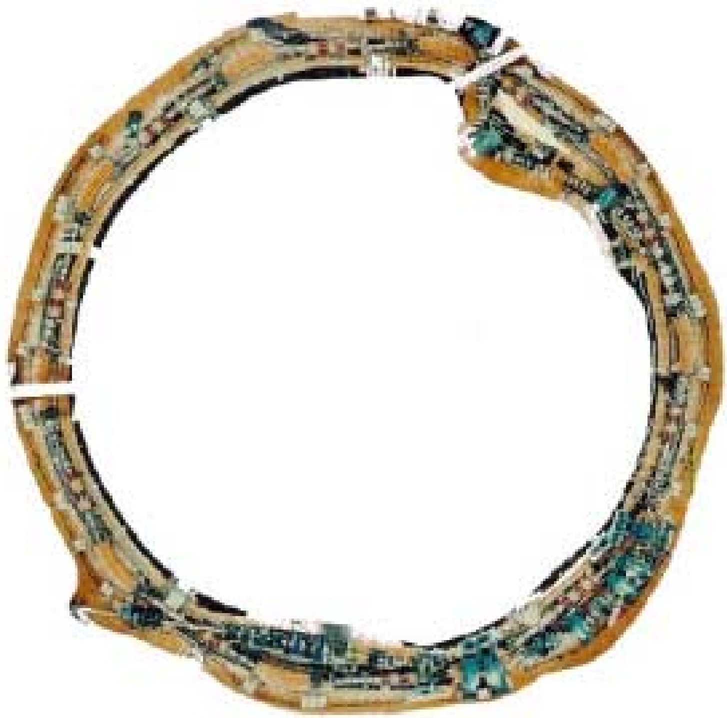
Cooling experiment at PSI?

Unofficial: "Will be difficult to host experiment", "Has held discussions with RAL to ensure that experiment takes place somewhere"



Cooling experiment at RAL?

ISIS



- 800 MeV synchrotron; 240kW
- 50 Hz, >100_s at close to maximum energy, 800 MeV
  ⇒ ISIS is cw for cooling experiment!
- 2 bunches, each 100ns long, separated by 230ns
- Each makes 200 turns during 100_s
- Target in ring could see 50MW for cooling experiment!

Unofficial: "Will encourage submission of proposal with technical help from RAL"

CLRC

New beamline

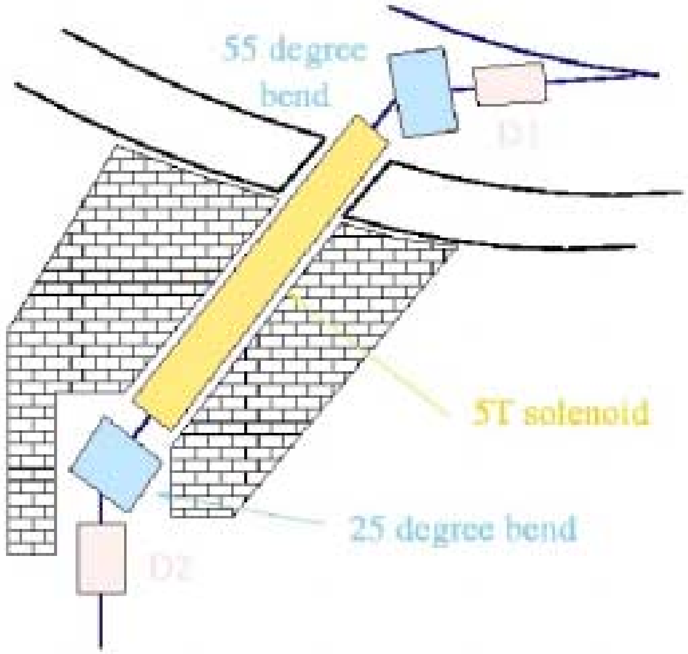
- Capture at 20/30°
- 15-20m long
- Main change: 5T, 10m, 20cm SC solenoid
- Muon transmission 2.0-2.5%
- Pion transmission ~0.1%

Simulations

For 10^7 protons at 800 MeV:

€ ~50/60 muons/bunch/turn

€ background ~2.5 pions at 300 MeV/c

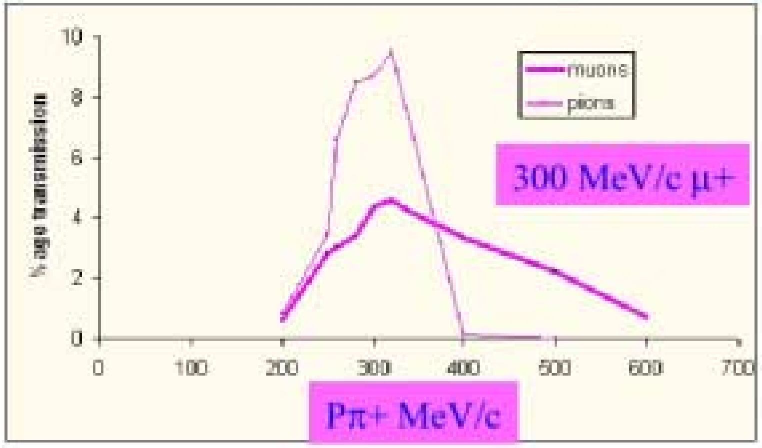


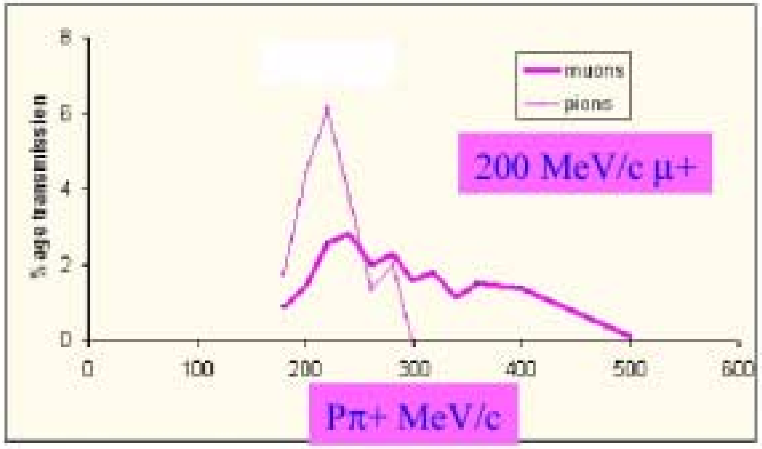
⇒ 1./1.2 × 10^6 muon/s

Background

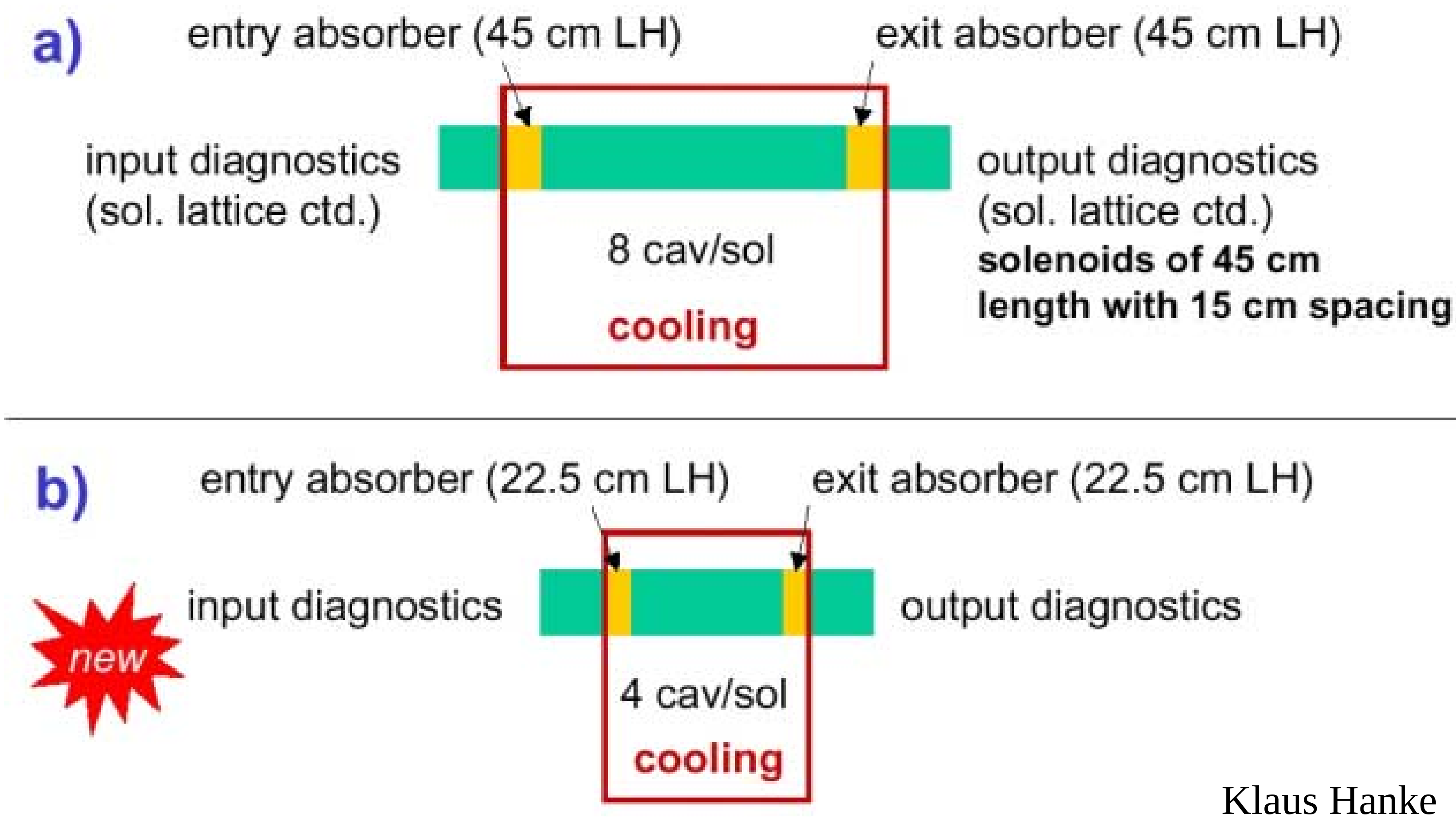
Could be a beam line from PSI

Background rejection using the solenoid

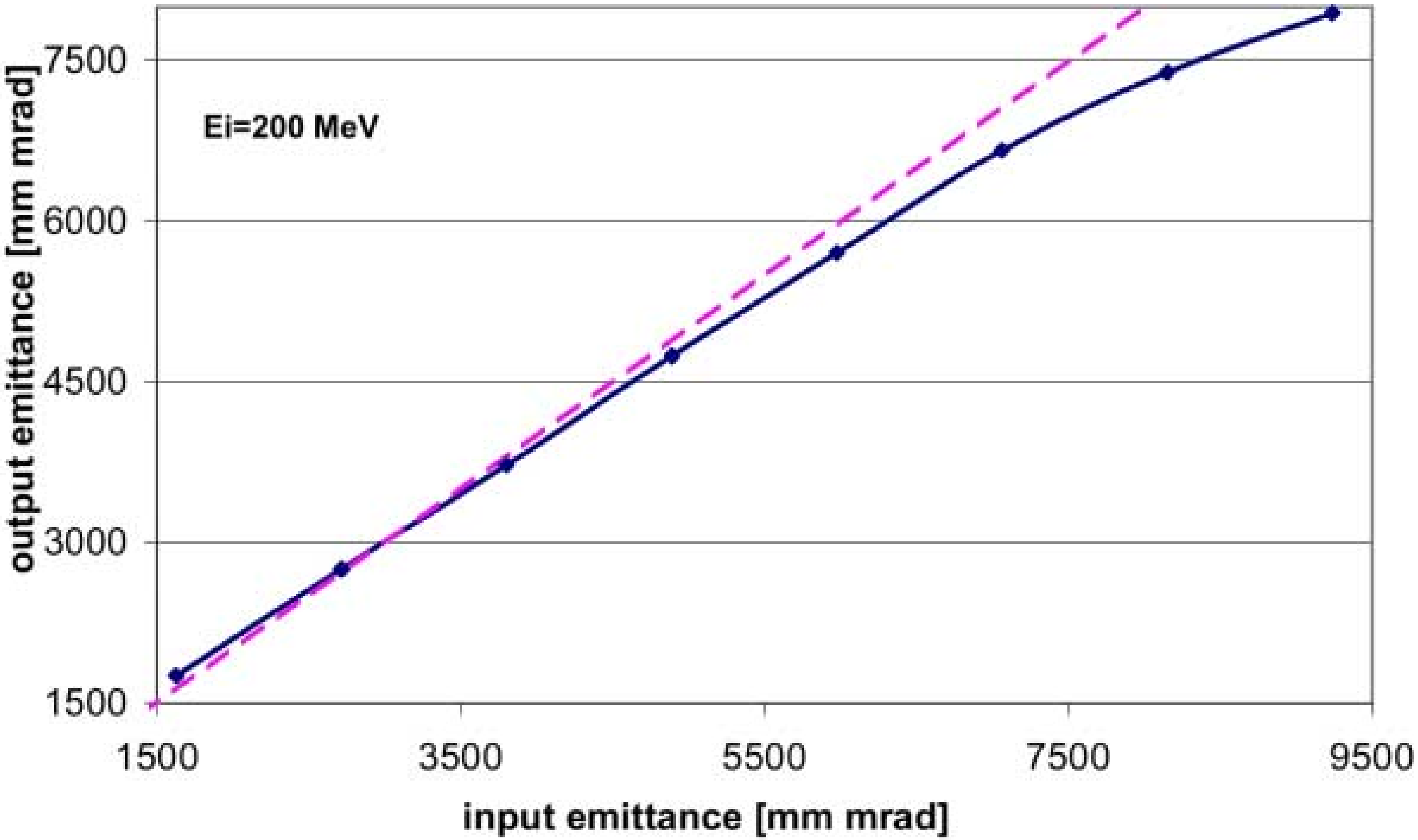


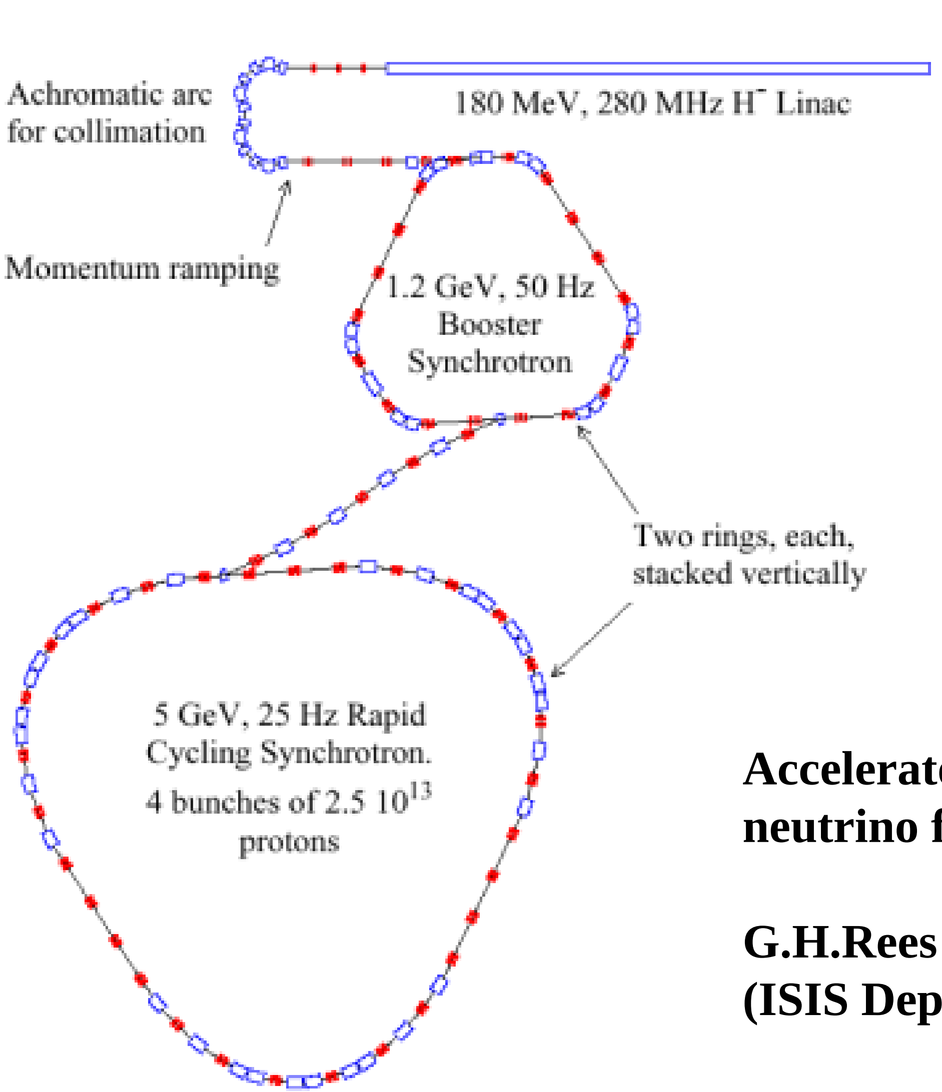


Lay-Out



Klaus Hanke

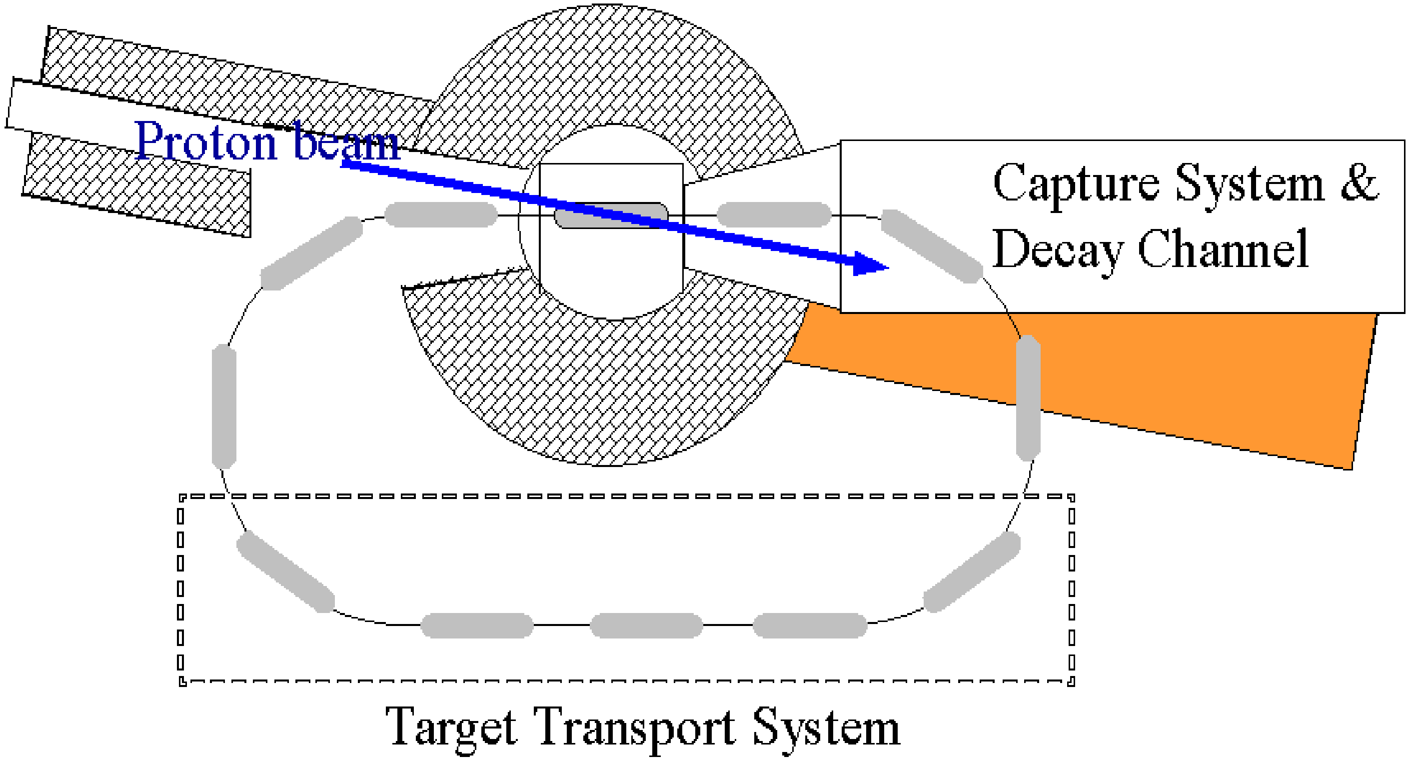

Ei=200 MeV
7500
6000
4500
3000
1500
output emittance [mm mrad]
1500
3500
5500
7500
9500
input emittance [mm mrad]



Accelerator studies for a neutrino factory Proton driver design

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

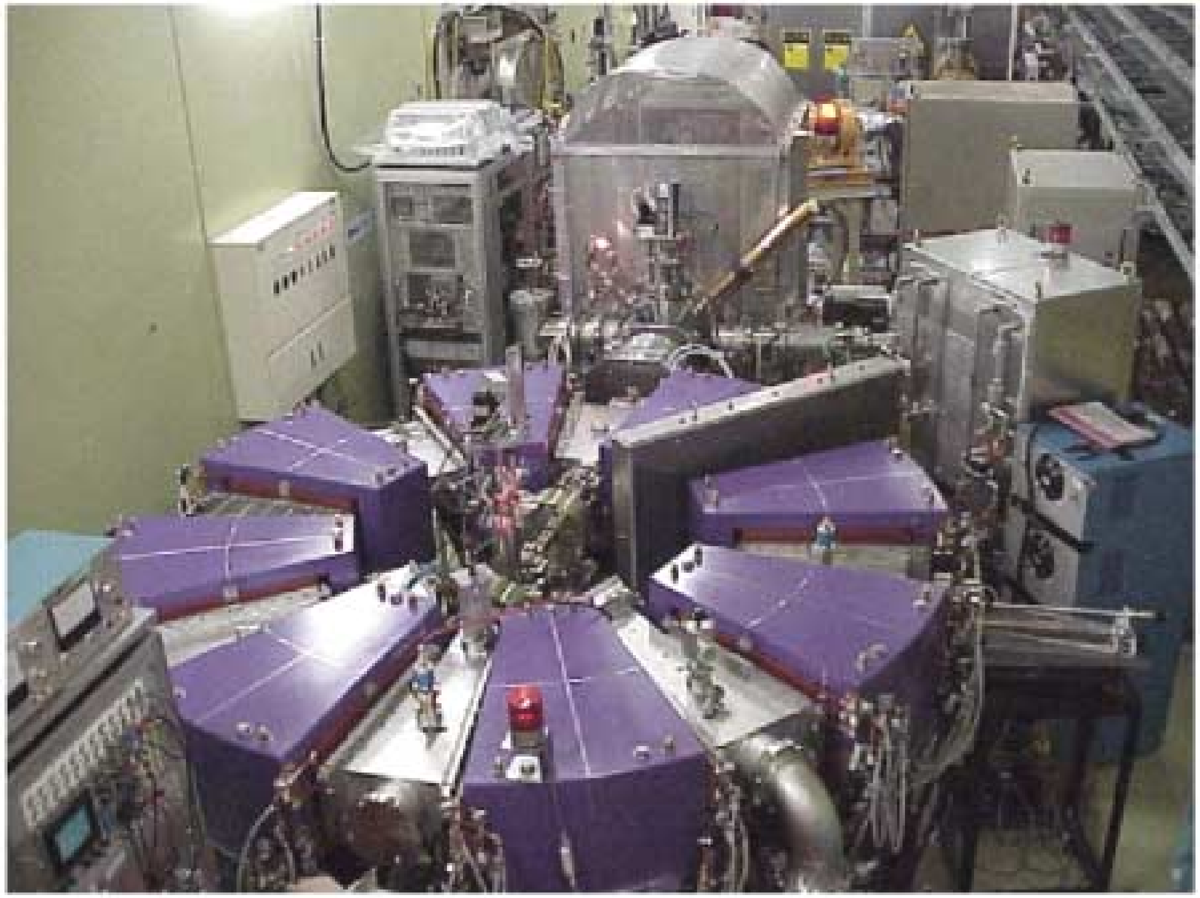
Schematic of the 5 GeV, 50 Hz RCS Design



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

Yoshitaka Kuno
Osaka University

PoP proton FFAG model *(1 MeV)*



Yoshitaka Kuno
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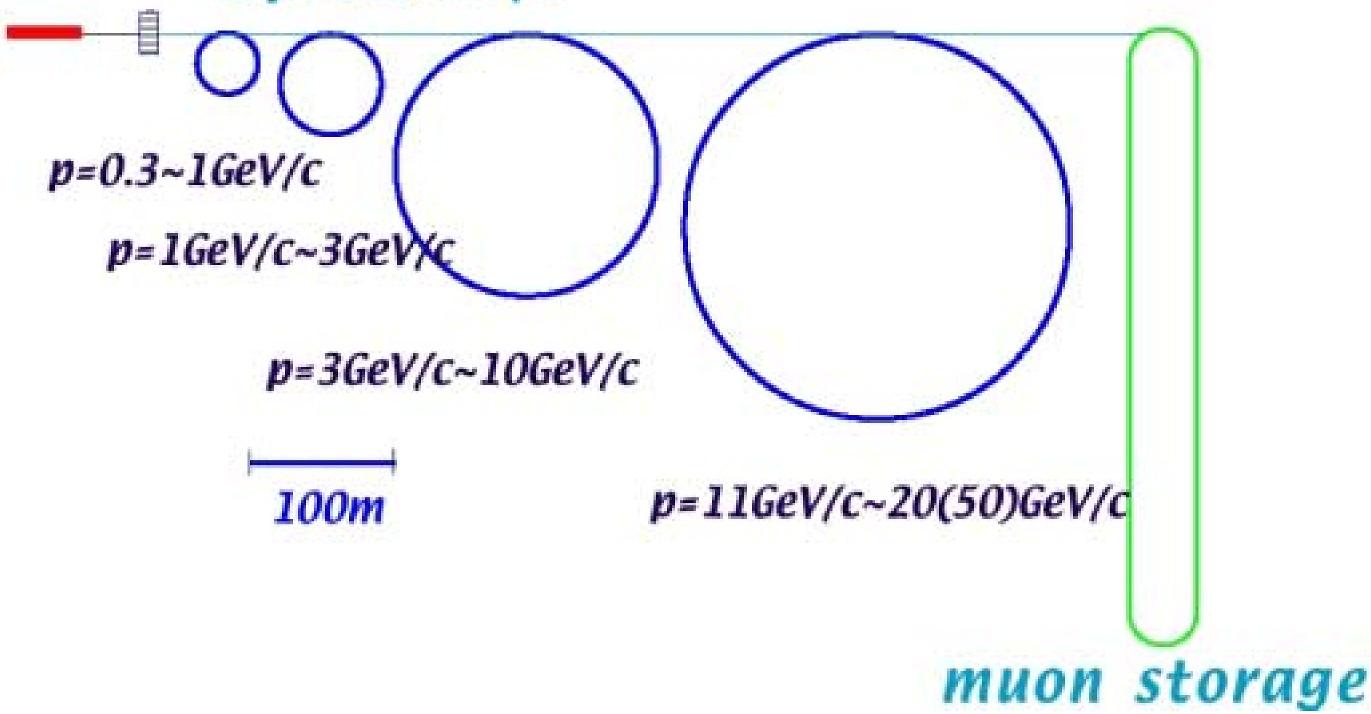
Magnet of 150-MeV proton FFAG

Yoshitaka Kuno
Osaka University

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



Yoshitaka Kuno
Osaka University

Parameters

Conventional

Study II

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)

in report:4.4 for 4.4MW