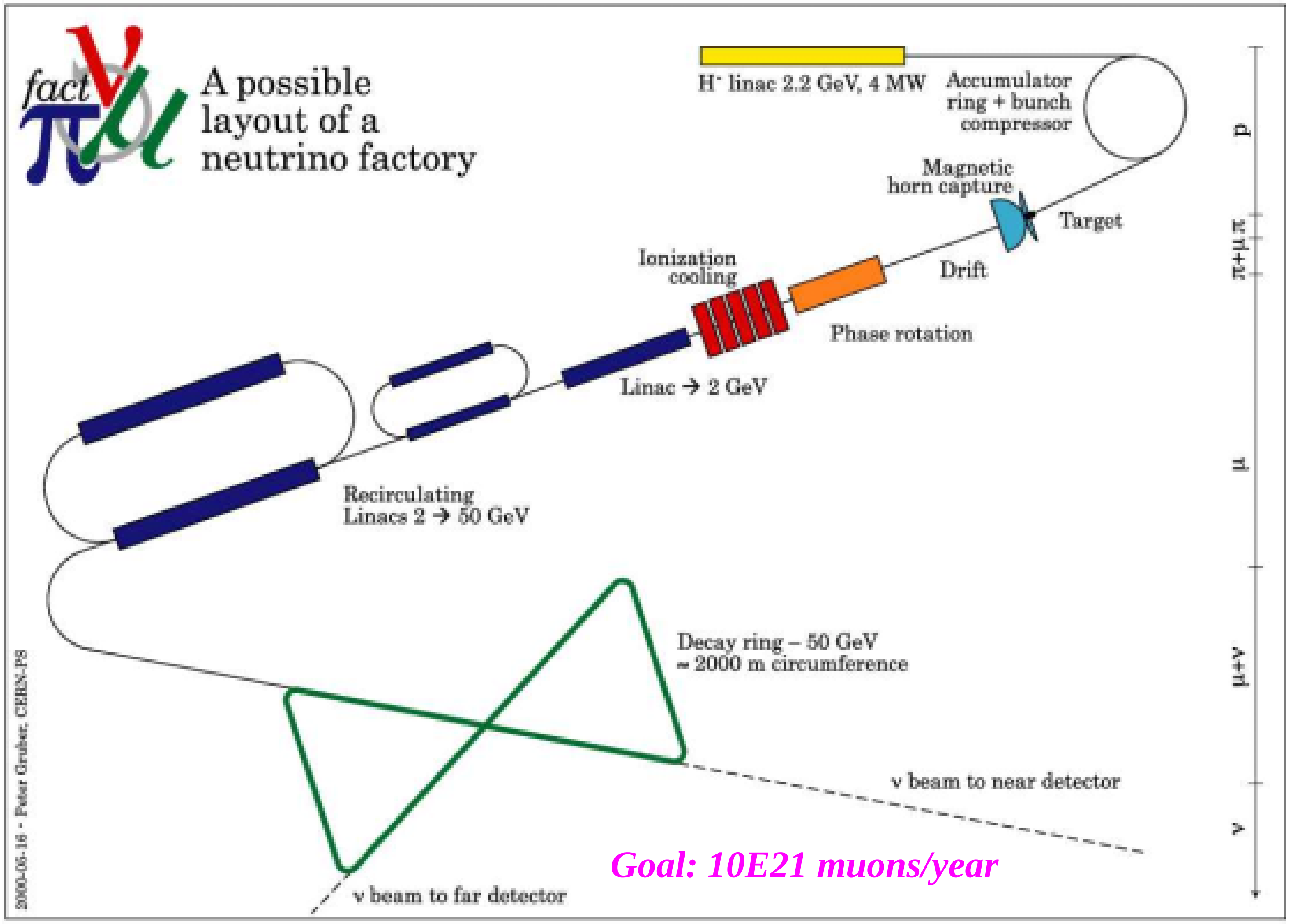
Update of R & D in Europe

H. Haseroth

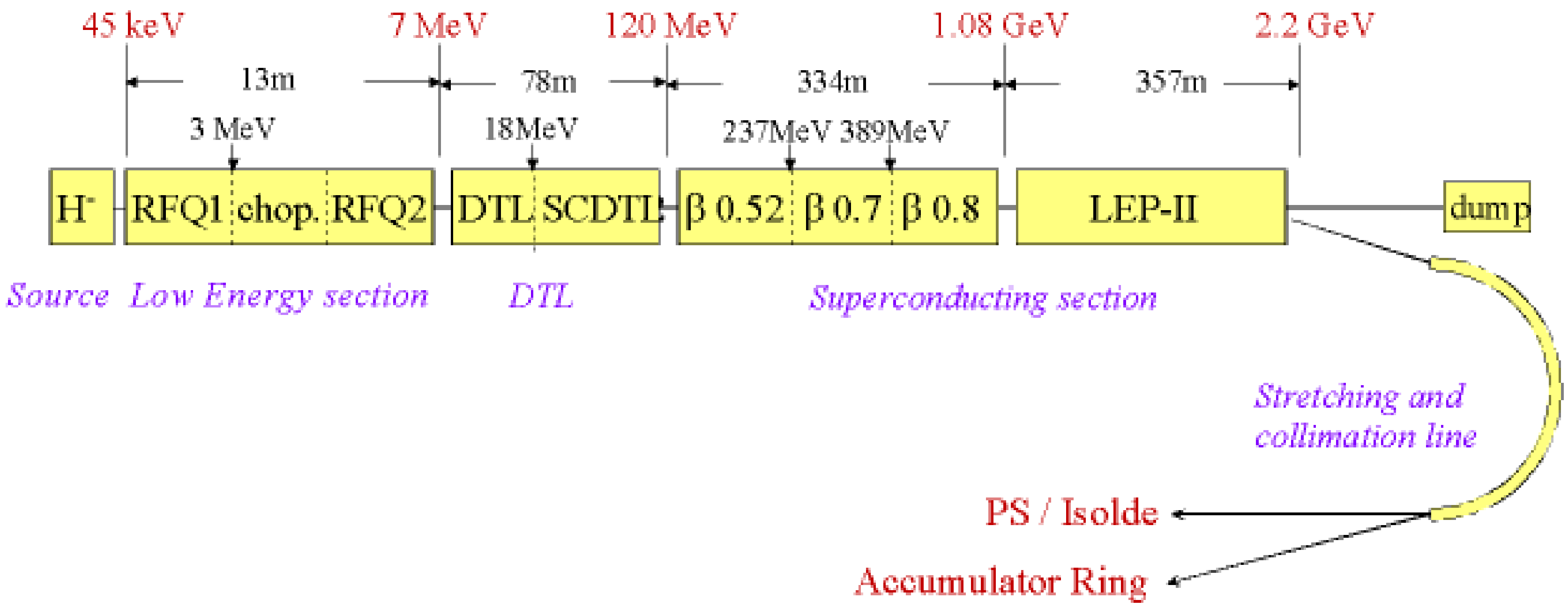
for the

Neutrino Factory Working Group at CERN

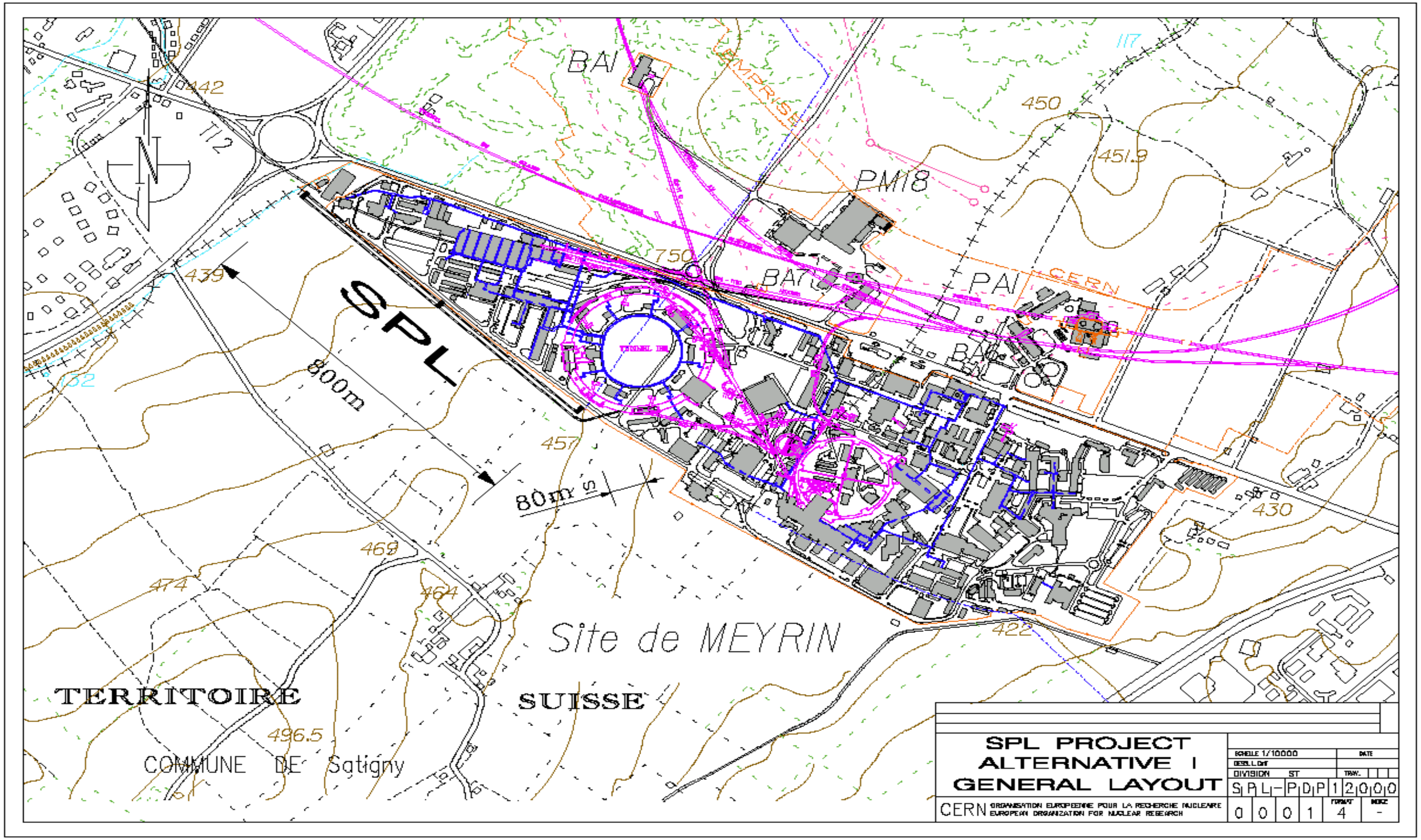


A possible layout of a neutrino factory
H⁻ linac 2.2 GeV, 4 MW
Accumulator ring + bunch compressor
Magnetic horn capture
Target
Drift
Ionization cooling
Phase rotation
Linac → 2 GeV
Recirculating Linacs 2 → 50 GeV
Decay ring – 50 GeV
≈ 2000 m circumference
ν beam to near detector
ν beam to far detector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

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

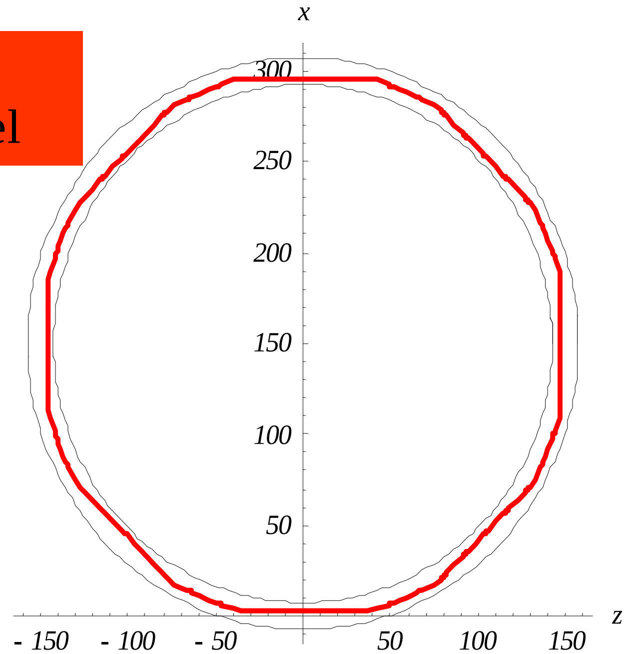


The SPL on the CERN site



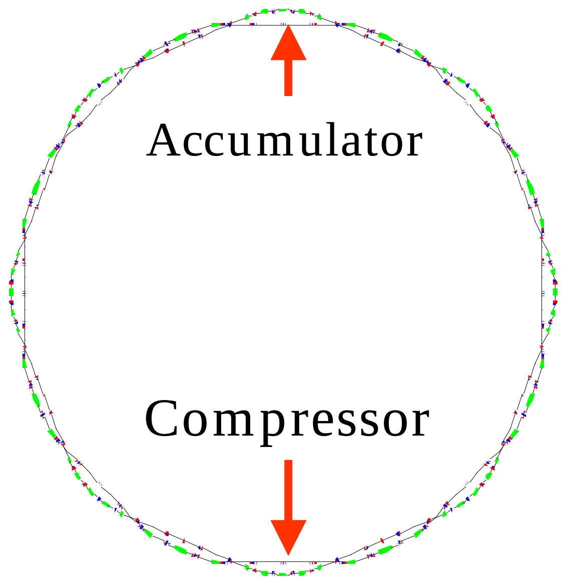
2.2 GeV RAL Accumulator

ISR tunnel



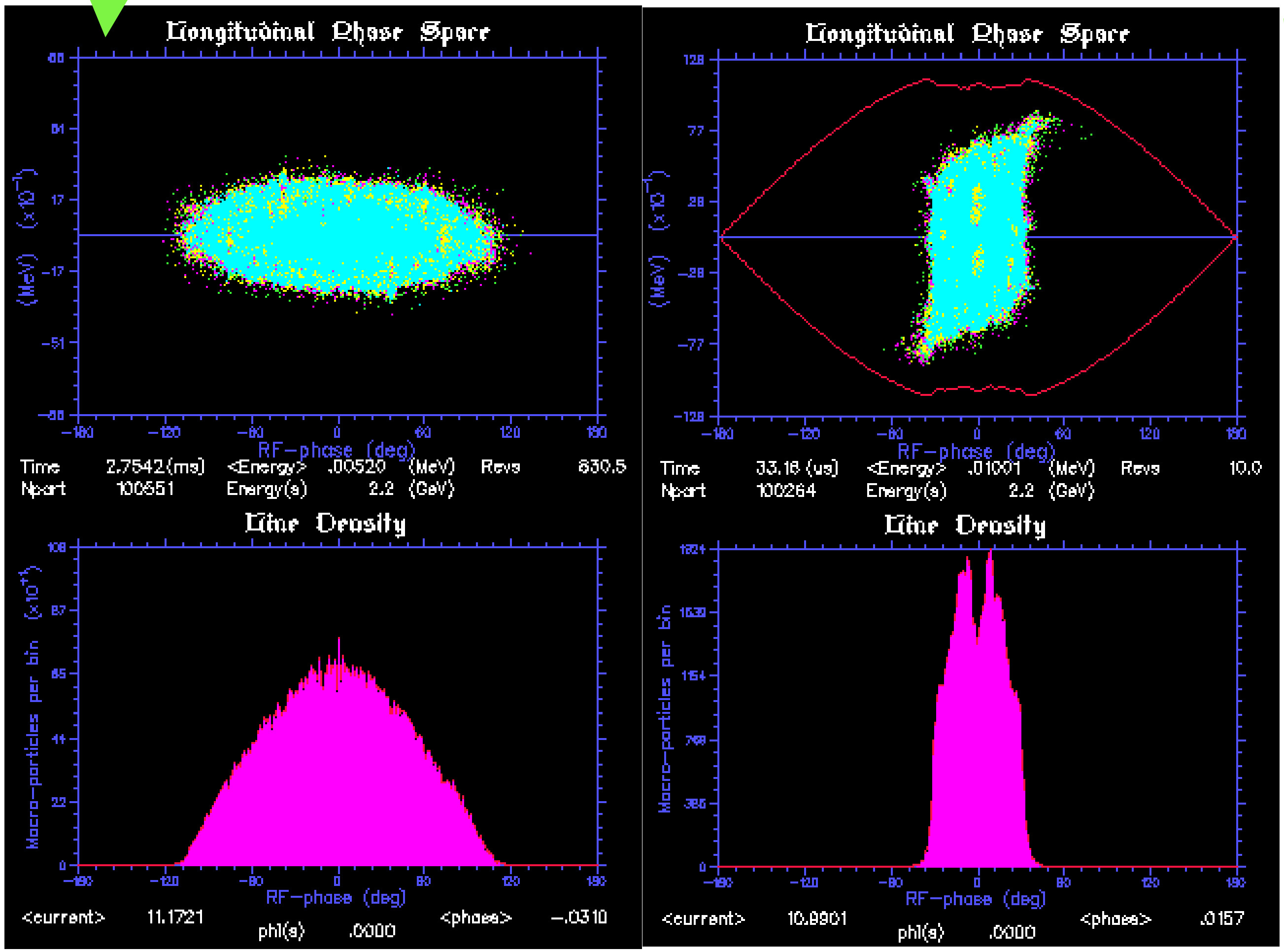
Mean ring radius=150 m

RAL Accumulator & CERN Compressor



in ISR Tunnel

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



Target ideas by H. Ravn

A particularly elegant solution of a magnetically levitated and driven high Z target ring cooled by radiation is now under study in order to verify the simulations and determine engineering parameters (P.V.Drumm, J.R.J.Bennett, C.J.Densham).

Recent tests in the low power ISOLDE beam of radiation cooled solid Ta converter targets have, however, shown severe deformation.

Recently P. Sievers has shown that dividing the solid into small granules may grossly reduce the damage caused by the thermally induced shocks observed in solid targets. Since each granule only absorbs a small fraction of the beam power and are not mechanically coupled to the others the damaging peak stresses observed in the oscillation of a single body are reduced.

As target for the maximum beam powers a jet of Mercury is proposed. The essential feature is that the target is presented to the proton beam as a continuous free surface liquid-metal-jet with ~20 mm diameter and an axial velocity of < 30 m/s. It is rapidly reformed after each beam pulse that only scatters the liquid due to the above-mentioned thermal expansion wave and allows the heat to be carried away efficiently from the production region without need for nearby beam windows.

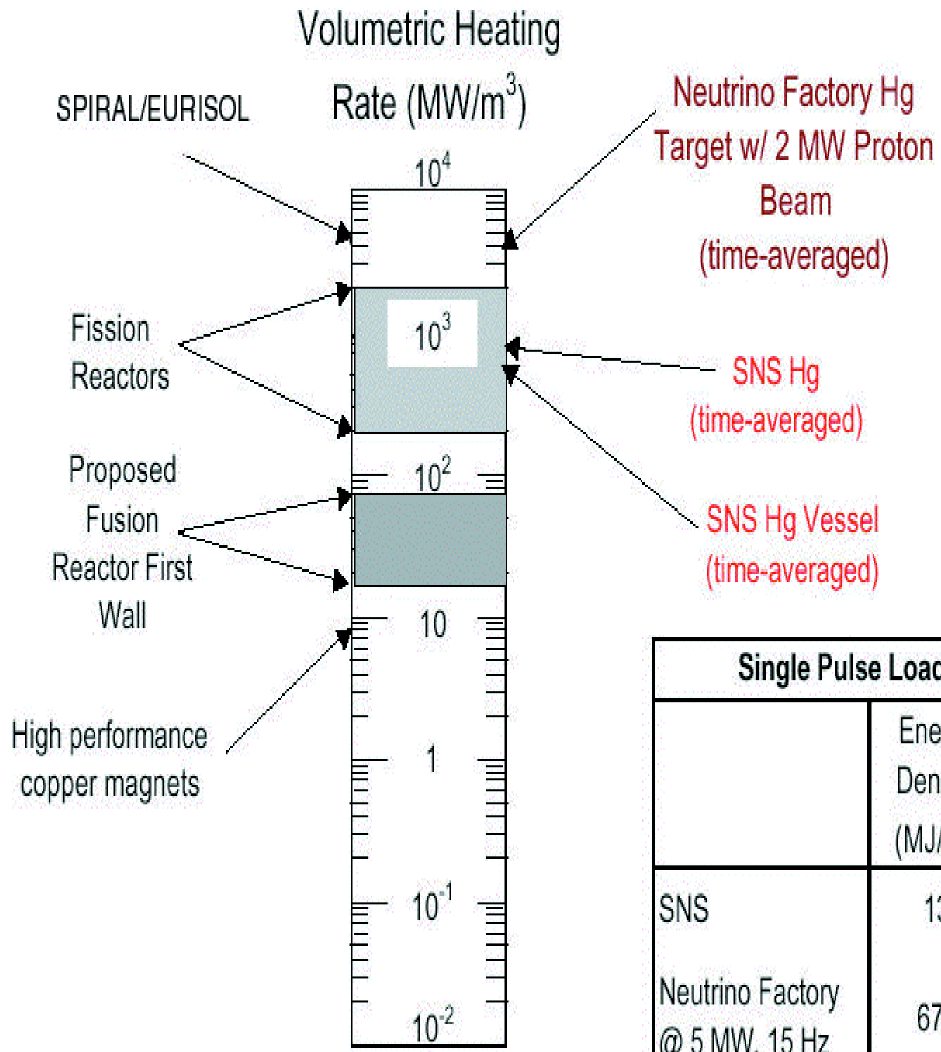
Like in the spallation neutron sources, the metal Mercury has been chosen as the most promising high Z target and coolant material but it could be replaced by several other metals or alloys including low Z elements.

The following additional advantages of a Hg-jet target should be noted:

- High pion yield (high Z)
- High source brightness (high density)
- Flowing liquids have excellent power handling capabilities
- No water radiolysis
- Liquid at ambient temperature (no liquid-to-solid phase change issues)
- Minimal waste stream (compared to solid alternatives) since the Hg is continuously reused.
  The majority of the radioactive reaction products may even be concentrated and removed from the Hg by distillation
  No confinement tubing (free surface jet)
  No need for near by beam windows (differential pumping confinement)

Target heat load comparison

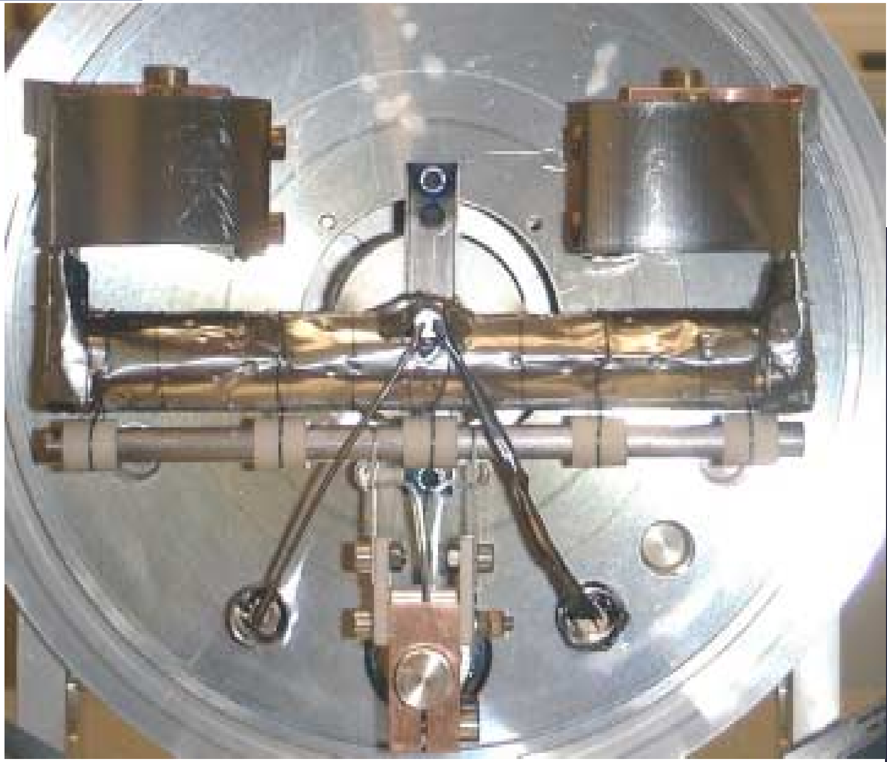
- The EURISOL target station, converter target and support facility is similar to those planned for:
- Neutrino factories
- Spallation neutron sources ESS and SNS
- Nuclear waste transmutation ADS
- ***It is characteristic that they all use molten metal target and heat transfer technology!***



Single Pulse Loads in Hg

	Energy Density (MJ/m³)	ΔT (K)
SNS	13	7
Neutrino Factory @ 5 MW, 15 Hz	670	350

ISOLDE converter targets



Ta-rod after irradiation with 6E18 protons in 2.4 μs pulses of 3E13

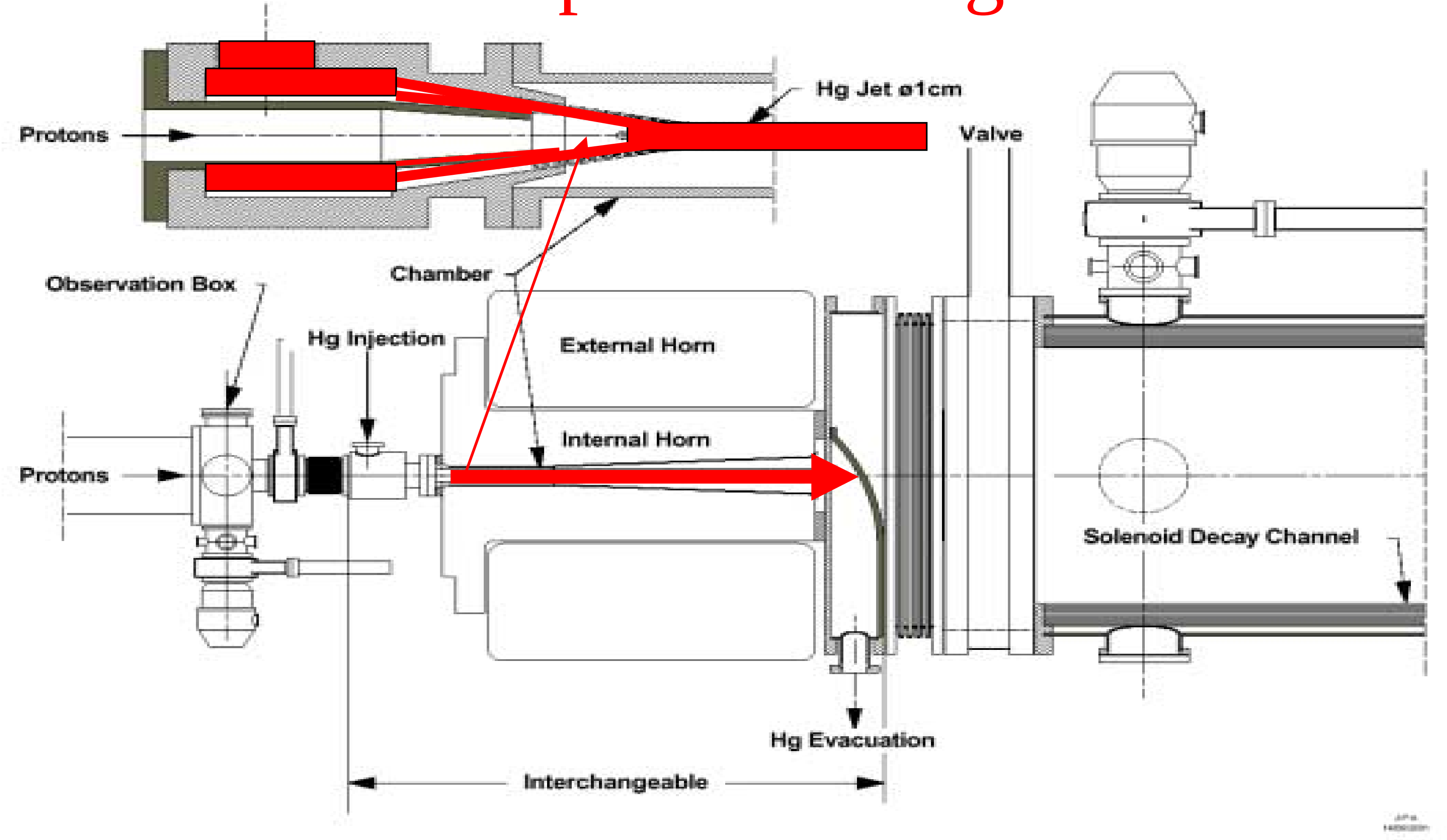
Ta-converter mounted below the UC target before irradiation

•*R. Catherall et al.*

Why a Mercury-Jet

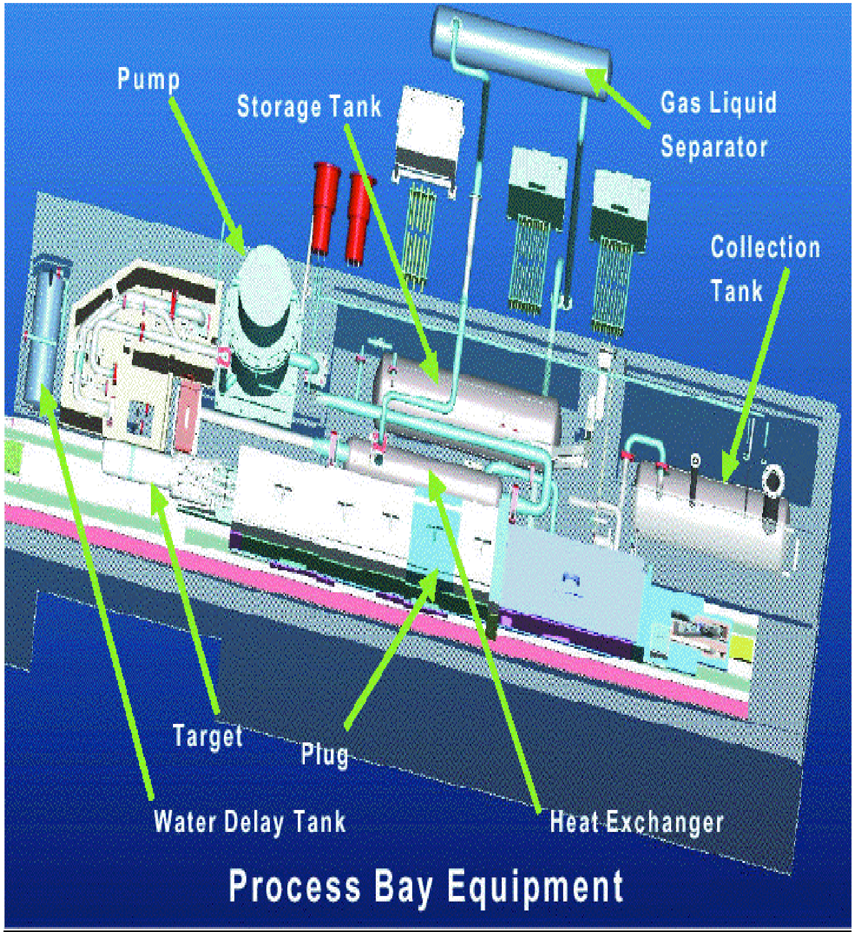
- High pion yield (high Z)
- High source brightness (high density)
- Flowing liquid have excellent power handling capabilities
- No water radiolysis
- Liquid at ambient temperature (no liquid-to-solid phase change issues)
- Minimal waste stream (compared to solid alternatives)
- Passive removal of decay heating
- No dominant long-lived radiotoxic products
- No confinement tubing (free flowing jet)
- No beam windows (differential pumping confinement)

Hg-jet p-converter target with a pion focusing horn



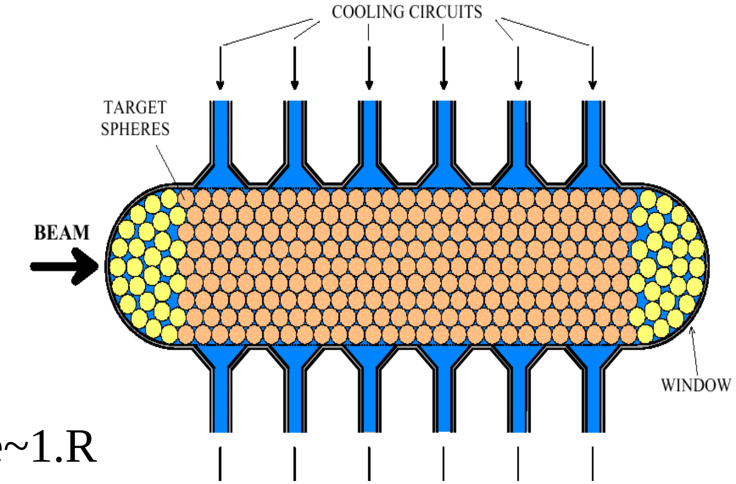
Hg-jet system

- Power absorbed in Hg-jet 1 MW
- Operating pressure 100 Bar
- Flow rate 2 t/m
- Jet speed 30 m/s
- Jet diameter 10 mm
- Temperature
  - Inlet to target 30° C
  - Exit from target 100° C
- Total Hg inventory 10 t
- Pump power 50 kW

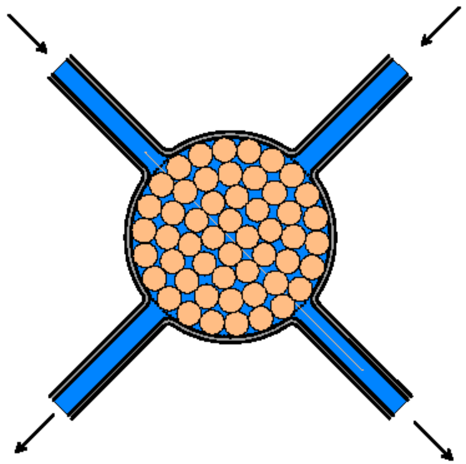


Water-cooled granular target

- P. Sievers/CERN

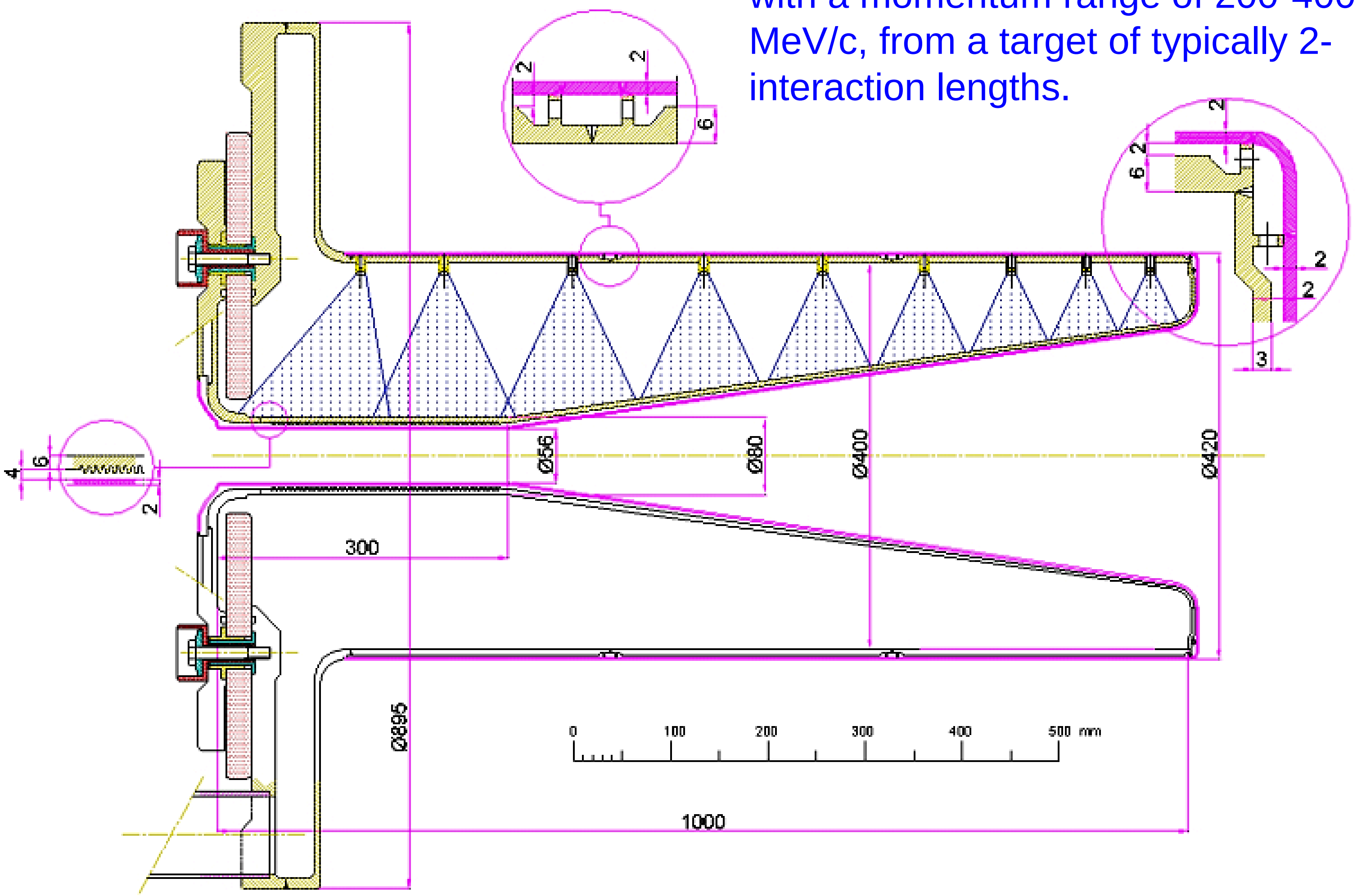


Ta-Spheres, ρ = 16.8 g/cm
R = 1mm
Packing density ~60% (~140 spheres/cm^3)
R = 10g/cm^3
Small spheres good for cooling: surface/volume~1.R
Water cooling:
v = 6m/s through 20% of cross-section
V = 11l/s
ΔT =18K (20% of 4MW, S. Gilardoni)
ΔT =36K
ΔP =4-5 Bar
Re ~ 10^4



Magnetic Horn, prototype

The horn will be designed to focus particles emitted at large angle, and with a momentum range of 200-400 MeV/c, from a target of typically 2-interaction lengths.



NEUTRINO FACTORY - Horn 1 prototype

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

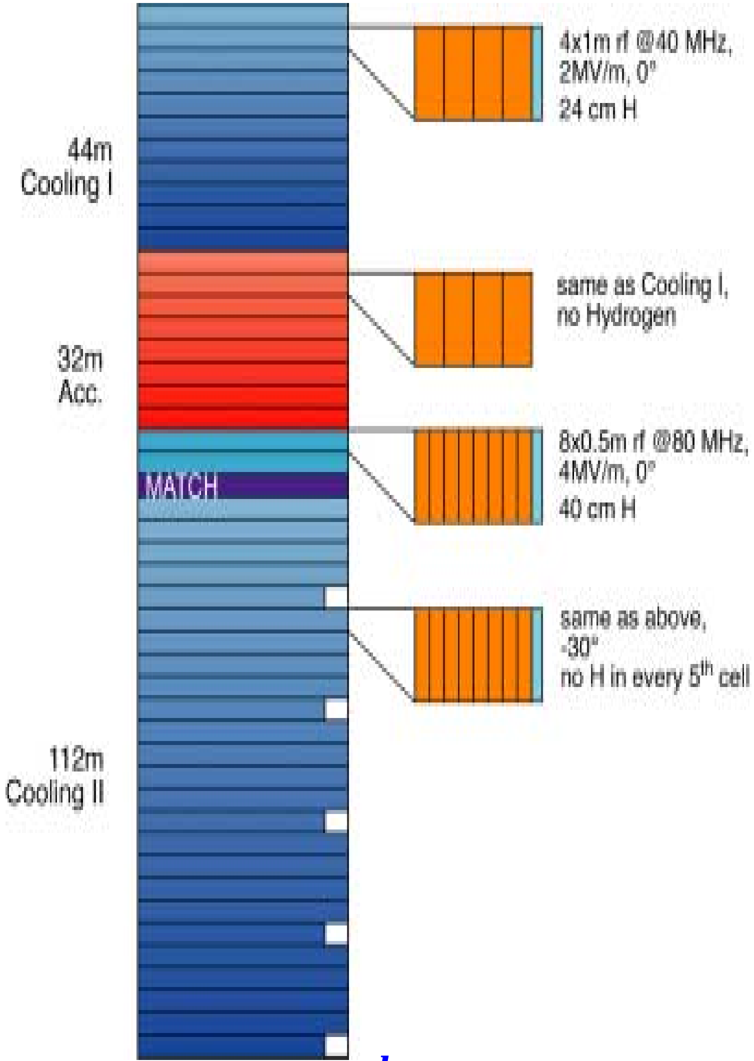
>> end of February 2002

Conclusion and target R&D

- For the free surface Hg-jet no show stopper has been identified and interesting solid alternatives exists
- The needed R&D as suggested below can only be addressed by a major target collaboration
- Study the hydrodynamics of full scale jet (jet stability, velocity and pumping system)
- Continue the in beam Hg-trough studies at 1.4 GeV PS-Booster beam at 1/5 of the NuFACT power density
- Start engineering study of the integration of the target plumbing in the horn or in a concentric ISOL target
- Design and build a ≈ 400 kA pulse current generators to drive a magnetic horn at 50Hz
- Continue the studies of alternative target concepts like radiation cooled solids and the water cooled granular target.

Layout of 40/80 MHz Cooling Channel

beam in

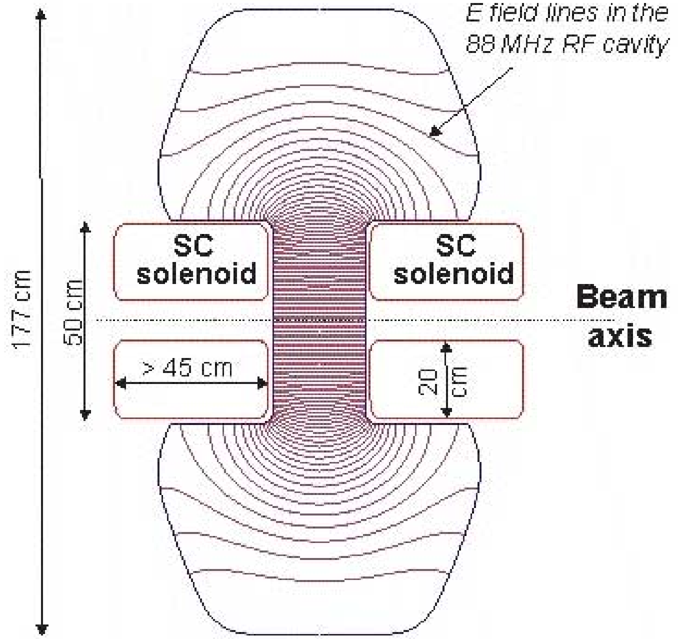


beam out

	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

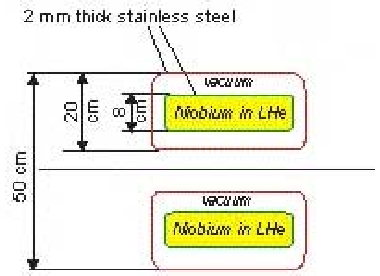
Table 3 Main parameters of the capture, phase rotation, cooling and acceleration section

88 MHz test cavity



88 MHZ TESTCAVITY

SUPERCONDUCTING
SOLENOID
ASSEMBLY

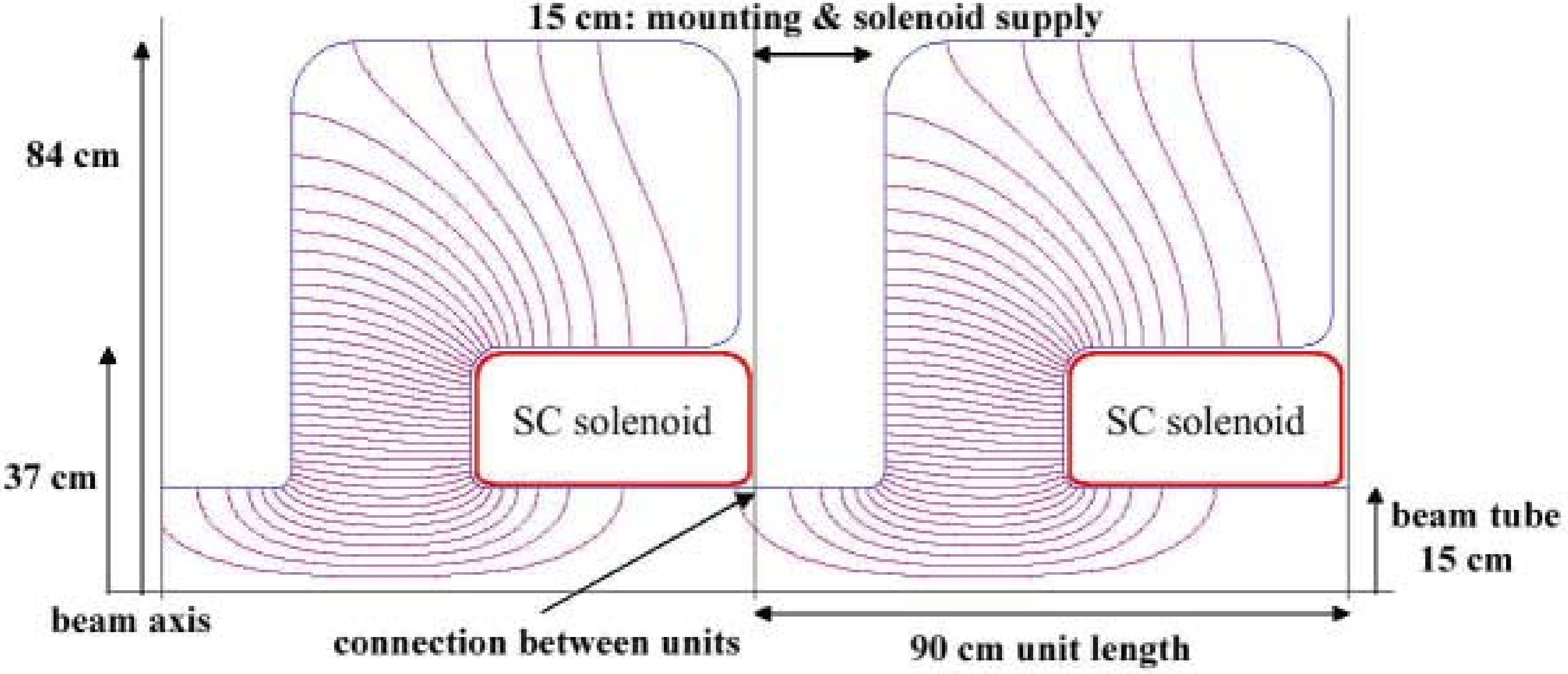


- An 88 MHz test cavity for high gradient is being prepared
  (2 MW amplifier driving a modified 114 MHz PS cavity)
  - High RF gradient without solenoid: end 2001
  - RF test with solenoid: mid-2002

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	

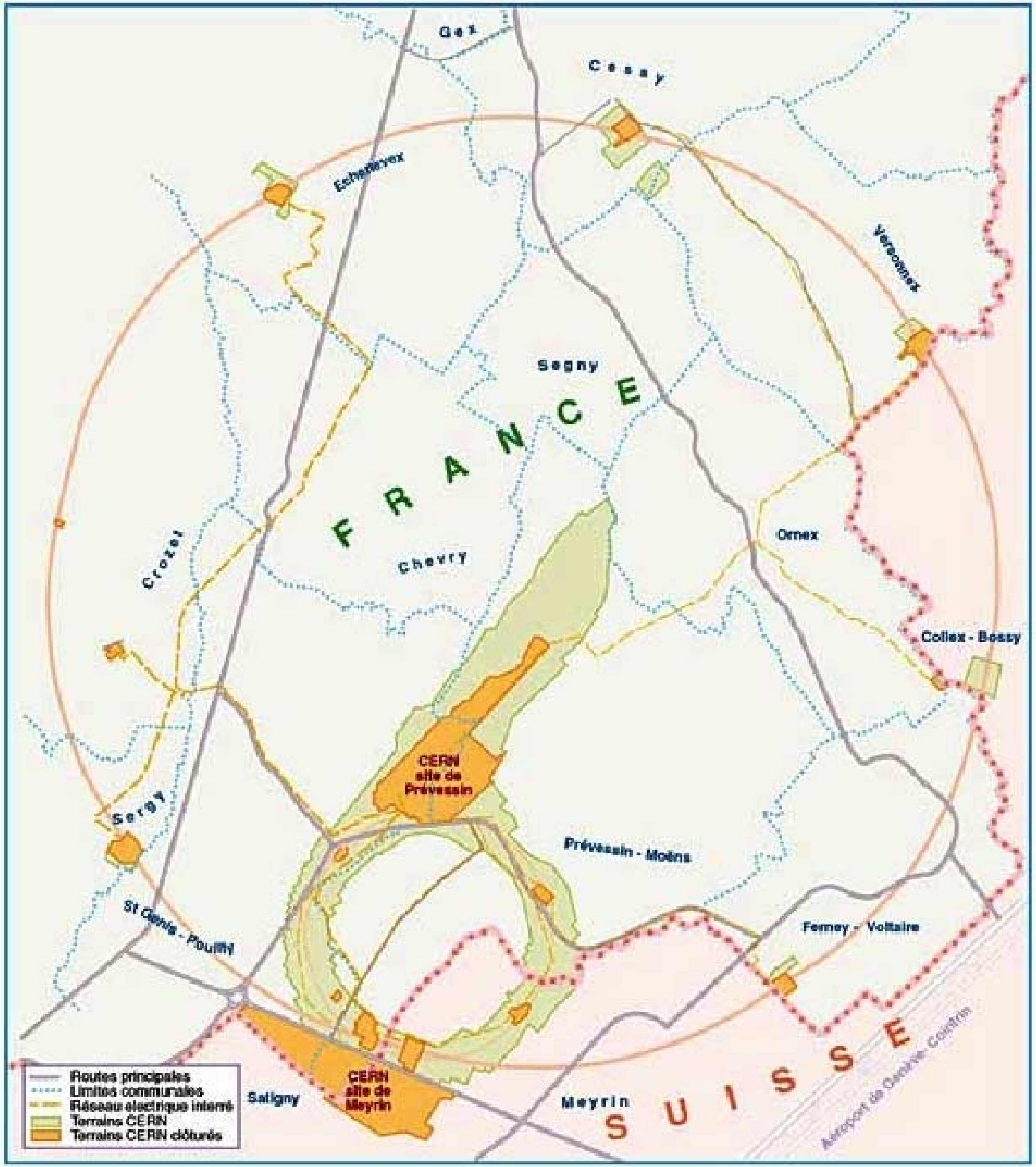
Parameters of Recirculating Linacs (RLAs)

	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 Decay Ring

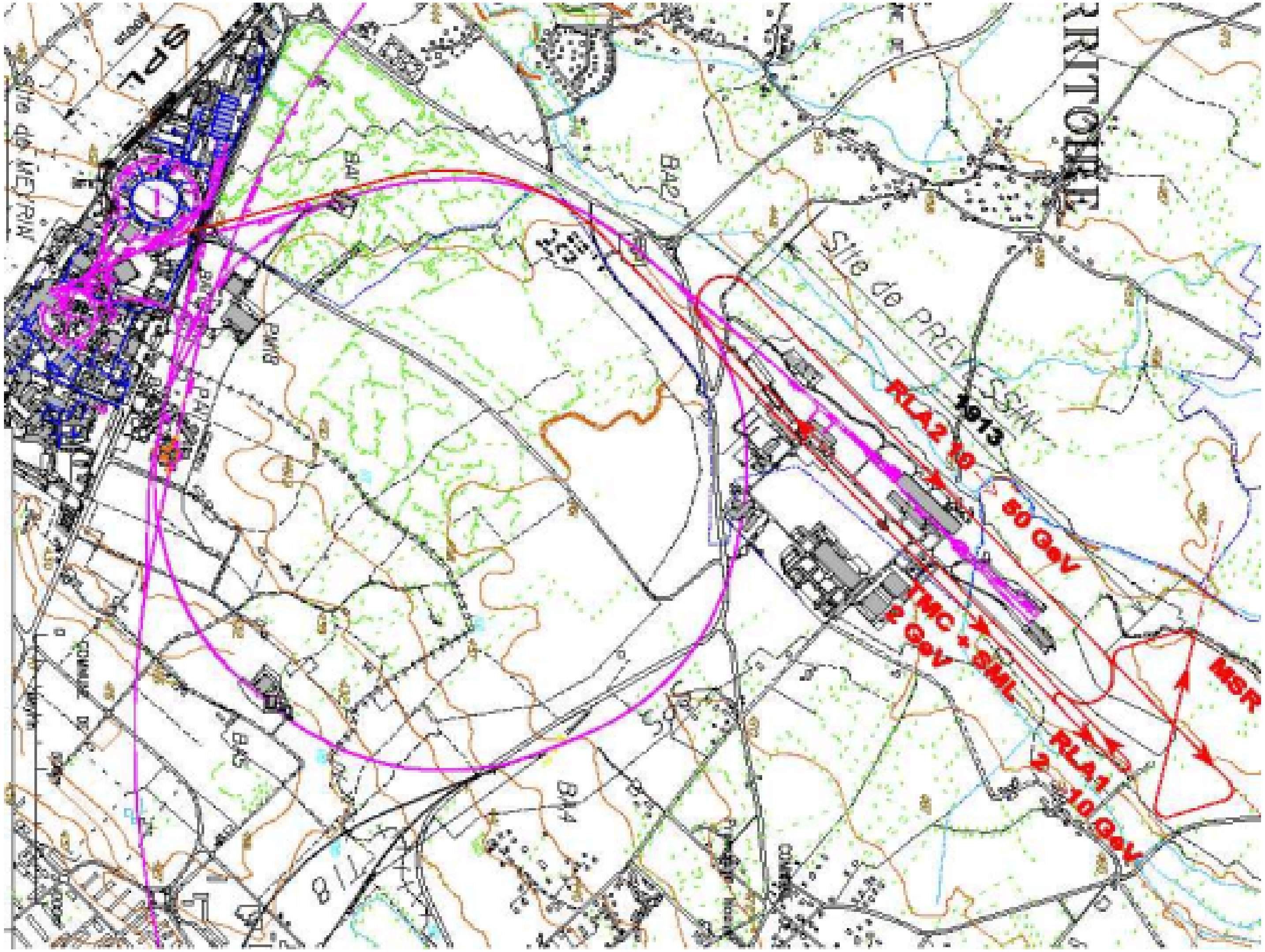
Design momentum, GeV	50
Muon fluence, s^{-1}	10^{14}
Configuration	Triangular
Normalised beam divergence in SS at σ_ε, mrad	0.1
Normalised beam emittance (σ_ε), mm rad	1.67
Aperture limit	3 σ_ε
Relative rms momentum spread	0.005
Bunch spacing, mm	851
Dipole field, T	6
Total length of straight sections,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

CERN Site



Gex
Cessy
Echenevex
Versonnex
Segny
FRANCE
Chevry
Crozet
Ornex
Collex - Bossy
CERN site de Prévessin
Prévessin - Moëns
Sergy
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



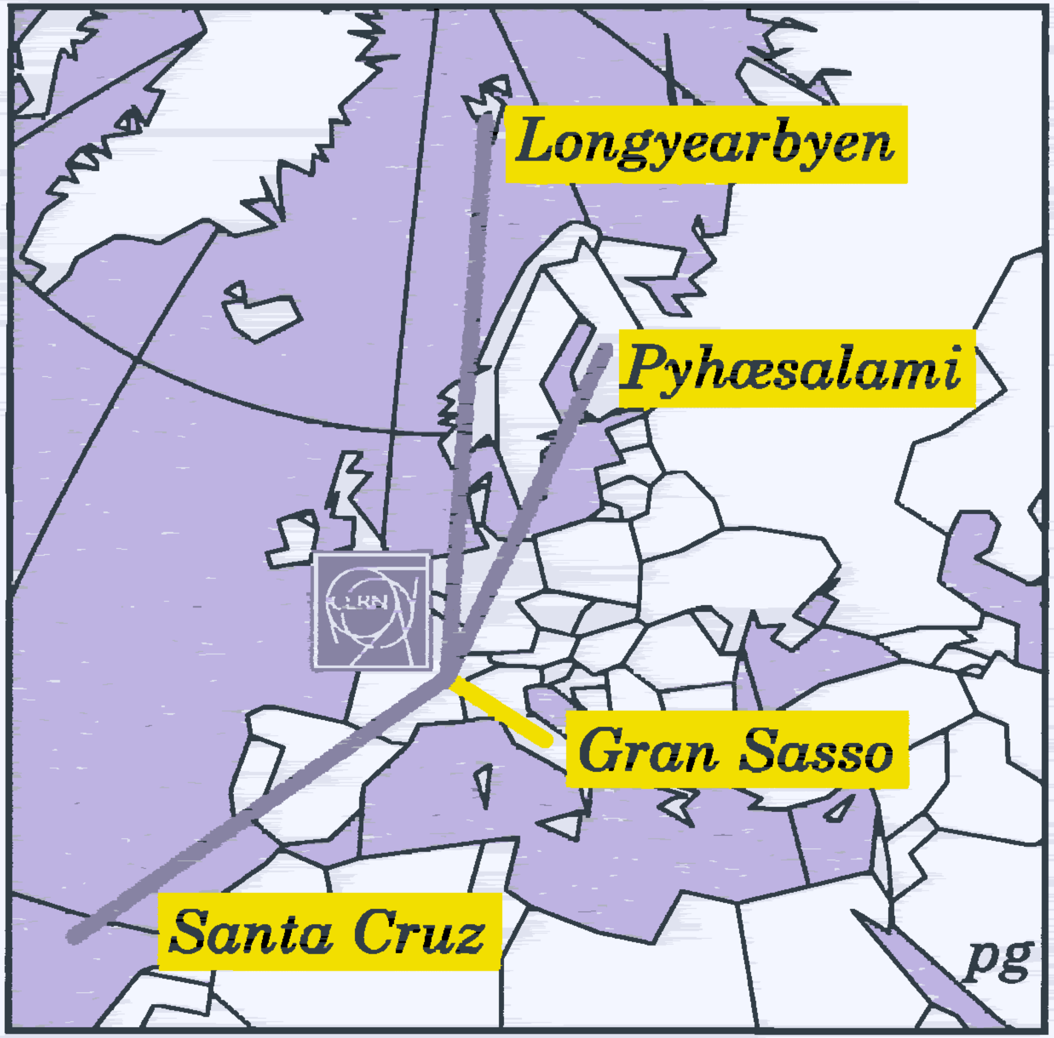
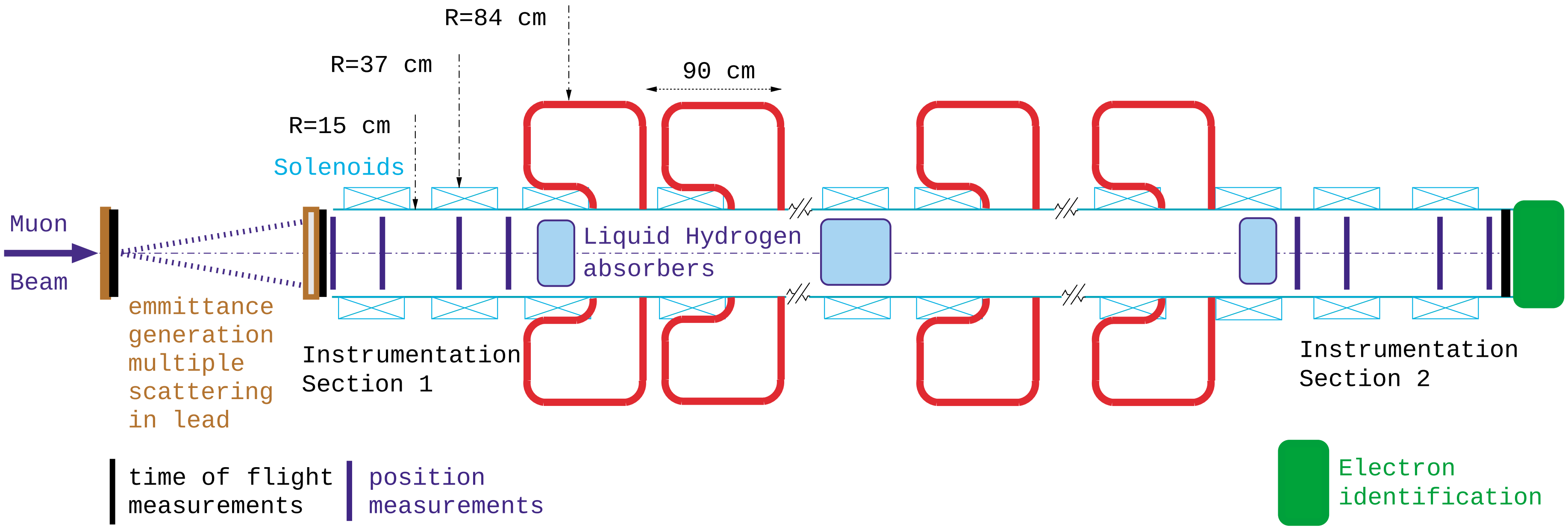


Figure 1: Overview of the detector positions currently under investigation.

Cooling Experiment



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)

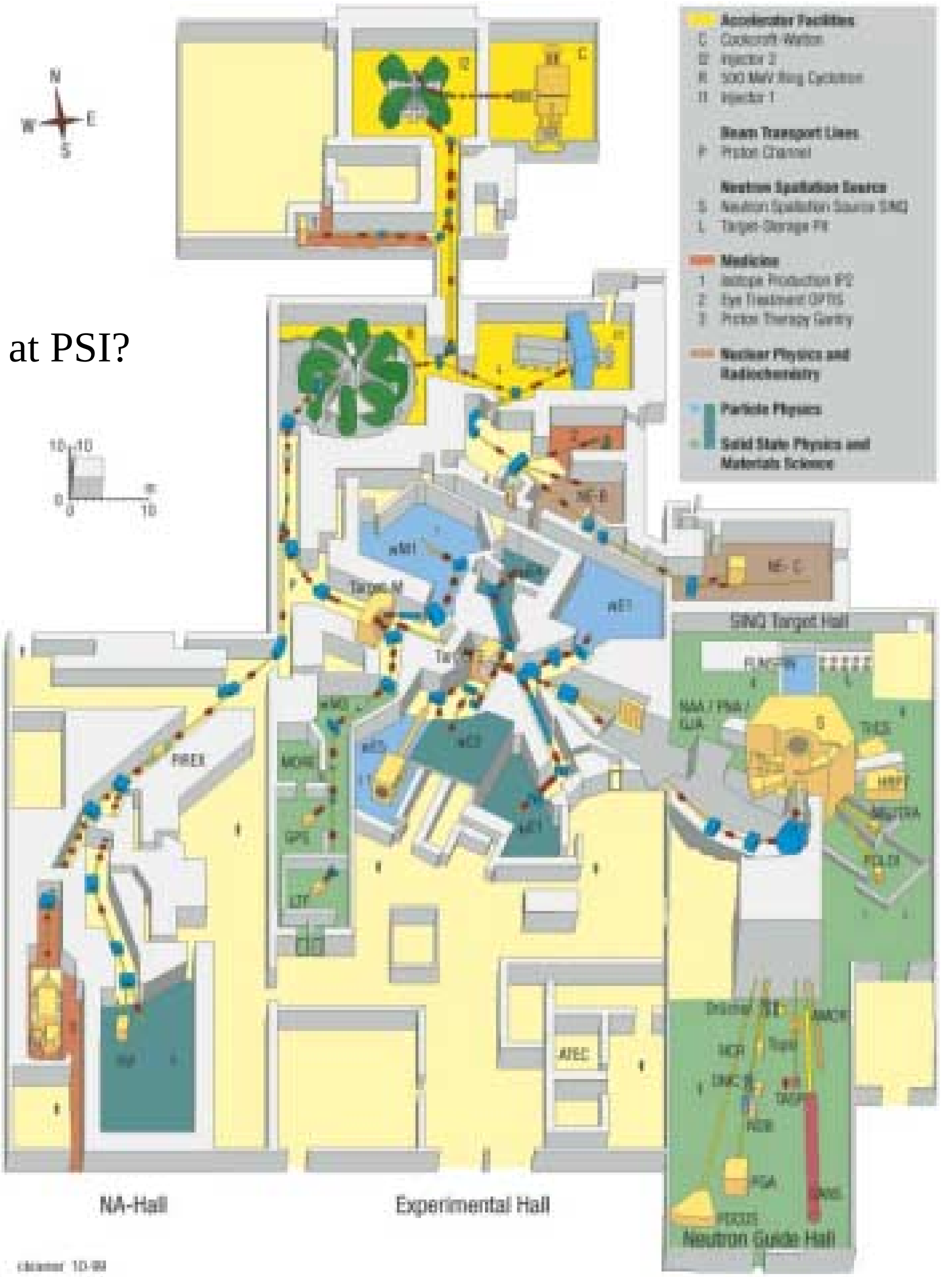
3) Swiss confederation, RAL, EU money?

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

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

+ a Muon Beam (PSI or RAL)

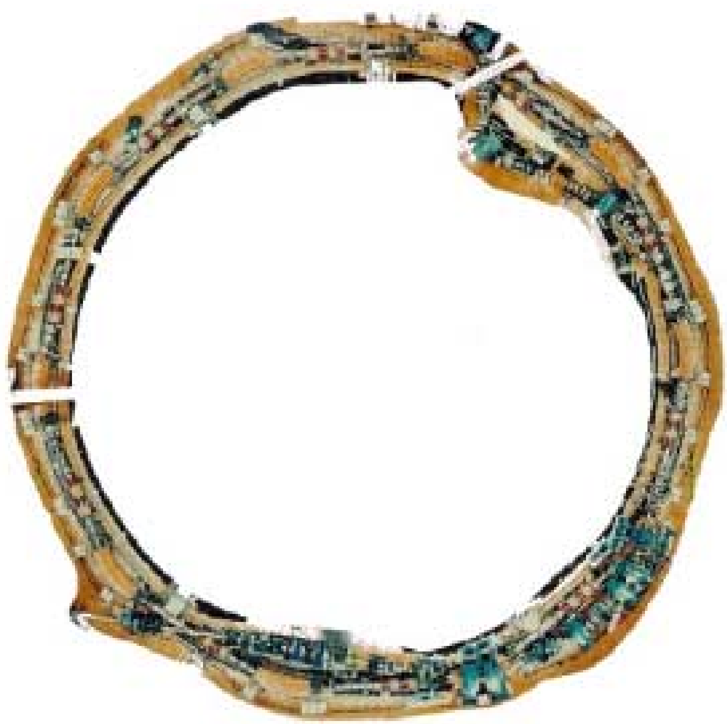
Cooling experiment at PSI?



H. Haseroth
May 9-15, 2002

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

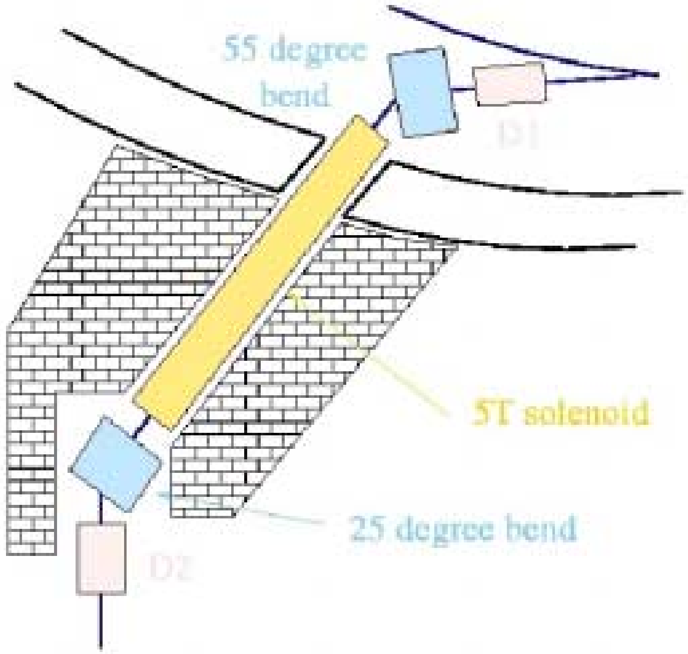
- Capture at 20/30°
- 15-20m long
- Main change: 5T, 10m, 20cm SC solenoid
- Muon transmission 2.0-2.5%
- Pion transmission ~0.1%

Simulations

For 10^7 protons at 800 MeV:

€ ~50/60 muons/bunch/turn

€ background ~2.5 pions at 300 MeV/c

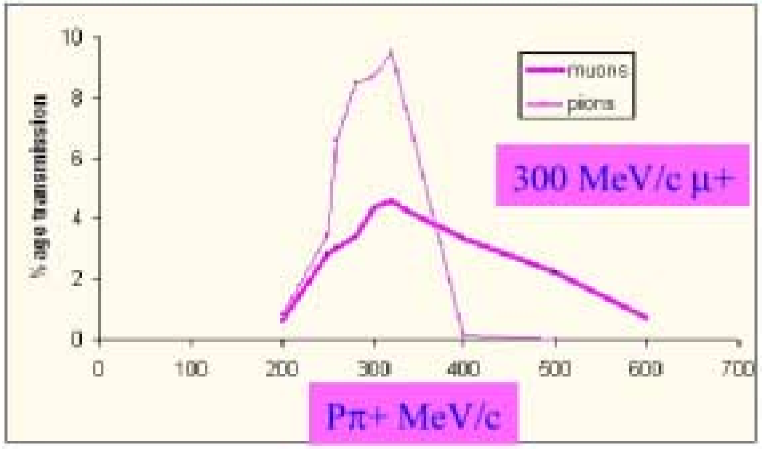


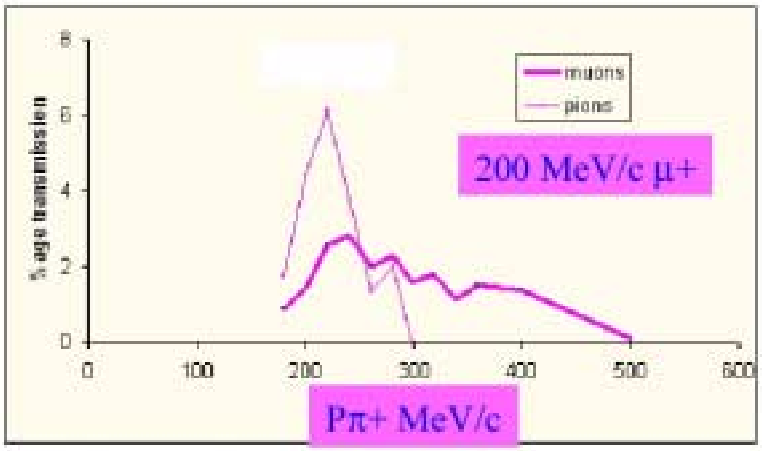
⇒ 1./1.2 × 10^6 muon/s

Background

Could be a beam line from PSI

Background rejection using the solenoid





88 MHz Option: Lay-Out

a) entry absorber (45 cm LH) exit absorber (45 cm LH)

input diagnostics
(sol. lattice ctd.)

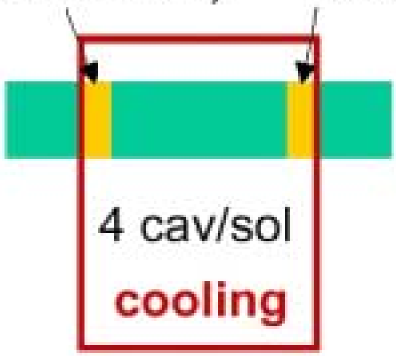
output diagnostics
(sol. lattice ctd.)
solenoids of 45 cm
length with 15 cm spacing

---

b) entry absorber (22.5 cm LH) exit absorber (22.5 cm LH)

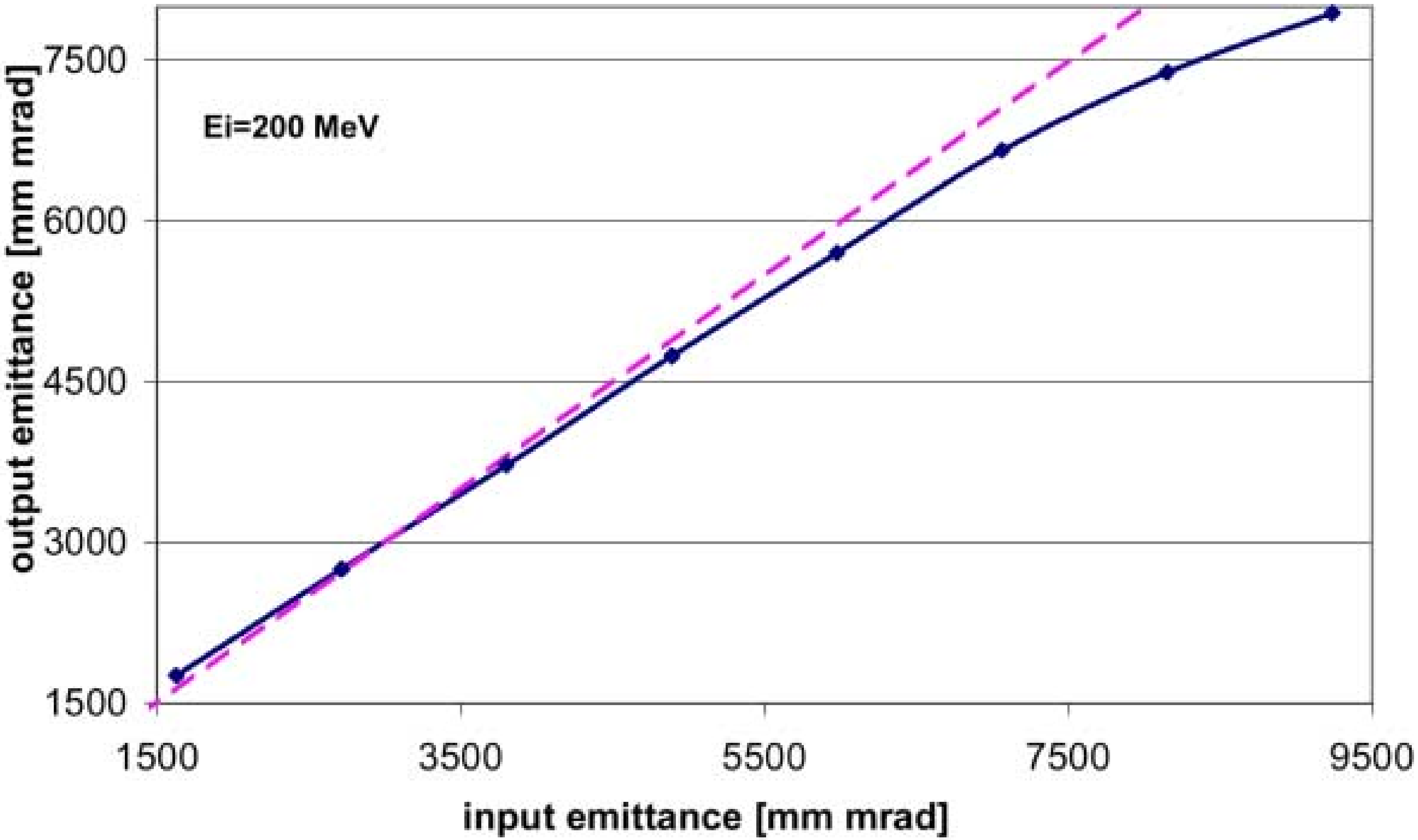
new

input diagnostics

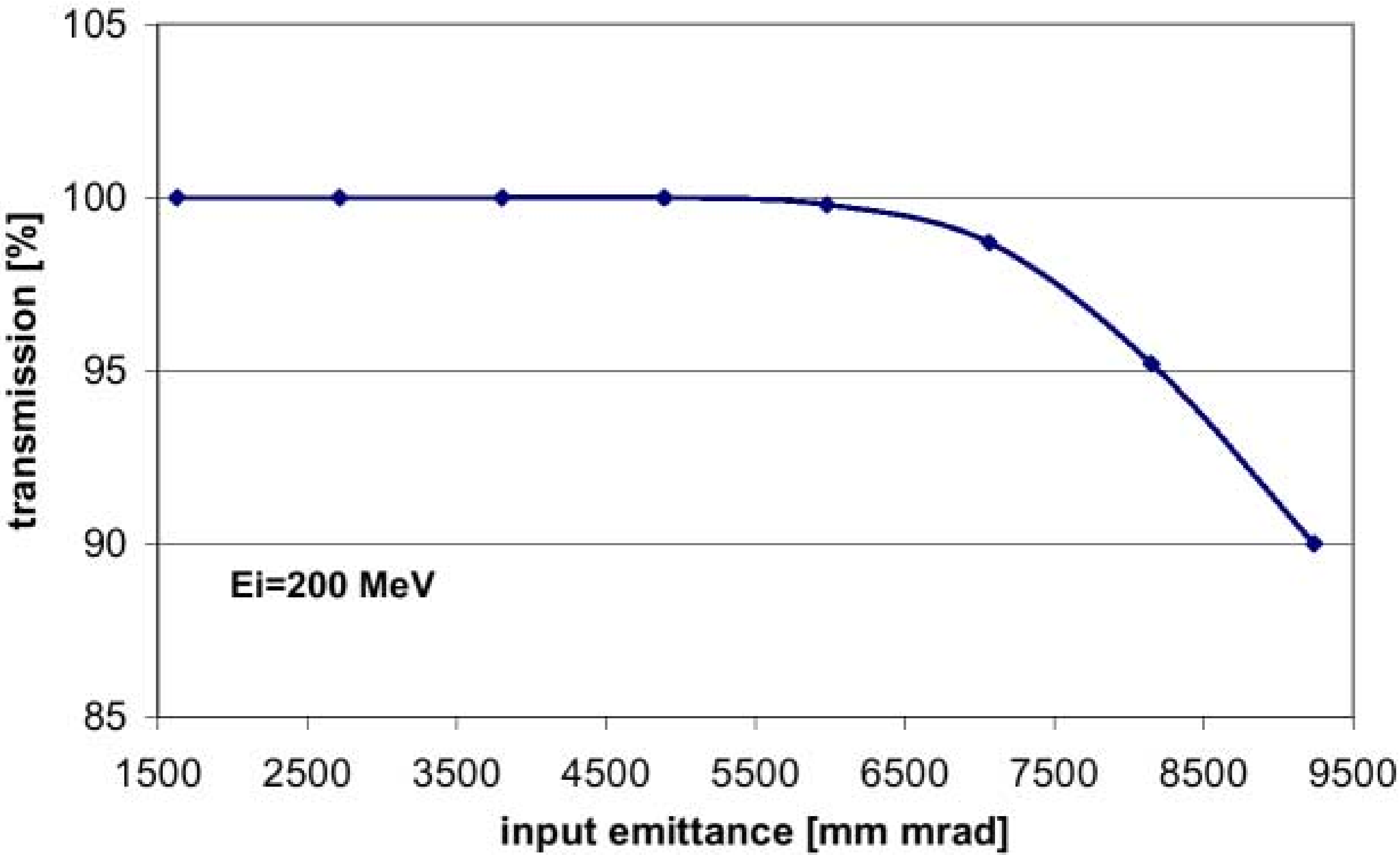


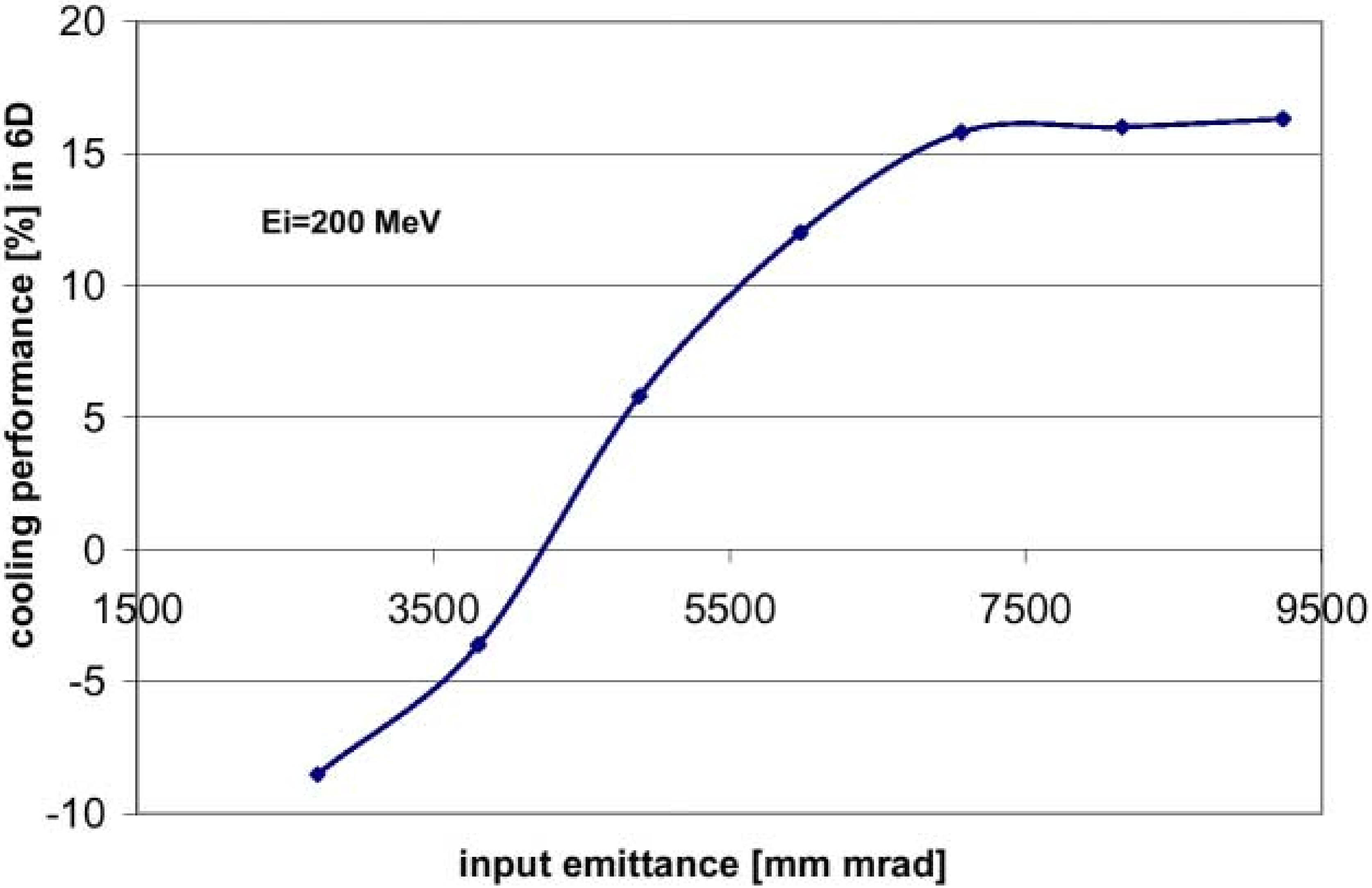
output diagnostics

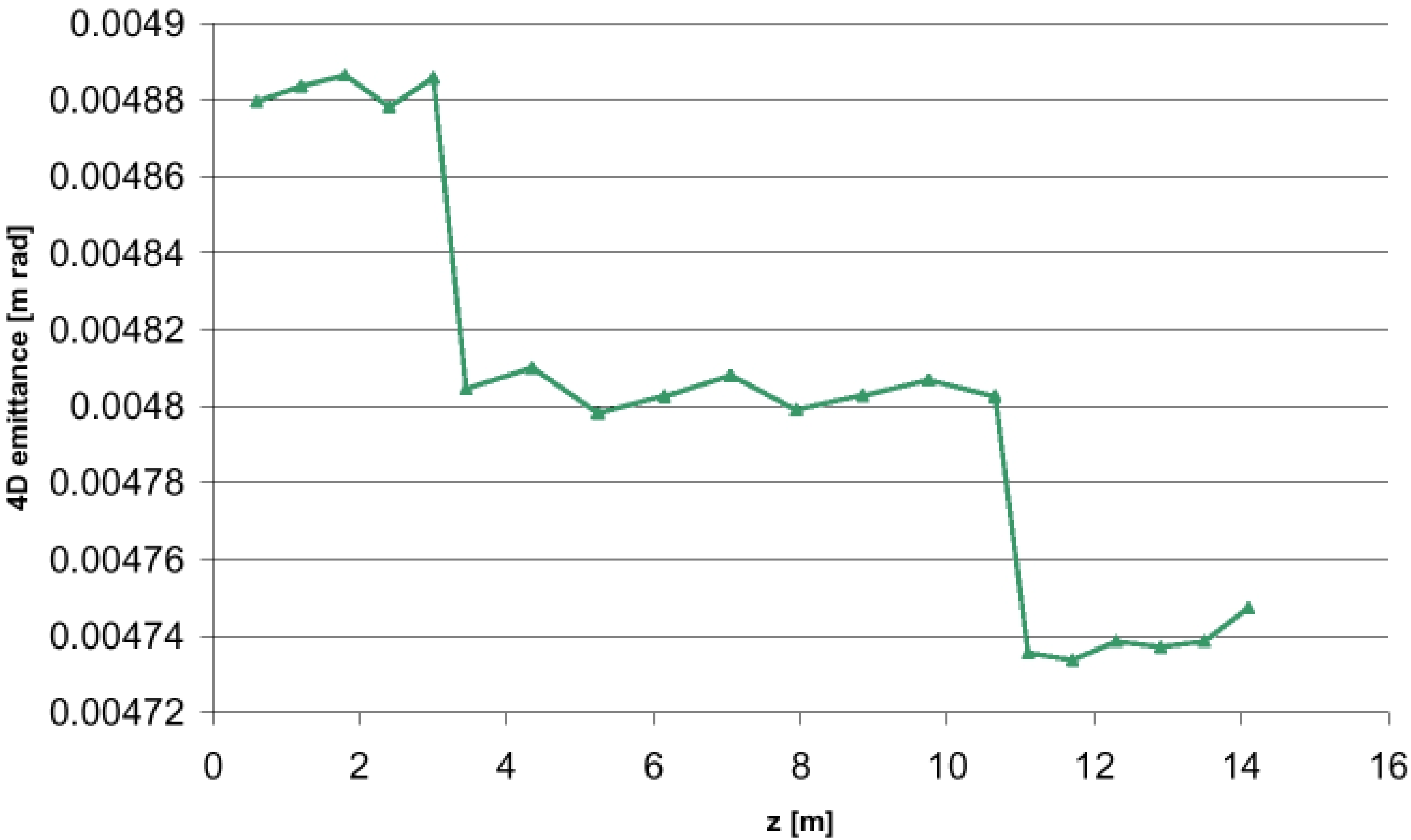
Klaus Hanke



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]


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

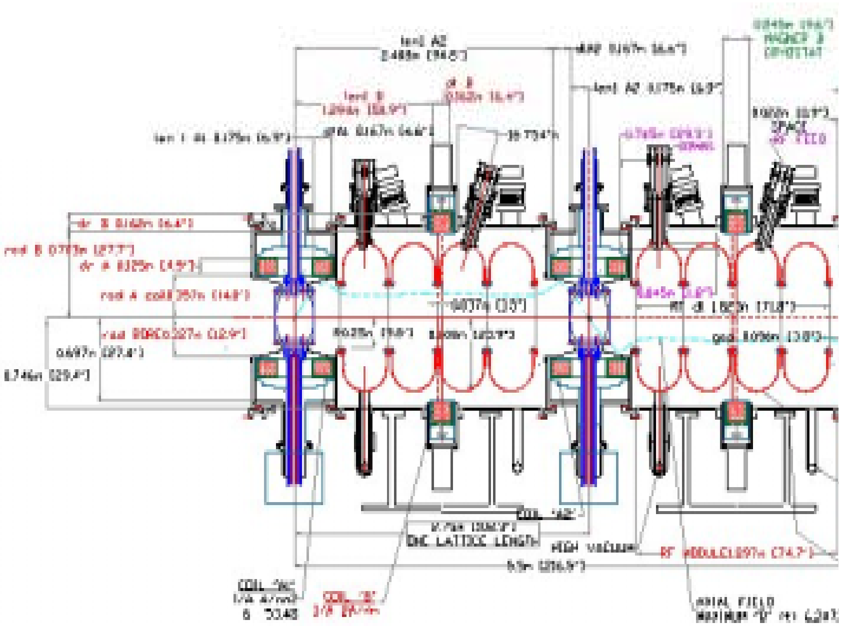
a detailed parameter scan has been performed to evaluate the performance of the channel for various input beams, settings etc. (E.-S.Kim, K.Hanke, to be published)

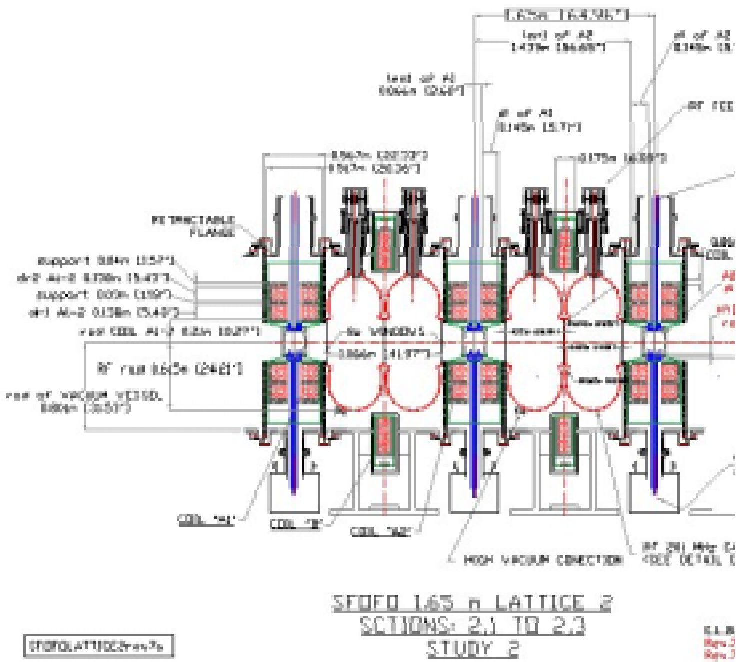
simulation of a 200 MHz option under way

Klaus Hanke

Preliminary Study of the Cooling Channel based on the 200 MHz Cavities

M. Migliorati et al

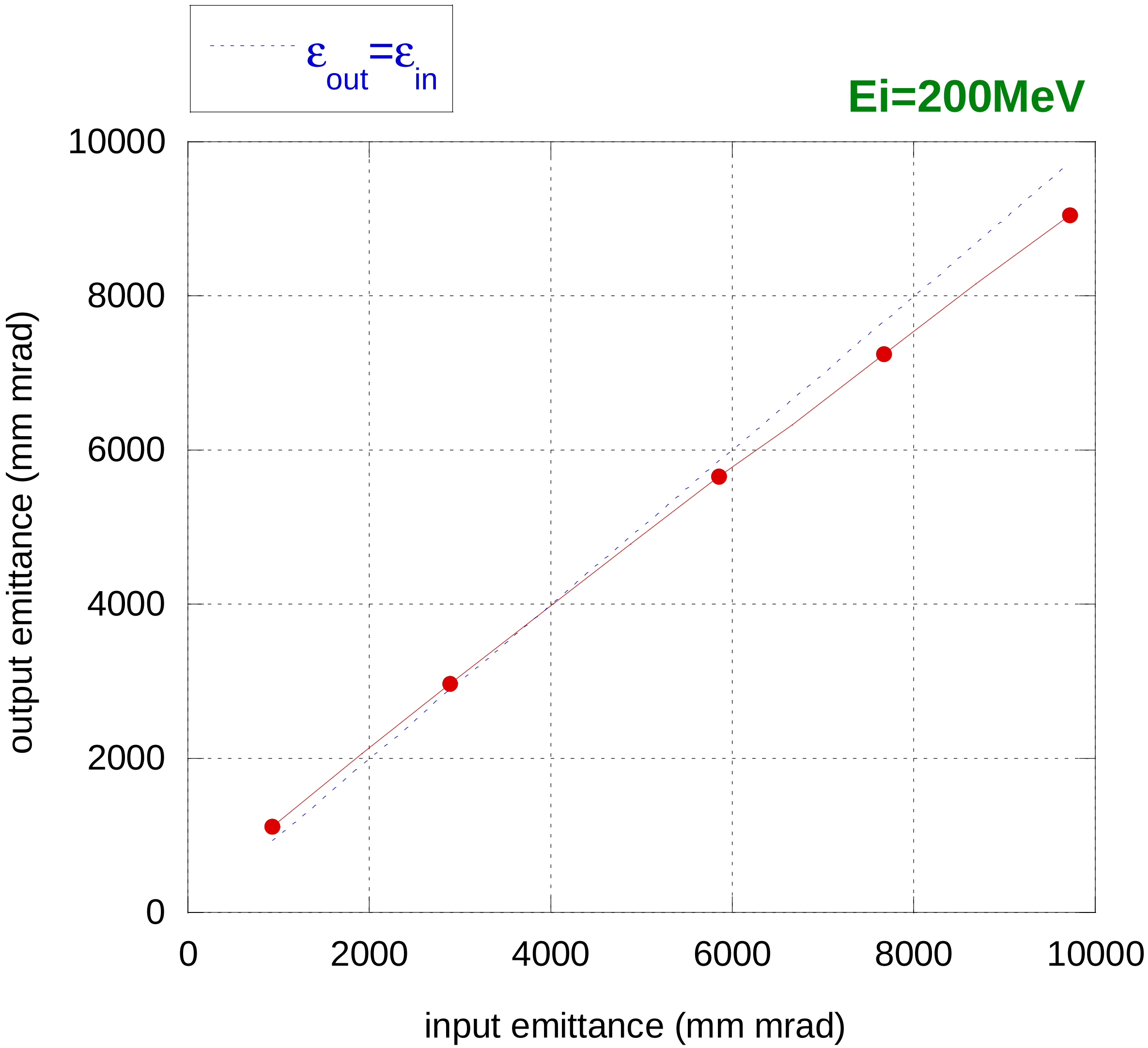




SFOFOLATTICE1rev7a

SFOFO 2.7m LATTICE 1
SECTIONS 1.1 TO 1.3
STUDY 2

E.L.Black II
2/9/2001
3/8/2001 M

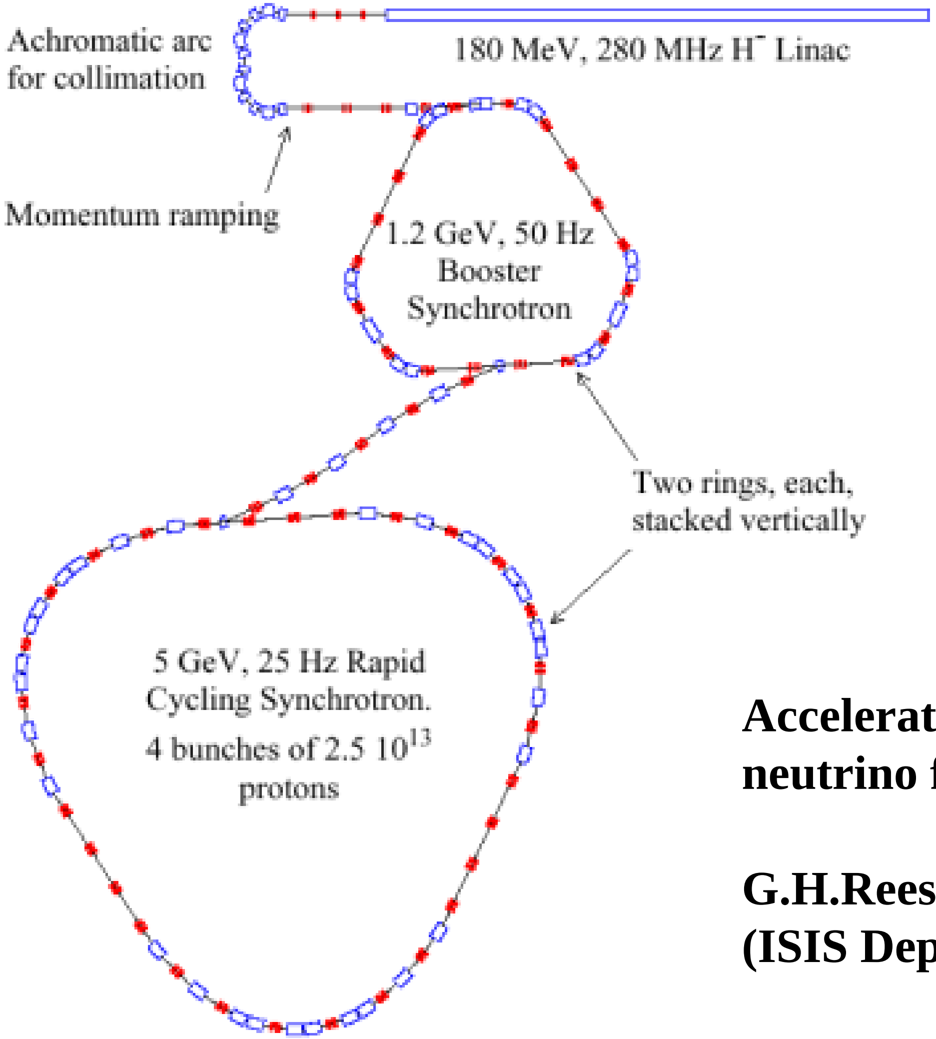


ε out =ε in
Ei=200MeV
10000
8000
6000
4000
2000
0
output emittance (mm mrad)
0
2000
4000
6000
8000
10000
input emittance (mm mrad)

Activities in the UK
(apart from collector/accumulator activities)

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.

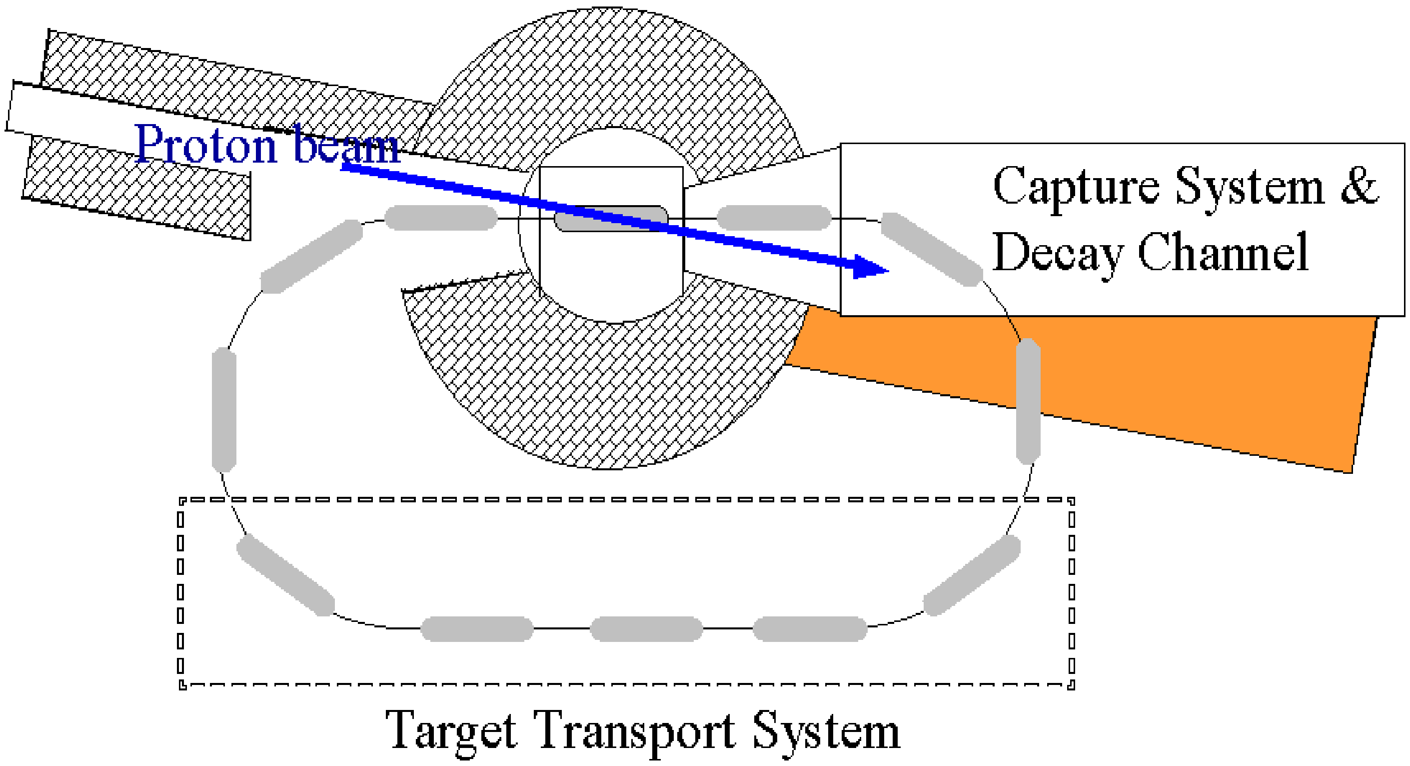
This would enable the UK to evaluate for itself how it would wish to contribute to future international particle physics facilities, with the option of making the contribution to the machine 'in kind' (as is done with the detectors)



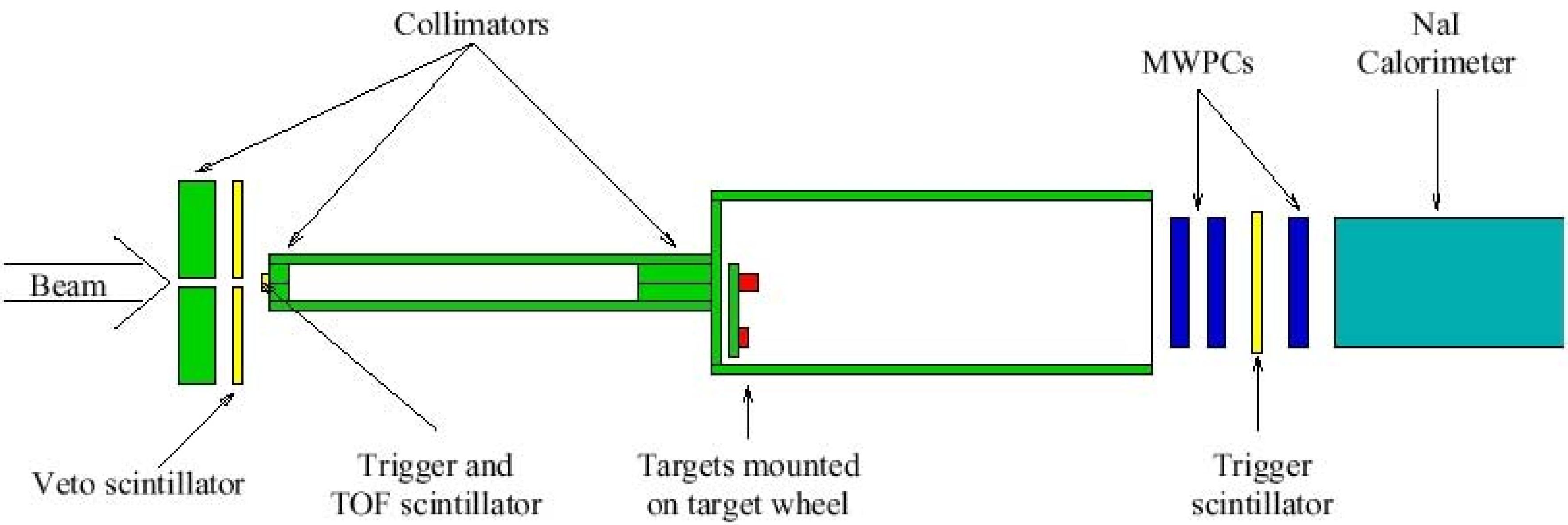
Accelerator studies for a neutrino factory Proton driver design

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)

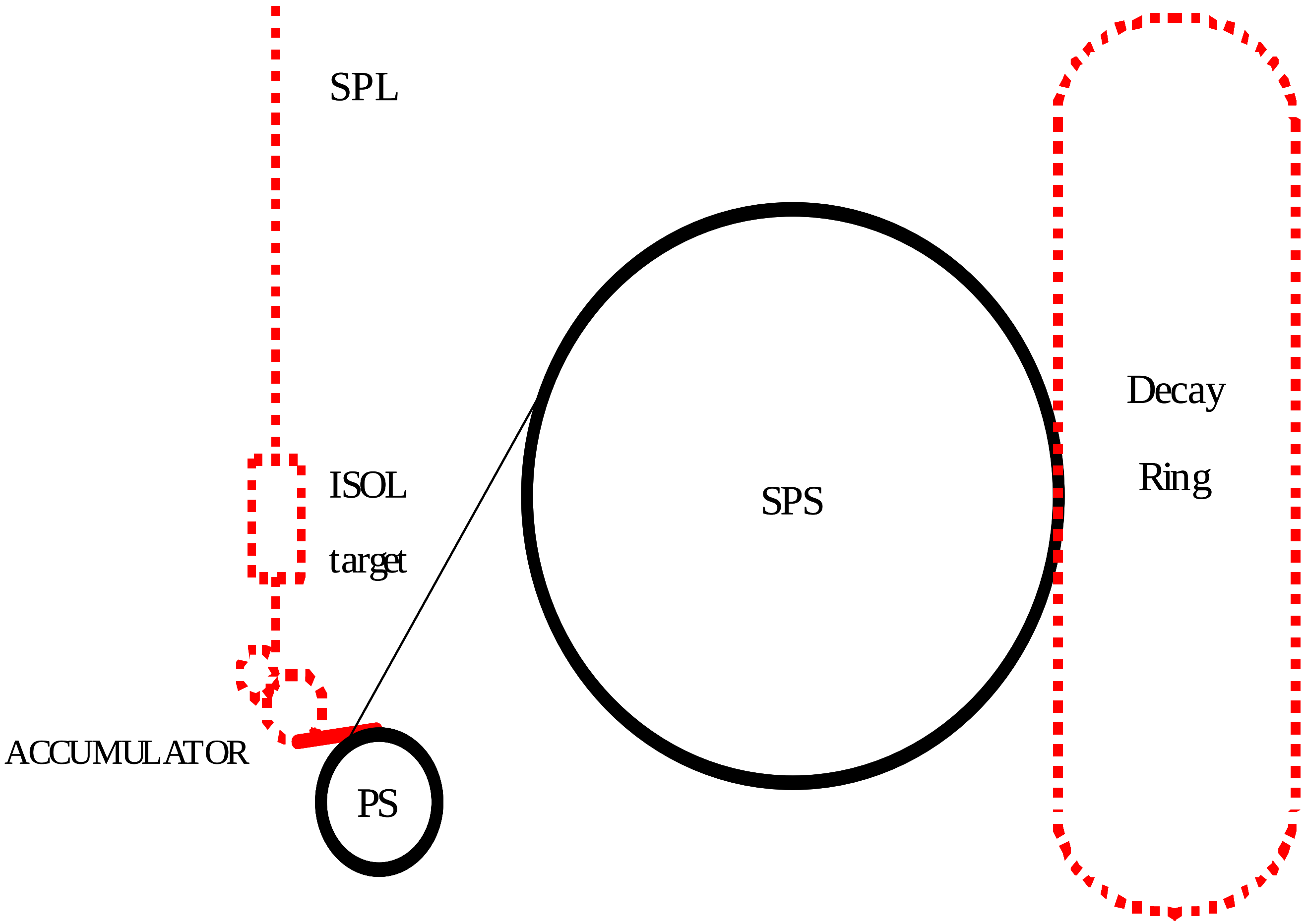


The MuScat experiment

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

Beta Beam

(P. Zucchelli)



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Beta Beam

(P. Zucchelli)

The beta-beam requires that ions be accelerated to a Lorenz gamma of 150 for ^{6}He and 60 for ^{18}Ne. The neutrino source itself consists of a storage ring for this energy range, with long straight sections in line with the experiment(s). Such a storage ring does not exist at CERN today, nor does a high intensity proton source for the production of the radioactive ions. Nevertheless, it seems prudent to study if any of the existing CERN accelerator infrastructure can be used as this could still represent an important saving for a beta-beam facility. Such a study has been started and has already revealed some important facts.

	^{6}He ($T_{1/2}$=0.8 s)	^{18}Ne ($T_{1/2}$=1.67 s)
Accumulator	1 s, 46 %	1 s, 26 %
PS	0.8 s, 12 %	0.8 s, 5 %
SPS	5 s, 3 %	2 s, 2 %

Losses for ^{6}He and ^{18}Ne in the different machines. The losses are given as the percentage of the initial beam intensity

M. Lindroos et al.

Beta Beam

(P. Zucchelli)

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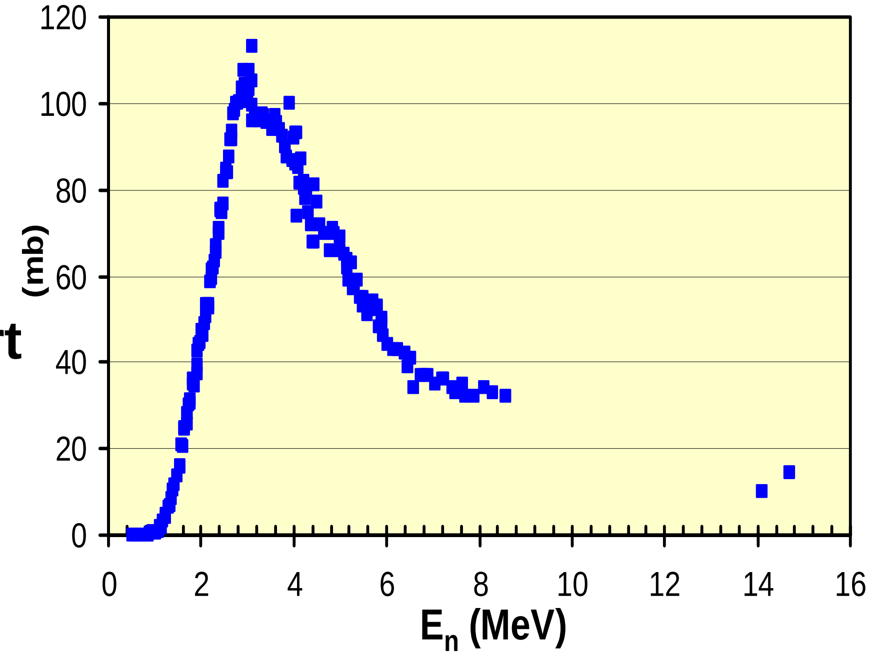
M. Lindroos

^{6}He production by ^{9}Be(n,α)

^{9}Be(n,α)^{6}He reaction favorable:

- **Threshold: 0.6 MeV**
- **Peak cross-section 105 mb**
- **Good overlap with evaporation part of spallation neutron spectrum: n(E)~√E*exp(-E/E$_e$)**
- **E$_e$: 2.06 MeV for 2 GeV p on Pb**
- *G.S. Bauer, NIM A463 (2001) 505*
- **BeO very refractory**
- *U. Köster et al., This conf.*



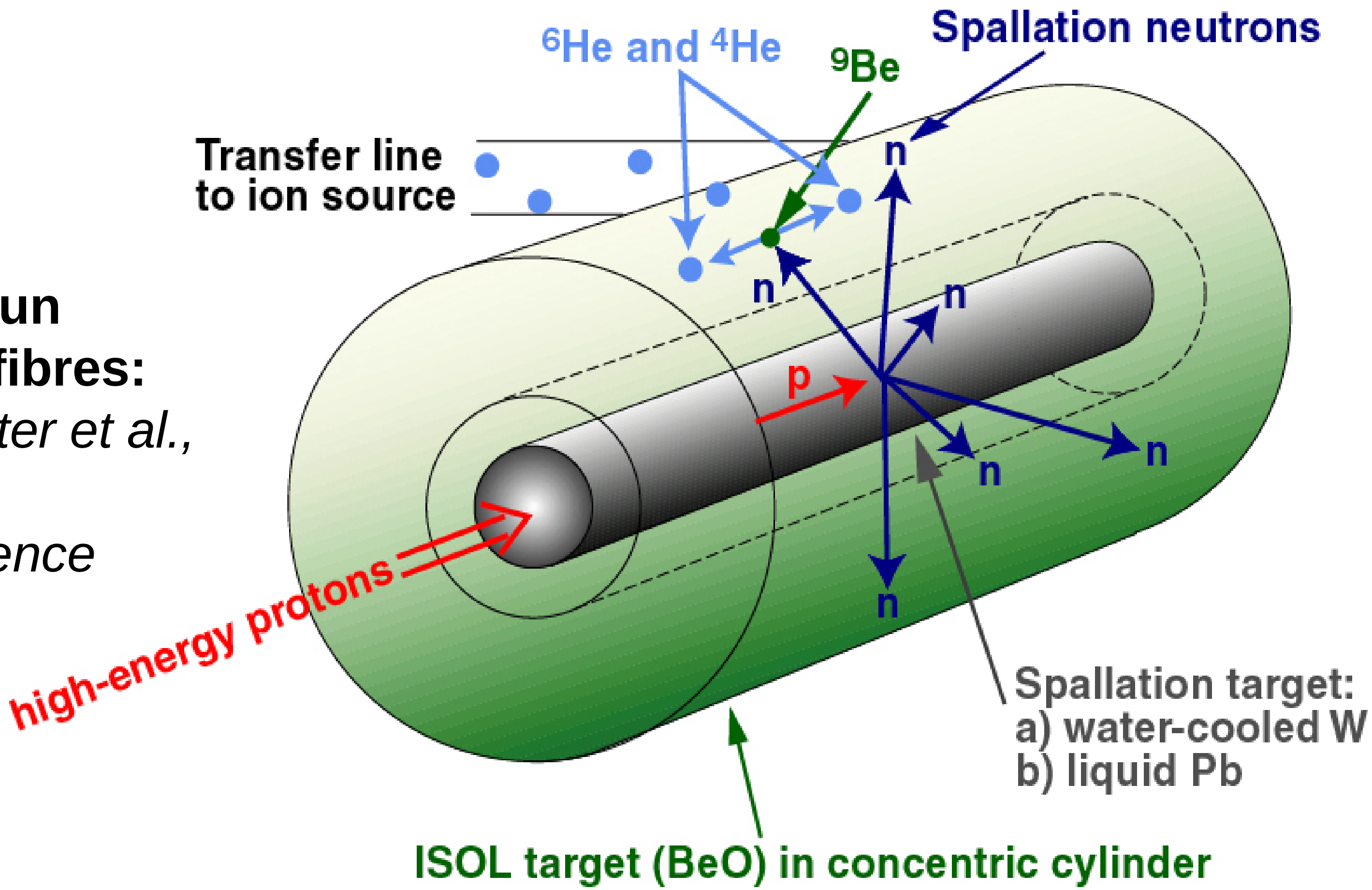
^{6}Li(n,p)^{6}He reaction less interesting:

- **Threshold: 2.7 MeV**
- **Peak cross-section 35 mb**
- **Li compounds rather volatile**

H. Ravn

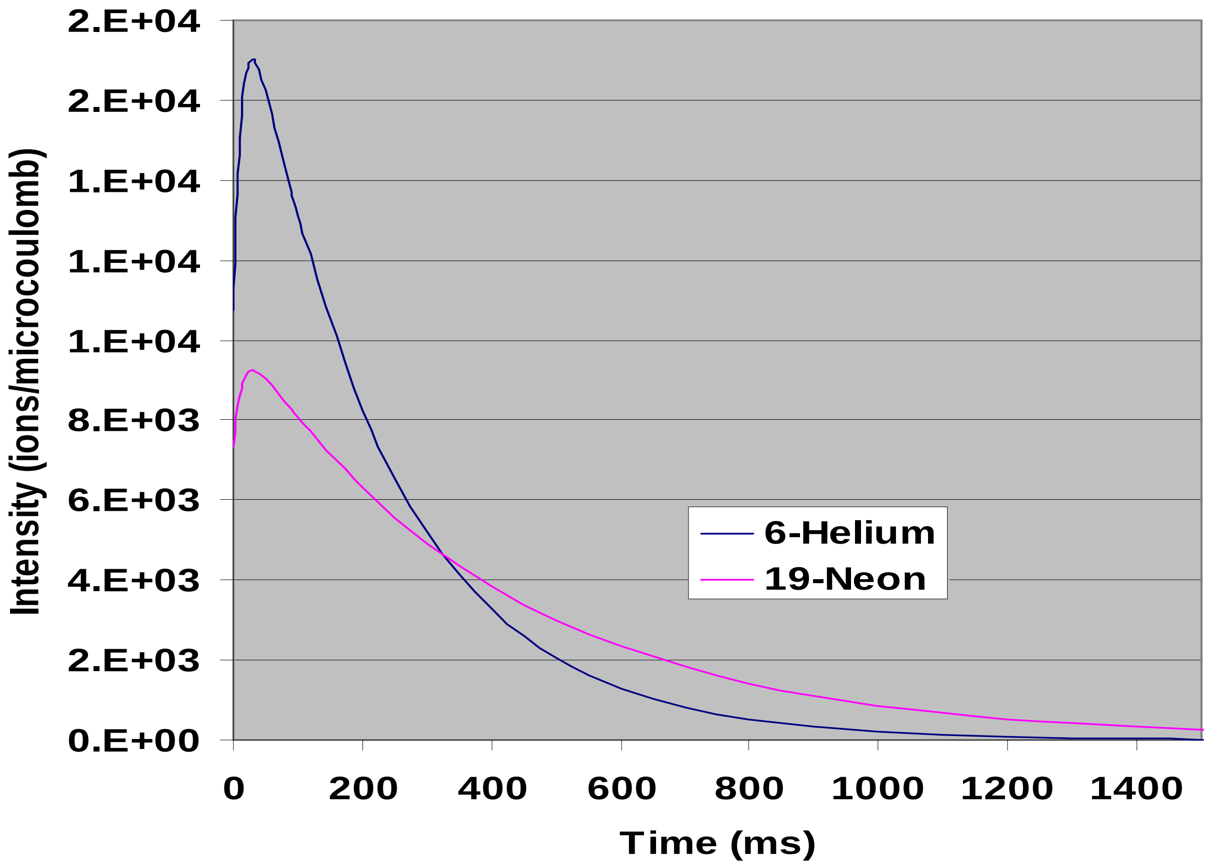
^{6}He production by ^{9}Be(n,α)

Berylliun oxide fibres:
U. Köster et al., This conference



Layout very similar to proposed NuFact and EURISOL converter targets aiming for 10^{15} fissions per s.

H. Ravn



H. Ravn

Target element and technique	Target thickness	Cross section	Proton driver beam		Rate in target	Transfer	6-He Beam
	g/cm2	cm2	Energy (GeV)	Intensity (mA)	atoms/s	efficiency	ions/s
MgO target technology presently operating	3	1.00E-27	1	0.004	1.86E+09	0.025	4.65E+07
BeO technology improved with known technique and SPL	30	1.00E-26	1	0.1	4.65E+12	0.25	1.16E+12
New BeO target technology to be developed for SPL	30	1.00E-26	2.2	2.5	3.14E+14	0.25	7.84E+13
Mercury-jet target technology to be developed for SPL	800	2.60E-26	2.2	2.5	9.75E+14	0.05	4.88E+13
			Spallation neutrons (n,α)				
BeO with converter technology under development and SPL	3	6.80E-25	2.2	2.5	2.13E+15	0.25	5.33E+14

First meeting of the European Muon Concertation and Oversight Committee (EMCOC)
DRAFT

A. Blondel

1. Mandate

A neutrino factory based on a muon storage ring is the ultimate tool for studies of neutrino oscillations, including possibly leptonic CP violation. It is also the first step towards $\mu^+\mu^-$ colliders. This interesting type of new accelerators has already been the object of conceptual studies, starting in the US and more recently in Europe and Japan. A European Neutrino Factory Complex may be one of the future possibilities for CERN.

A first round of studies has shown that a neutrino factory could probably be built with accessible technologies, and with performances matching the requirements of an exciting physics programme. The cost evaluations are however quite high and the techniques envisaged have often never been applied in practice. Many appealing and partially explored options exist for several of the subsystems. It thus appears that a sizeable programme of R&D will be necessary.

It is felt desirable that accelerator R & D effort be kept at a level allowing CERN an active but affordable role in a framework of enhanced collaboration among Laboratories.

It is proposed to develop a European Collaborative effort to undertake a programme of studies at the theoretical, engineering and experimental levels. The first step, as already discussed since 2000, is to assemble a Muon Concertation and Oversight Committee.

The first task of this committee will be to review the status of R&D studies and plans and of the more or less formal collaborations that have already taken place, and to establish a fist set of basic goals. Two persons (one representative and one surrogate) of the major participating laboratories and funding agencies had been nominated. An organisational structure should be discussed and proposed to the relevant authorities.

Present:
CERN: Carlo Wyss, Helmut Haseroth
CEA-DAPNIA: Alban Mosnier
Geneva: Alain Blondel
GSI: Oliver Boine-Frankenheim
INFN: Marco Napolitano (Napoli), Andrea Pisent (Legnaro)
IN2P3: Stavros Katsanevas, Marcel Lieuvin
PSI: Ralph Eichler
RAL : Ken Peach

Excused François Pierre (CEA), Ingo Hofmann (GSI)

Task of EMCOG:

- Undertakes actions in order to promote and coordinate activities making optimal use of resources across the laboratories and ensure convergence on a unique conceptual design.

- Provides a forum where major European laboratories and funding agencies exchange information and ideas and monitor progress of R&D activities.

- Advises laboratories and funding agencies on the above matters and make proposals for implementing them.

The committee unanimously appointed the nomination of Carlo Wyss as chairperson of EMCOG and Alain Blondel as Scientific secretary.

FIRST SET OF BASIC GOALS

The long-term goal is to have a Conceptual Design Report for a European Neutrino Factory Complex by the time of LHC start-up, so that, by that date, this would be a valid option for the future of CERN.

An earlier construction for the proton driver (SPL + accumulator & compressor rings) is conceivable and, of course, highly desirable. The SPL, targetry and horn R&D have therefore to be given the highest priority.

Cooling is on the critical path for the neutrino factory itself; there is a consensus that a cooling experiment is a necessity.

The emphasis should be the definition of practical experimental projects with a duration of 2-5 years. Such projects can be seen in the following four areas:

1. High intensity proton driver. Activities on the front end are ongoing in many laboratories in Europe, in particular at CERN, CEA, IN2P3, INFN and GSI. Progressive installation of a high intensity injector and of a linear accelerator up to 120 MeV at CERN (R. Garoby et al) would have immediate rewards in the increase of intensity for the CERN fixed target program and for LHC operation. GSI…. EMCOG will invite a specific report on the status of the studies and a proposal for the implementation process.

2. Target studies. This experimental program is already well underway with liquid metal jet studies. Goal: explore synergies among the following parties involved: CERN, Lausanne, Megapie at PSI, EURISOL, etc…

3. Horn studies. A first horn prototype has been built and is being equipped for pulsing at low intensity.
5 year program to reach high intensity, high rep rate pulsing, and study the radiation resistance of horns. Optimisation of horn shape. Explore synergies between CERN, IN2P3 Orsay, PSI (for material research and fatigue under high stress in radiation environment)

4. MICE. A collaboration towards and International cooling experiment has been established with the muon collaboration in United States and Japanese groups. There is a large interest from European groups in this experiment. Following the submission of a letter of Intent to PSI and RAL, the collaboration has been encouraged to prepare a full proposal at RAL, with technical help fro RAL. PSI offers a solenoid muon beam line and CERN, which as already made large initial contributions in the concept of the experiment, could earmark some very precious hardware that could be recuperated. A summary of the requests should be presented by the collaboration.

It is noted that the first three items are also essential for a possible initial neutrino program with a high intensity low energy conventional neutrino beam (superbeam).

Theoretical studies. Many open questions exist on the design of Neutrino Factory. For instance:

Choice of proton driver: energy, intensity, time structure and repetition rate.
Muon beam preparation technique: FFAG vs phase rotation and cooling, possibility to combine the two.
Muon acceleration: FFAG vs recirculating linacs
It is believed that if a sufficient program of experimental activities exists, it should be naturally accompanied by theoretical studies.

Mandate is given to Helmut Haseroth to propose a Europe-wide neutrino factory working group.

Next meeting :

At the occasion of NUFACT02, for the summary talks followed by a meeting of the EMCOG. On Saturday 6, Sunday 7 July in London or Abingdon.

Tentative agenda of the next meeting:

0. approval of minutes etc…
1. report from proton driver studies and proposal for front end implementation
2. target activities and proposal by H. Ravn.
3. short report from MICE
4. European Union proposal report
5. Proposal for ENFWG