Neutrino Factory: The Machine,

Status and Plans

H. Haseroth

for the

Neutrino Factory Working Group

at CERN

The Basic Concept of A Neutrino Factory

⇒Proton driver

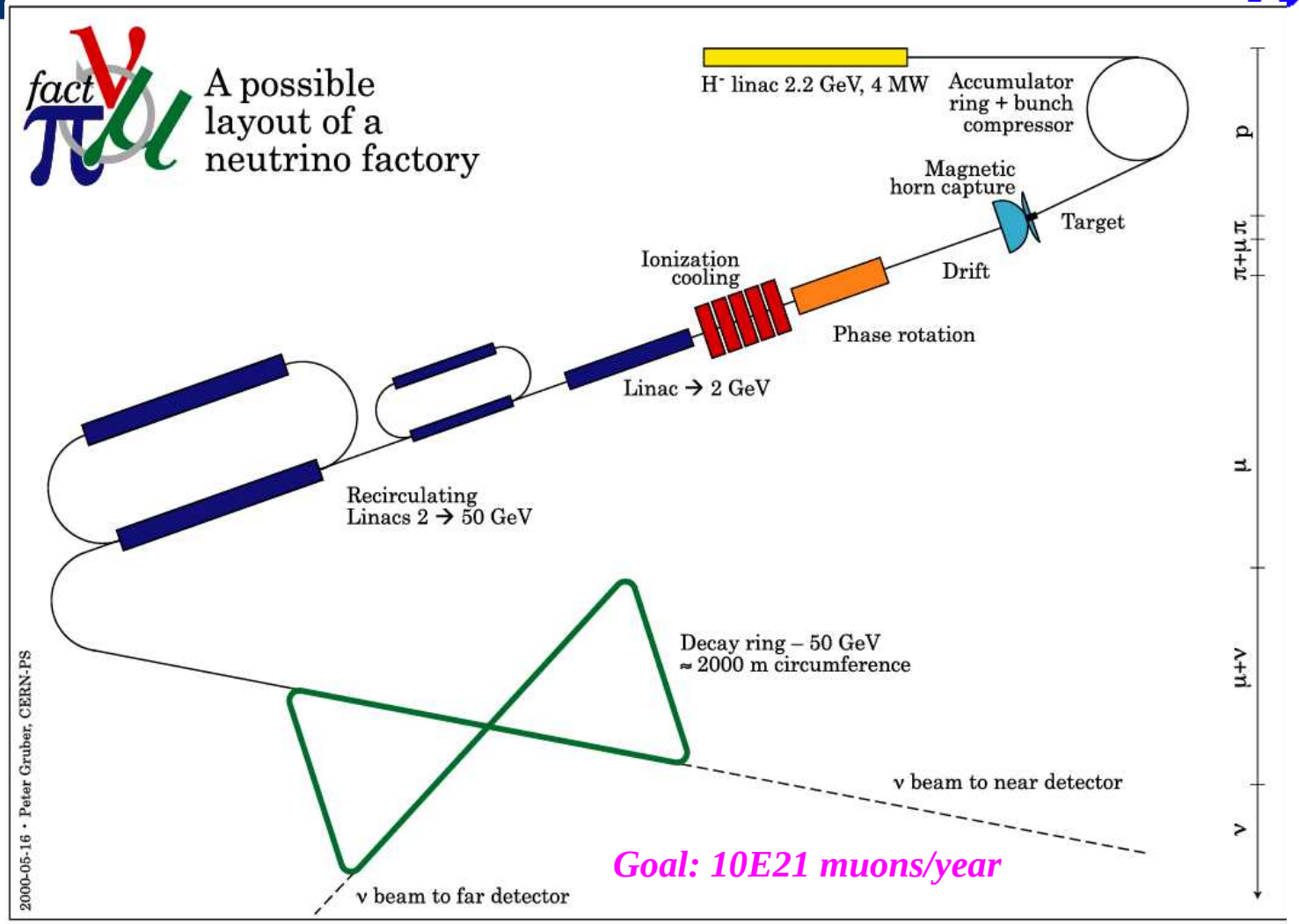
⇒High-power proton beam onto a target

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

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

⇒Acceleration of the muon beam with a linac and “RLAs” (Recirculating Linear Accelerators)

⇒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
2000-05-16 • Peter Gruber, CERN-PS
p
π+μ π
μ
μ+ν
ν

There are not too many options for the basic elements: What is special about the CERN study?

2.2 GeV Proton Driver

≈350 MCHF for the linac part (using LEP hardware)

Target for 4 MW

Collection of pions with horn

40/80 MHz capture/cooling system

(No-Cooling scheme studied)

No Be windows for RF cavities

RLAs and Decay Ring: Layout on CERN site possible

Detector locations being investigated: H. Wenninger et al.

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE

CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

DRAFT - 13.11.2000

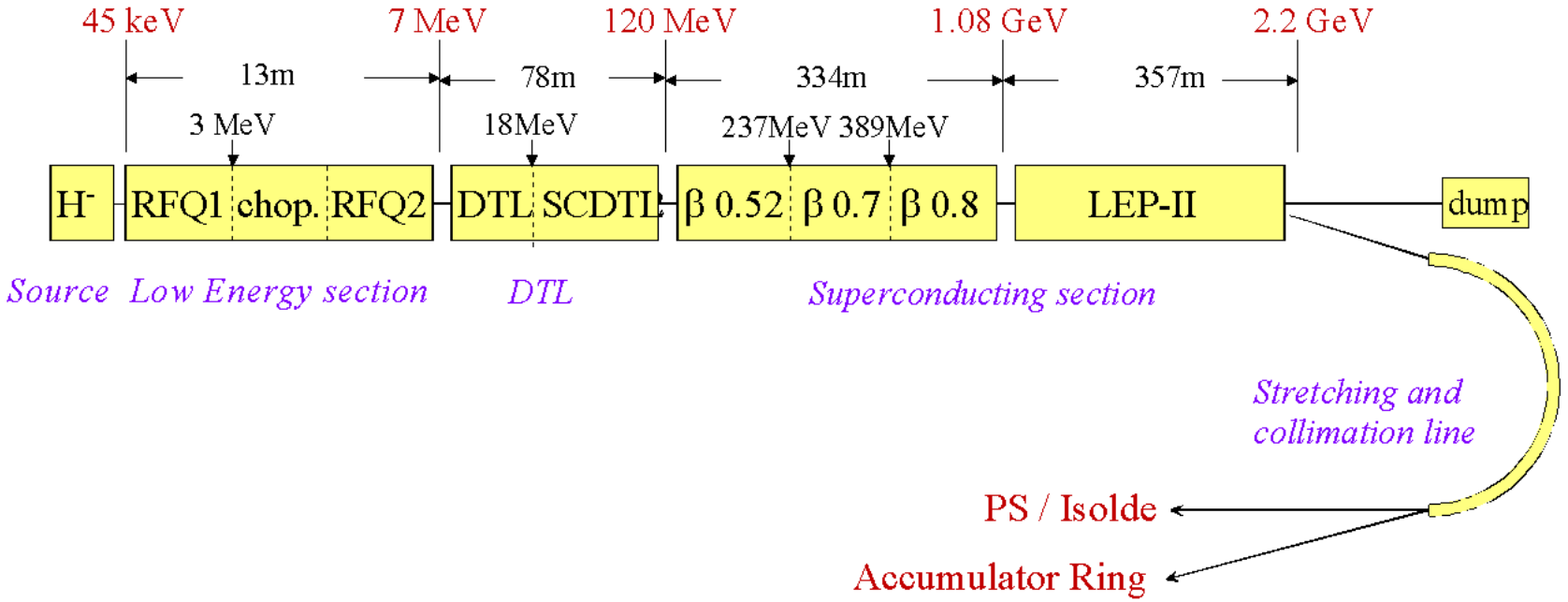
CONCEPTUAL DESIGN OF THE SPL, A HIGH-POWER SUPERCONDUCTING H⁻ LINAC AT CERN

B. Autin, A. Blondel, K. Bongardt, R. Cappi, F. Caspers, E. Cennini, E. Chiaveri, S. Claudet, R. Garoby, F. Gerigk H. Haseroth, C. Hill, N. Hilleret, J. Inigo-Golfin, M. Jimenez, A. Krusche, D. Kuchler, M. Lindroos, A. Lombardi, R. Losito, R. Nunes, M. Paoluzzi, J. Pedersen, M. Poehler, H. Ravn, M. Sanmartí, H. Schönauer, M. Silari, J. Tückmantel, A. Vital, M. Vretenar

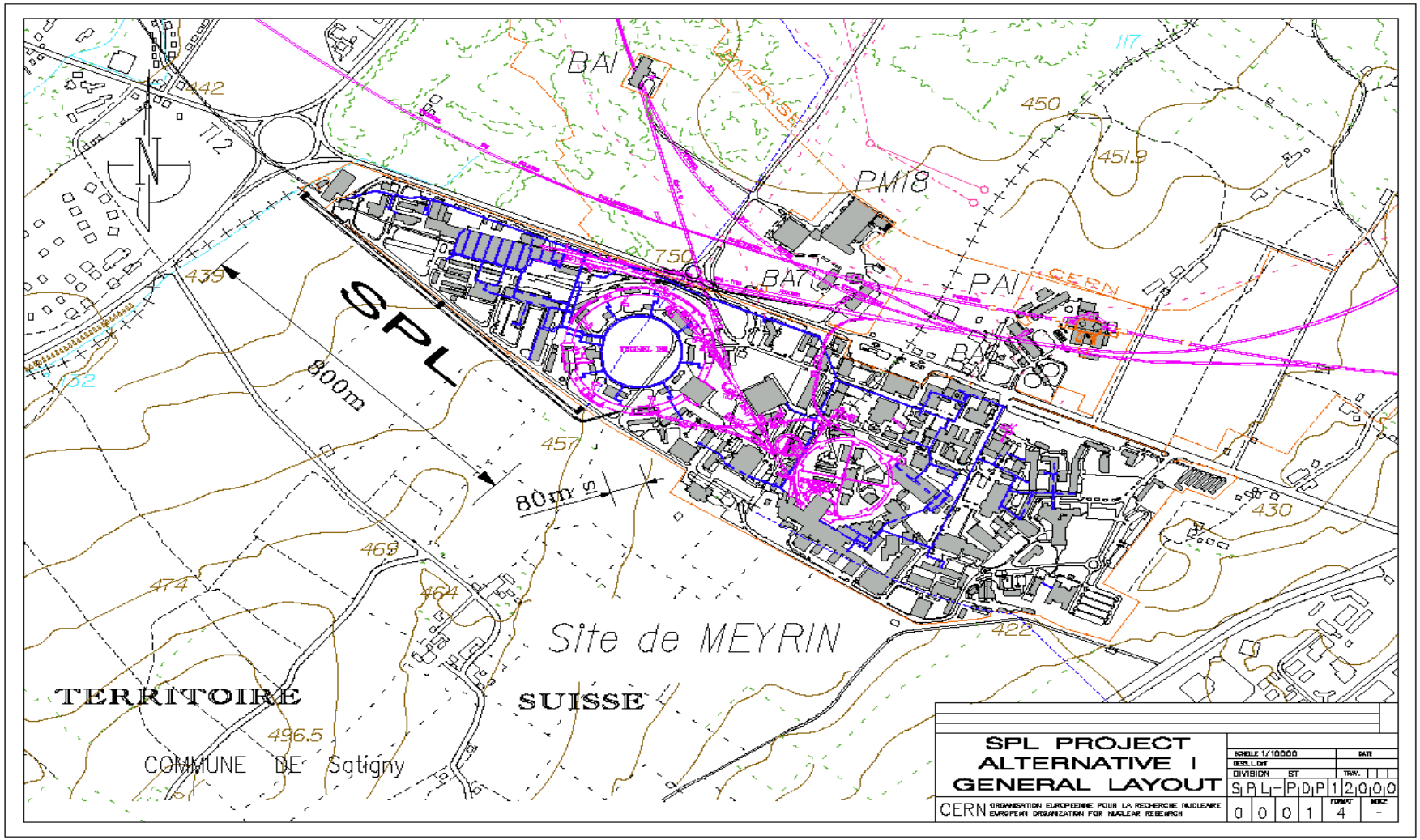
Editors: A. Lombardi,

M. Vretenar

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



The SPL on the CERN site



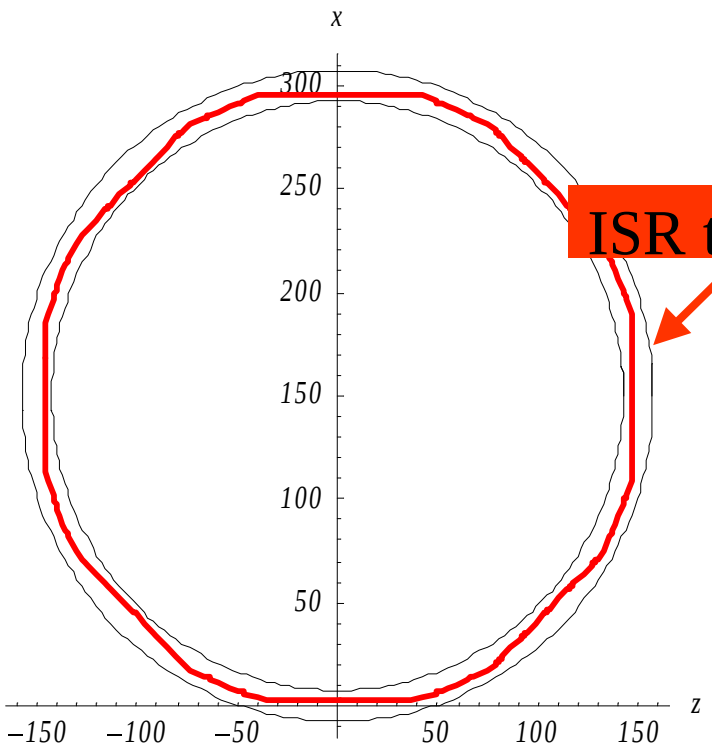
SPL TOTAL COST ESTIMATE

Last update: 22/11/2000

R. Garoby for the SPL study group

ITEM	COST ESTIMATES (MCHF)
H- Source	0.6
RFQs & LEBT	6
Chopper with high & low power electronics	3.5
DTL	9
Quads with power supplies	10
Tetrode amplifiers (+ spares)	20
Klystron amplifiers (+10 new klystrons)	25
Cavities servos and beam phase monitoring	3
Reduced beta SC cavities (+ spares)	55
Beta=1 SC cavities	5
Beam instrumentation	6.3
Controls	6
Civil engineering	75.7
Cooling & Ventilation	10
Controlled access & Alarm	1.3
Electricity	14.6
Cryogeny	40
Vacuum	8
Transfer lines (vacuum, magnets, power supplies)	4
Dumps (2 + 1.5 spare)	1.8
Radiation monitoring	0.5
Injection in the PS	4
Injection in ISOLDE	0.5
Land acquisition	1.5
Cavities cold test (3 bunkers + 5 years duration)	10
Contingencies	28.7
TOTAL	**350**

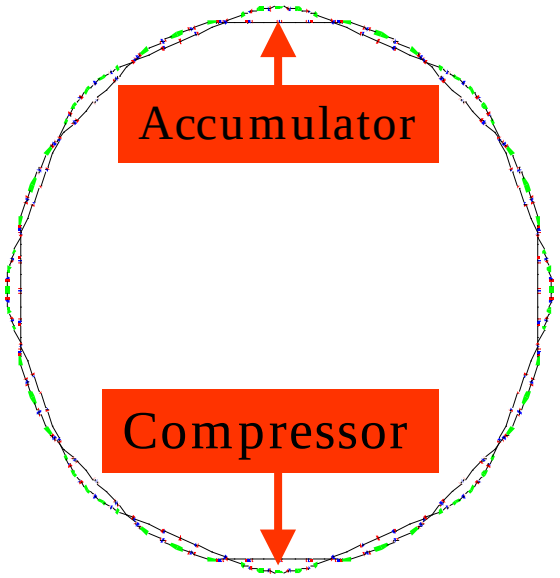
2.2 GeV RAL Accumulator



ISR tunnel

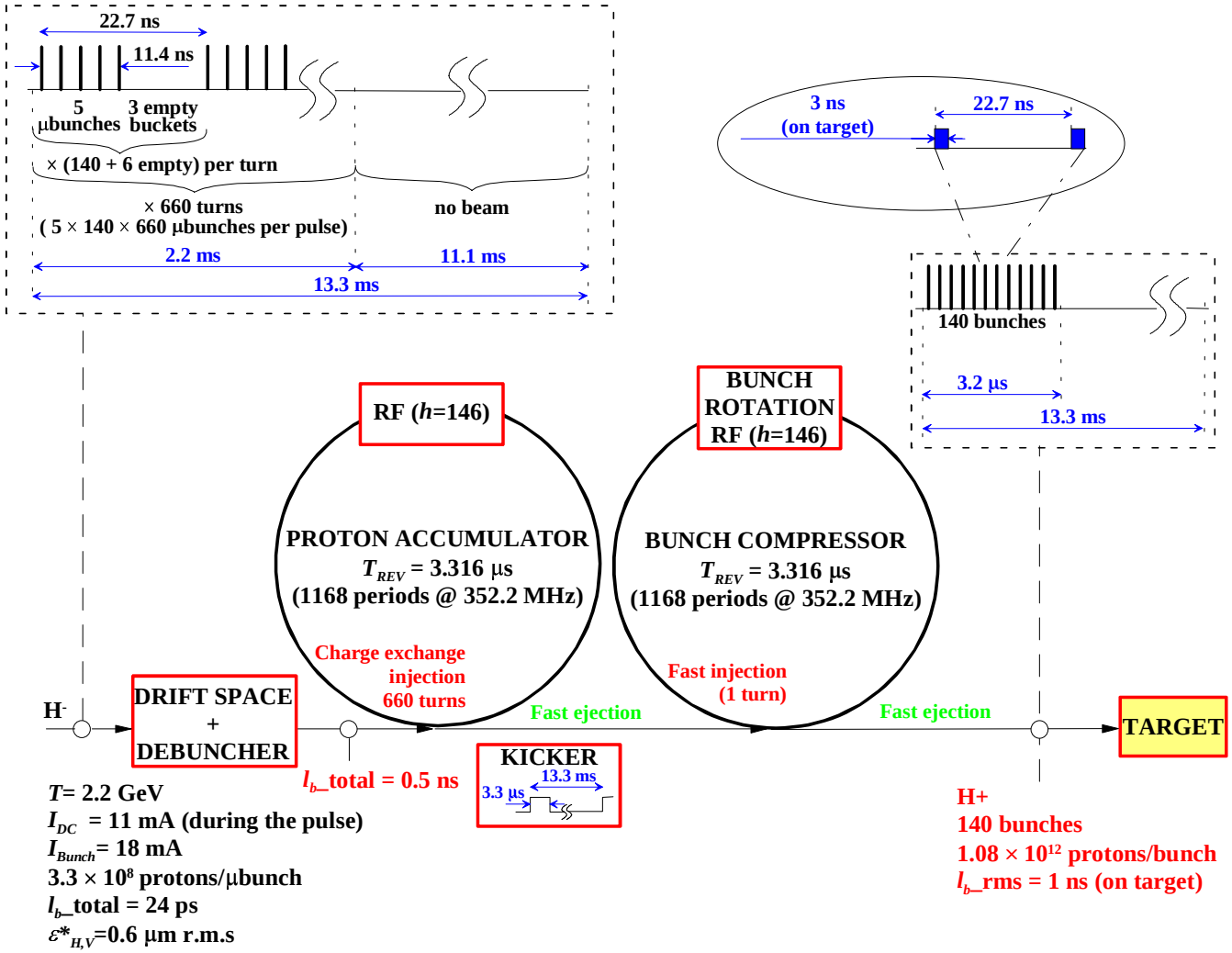
Mean ring radius=150 m

Accumulator & Compressor

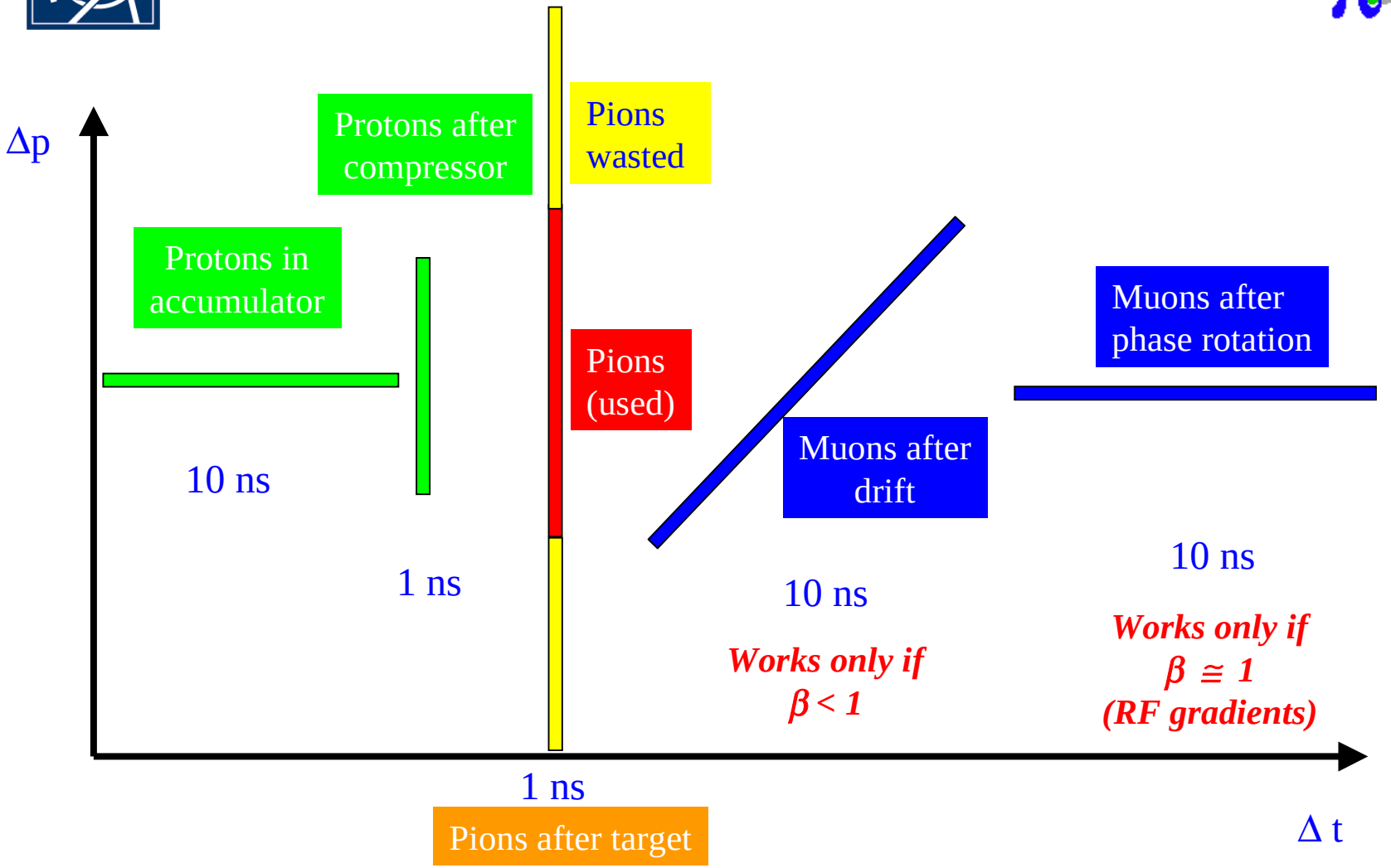


in ISR Tunnel

Accumulator-Compressor scheme for a Neutrino Factory



Why a compressor ring? Why bunch rotation? (146 bunches during 3.3μs)



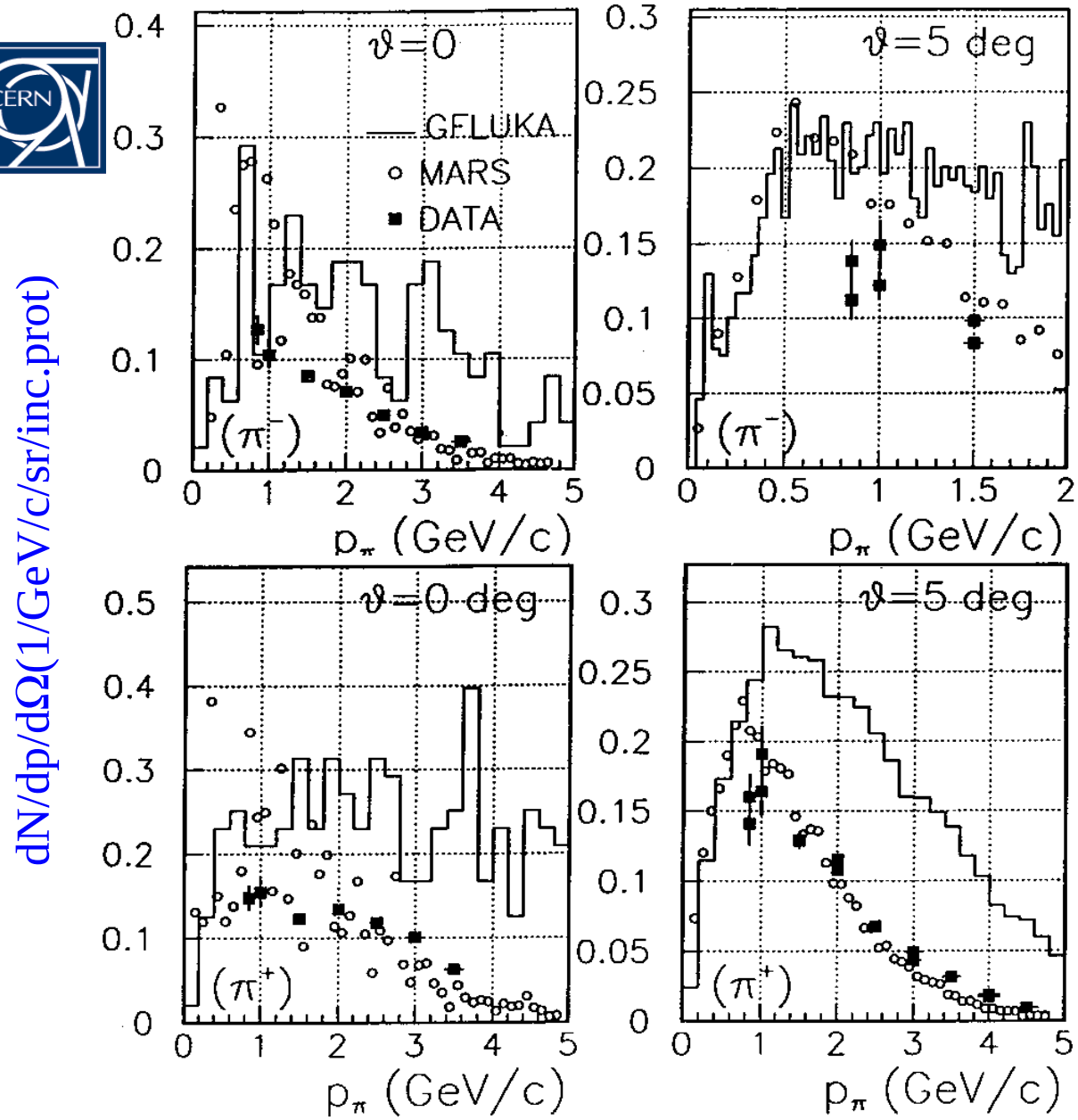
Target and Pion Capture

A number of ideas are under consideration which in principle should allow a beam power on target power of up to 4 MW.

The crucial problems are mechanical movements in high magnet fields, heat transfer, material stress, radiation damage and radioactivity confinement.

TARGET

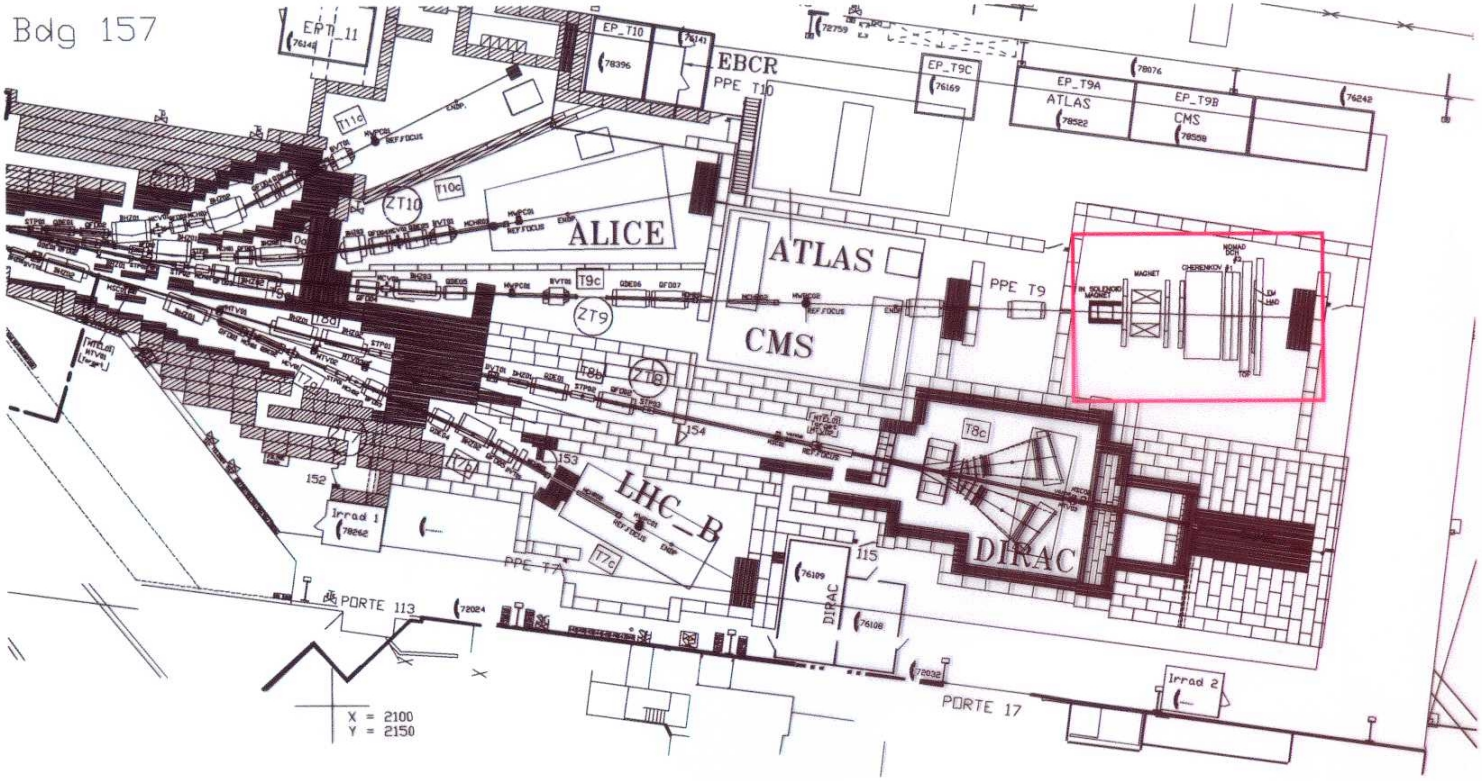
Equipment and expertise on liquid mercury technology exists at CERN and we believe that this is the most promising direction.



8 GeV/c protons on 10 cm Pb target

Large differences between GFLUKA, MARS and exp. data:

HARP will produce the required measurements at different energies and for different materials



Layout of the experiment to study Hadron Production for

the Neutrino Factory

and for the Atmospheric Neutrino Flux

PION collection: HORN

Since one is interested in the production of pions of only one polarity for any given proton bunch, we envisage a pion collection system based on azimuthal magnetic fields generated by a horn. A major advantage of horns is that the parts exposed to the beam are rather simple, inexpensive and can be radiation hard.

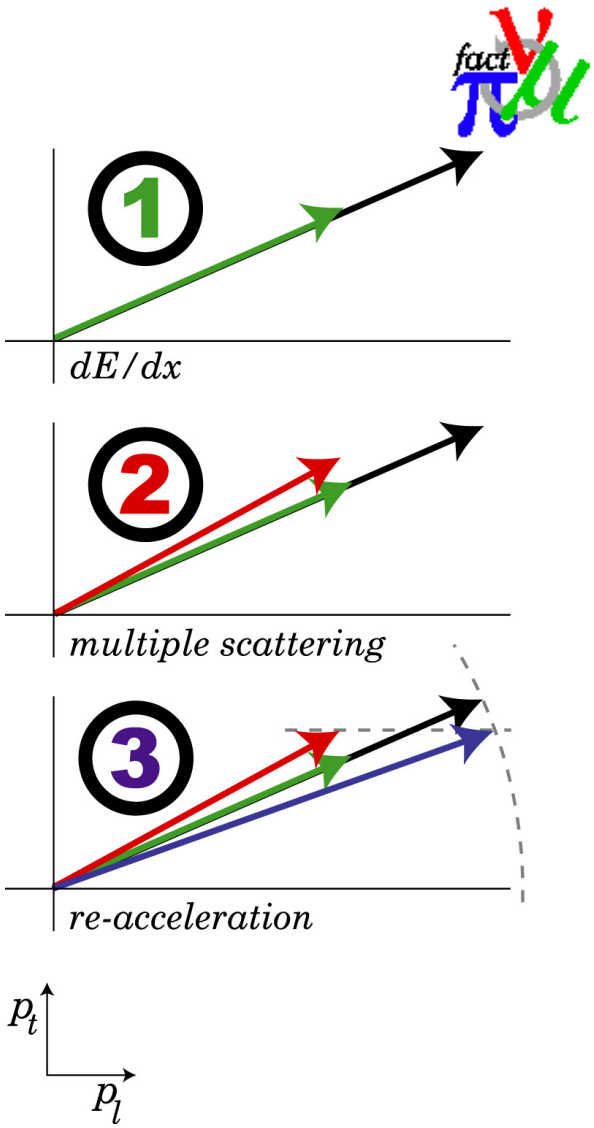
The horn will be designed to focus particles emitted at large angle, and with a momentum range of 200-400 MeV/c, from a target of typically 2-interaction lengths.

Principle of Ionisation Cooling

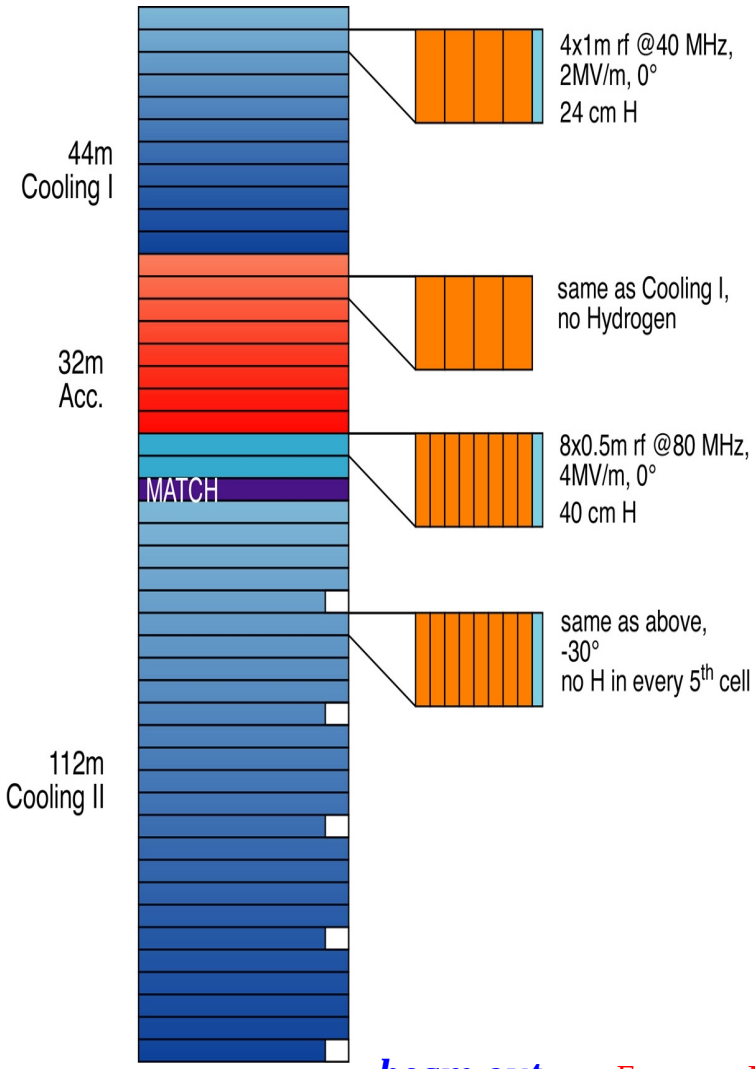
Ideally a muon is stopped by passing through some material and is being accelerated in the forward direction.

Because it would have decayed in the meantime, only some reduction in longitudinal and transverse momentum is applied. The longitudinal momentum is being replaced again by RF acceleration.

Problem: Heating because of multiple scattering.



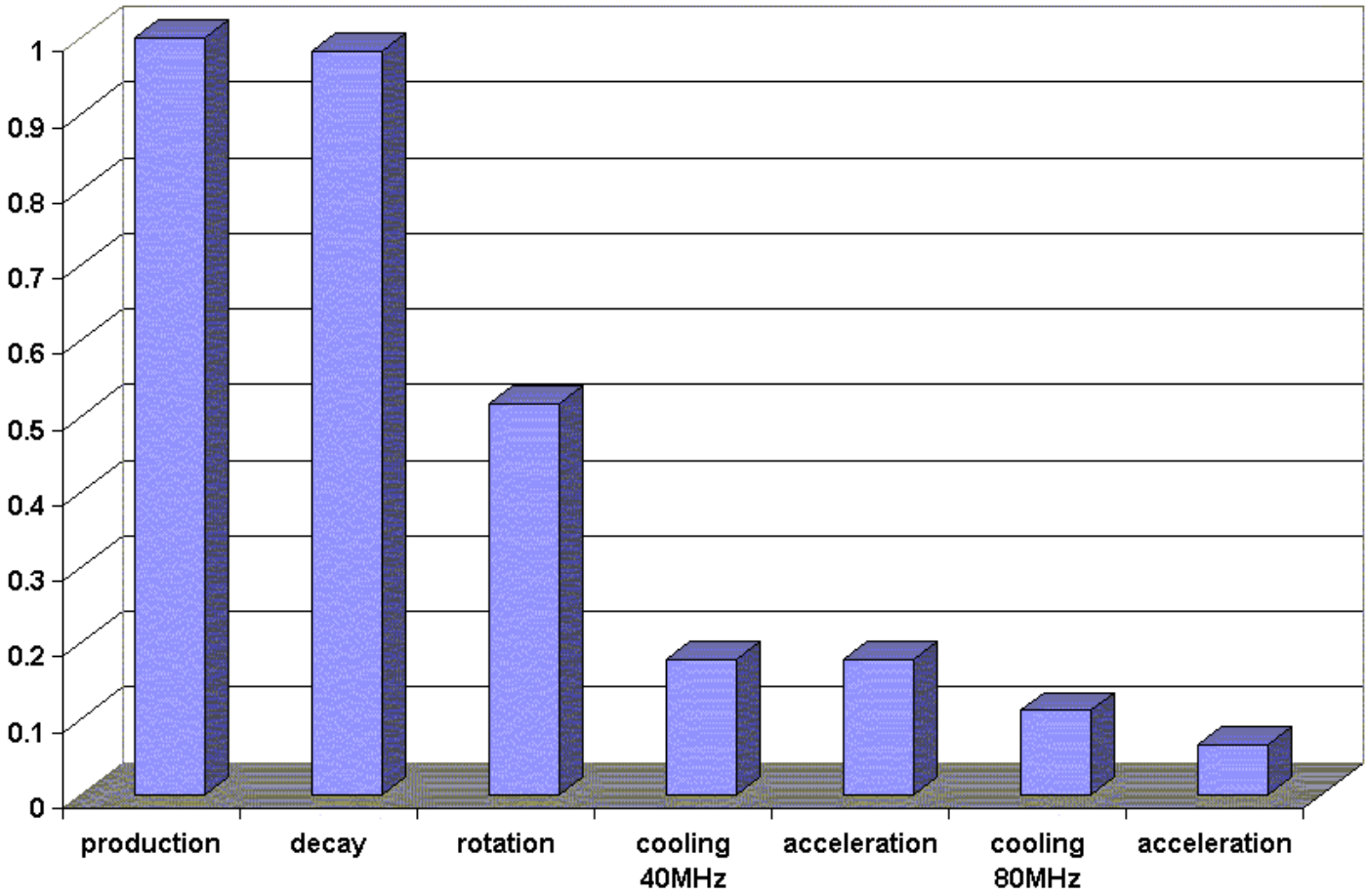
Layout of 40/80 MHz Cooling Channel



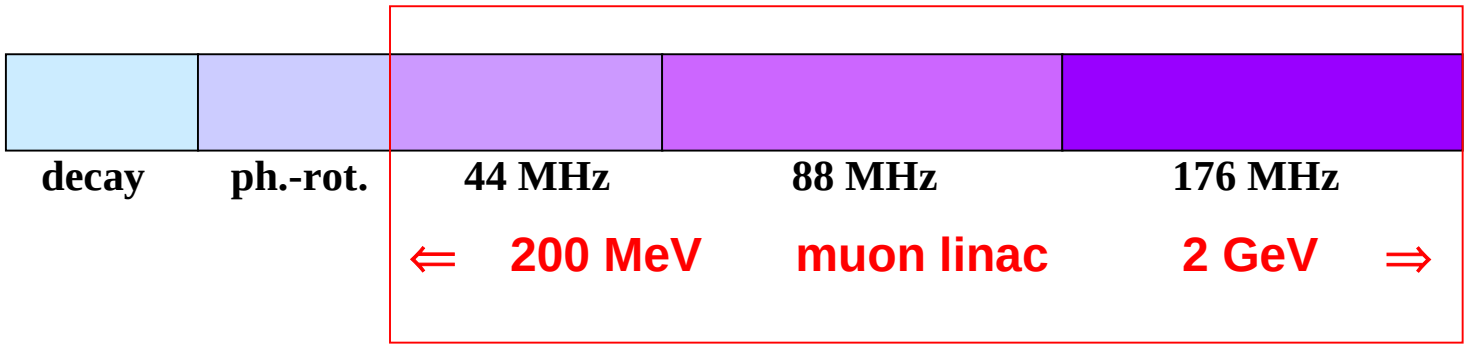
	Decay	Rotation	Cooling-I	Acceleration	Cooling-II	Acceleration
Length, m	30	30	46	32	112	≈450
Diameter, mm	600	600	600	600	300	200
Solenoid field, T	1.8	1.8	2.0	2.0	2.6	2.6
Frequency, MHz		44	44	44	88	88-176
Gradient, MV/m		2	2	2	4	4-10
Energy, MeV		200		280	300	2000

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

Pion/Muon Budget with Cooling



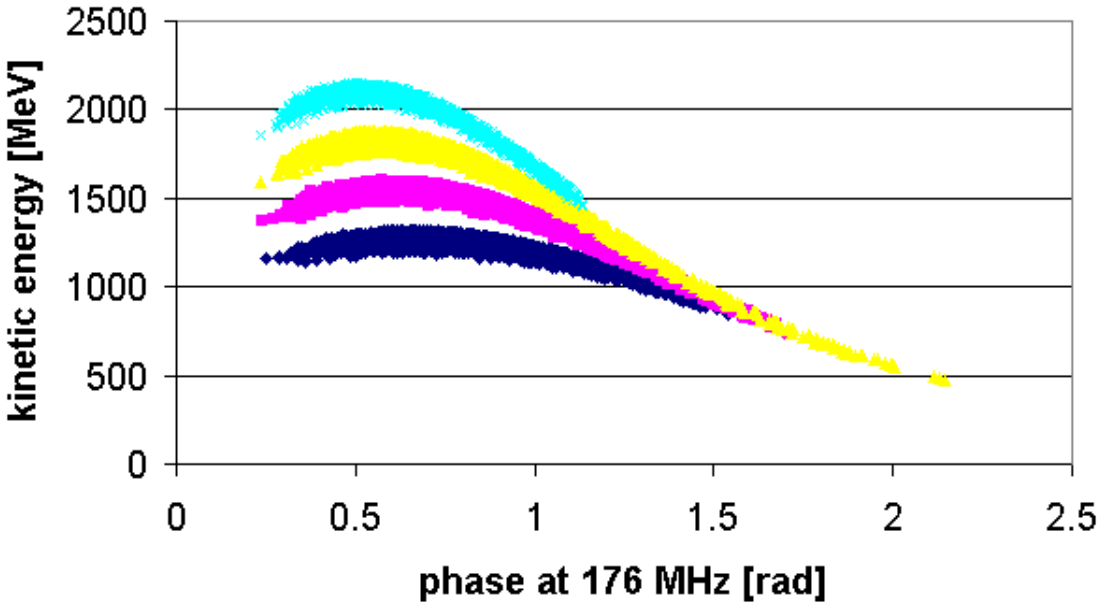
Study: Front-end without Cooling

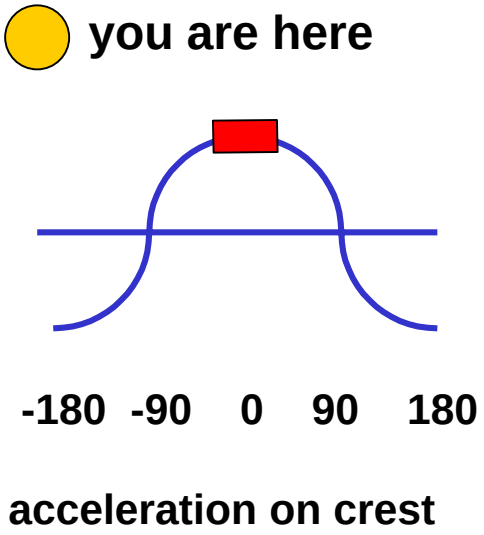


- target data from file
- decay channel, 30 m, 18 kG
- phase-rotation, 30 m, f = 44 MHz
- first acceleration section at 44 MHz, on crest
  2 MV/m, 44 cavities, cavity length 1 m, 20 kG, 44 m
- muon accelerator at 88 MHz, +- 45 deg
  4 MV/m, 520 cavities, cavity length 0.5 m, 26 kG, 260 m
- muon accelerator at 176 MHz, parameters to be defined
- total length up to 1 GeV: 364 m

Acceleration at 176 MHz

(no Cooling)

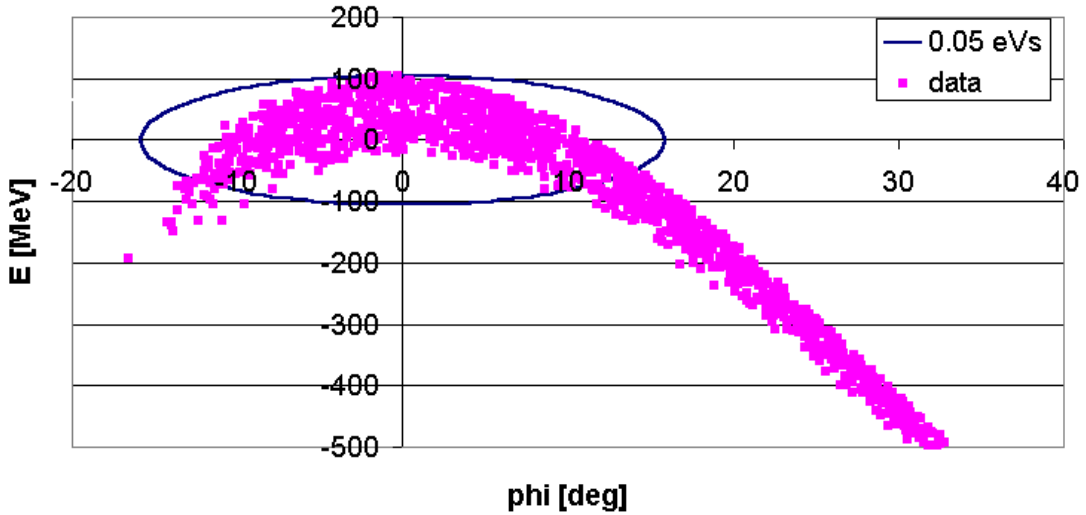




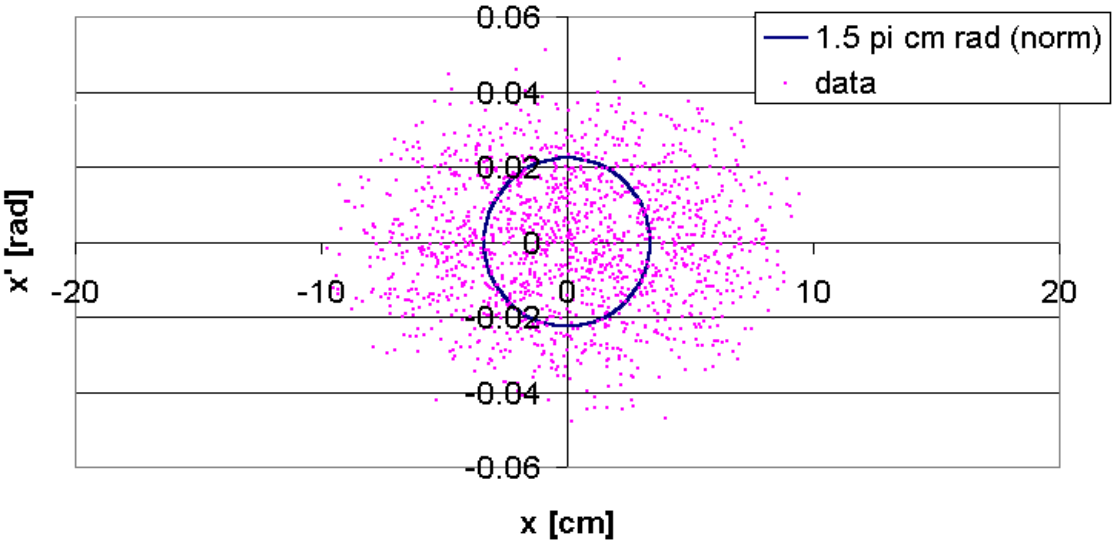
Muons in RLA Acceptance at 2 GeV

(no Cooling)

longitudinal



transverse



MUON Yield without and with Cooling

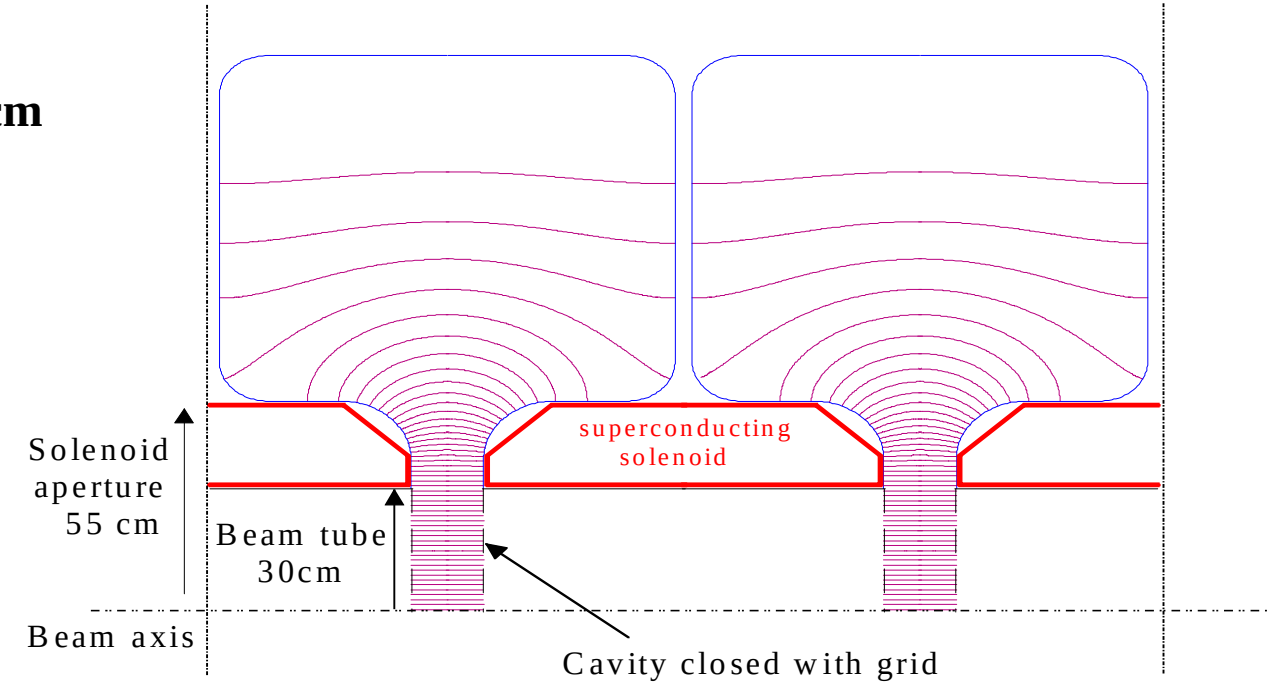
	NOCOOL	*with cooling*
long. emittance	0.05 eVs	0.05 eVs
rotation	6.7×10^{19}	6.7×10^{19}
44 MHz	6.8×10^{19}	
88 MHz	7.3×10^{19}	1.2×10^{21}
176 MHz	5.5×10^{19}	1.0×10^{21}

Note: Calculations have still to be made with the detailed field configurations!

44 MHz-cavities for muon capture and bunch rotation

Outer rad. = 144cm
Gap length = 16cm
Cavity length = 100 cm

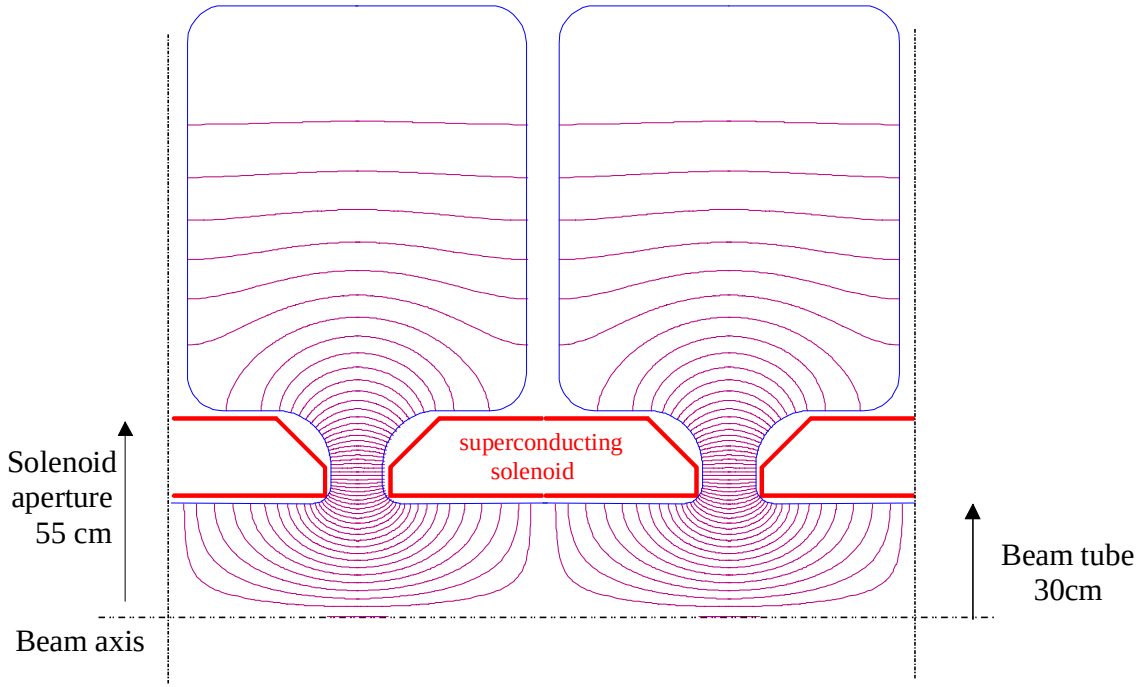
E_{MEAN} = 2MV/m
Z_{TT} = 5.5 MΩ/m
P = 0.73 MW/m
Q = 48000
T_{FILL} = 350 μs
P_{MEAN} ~ 60 kW/m

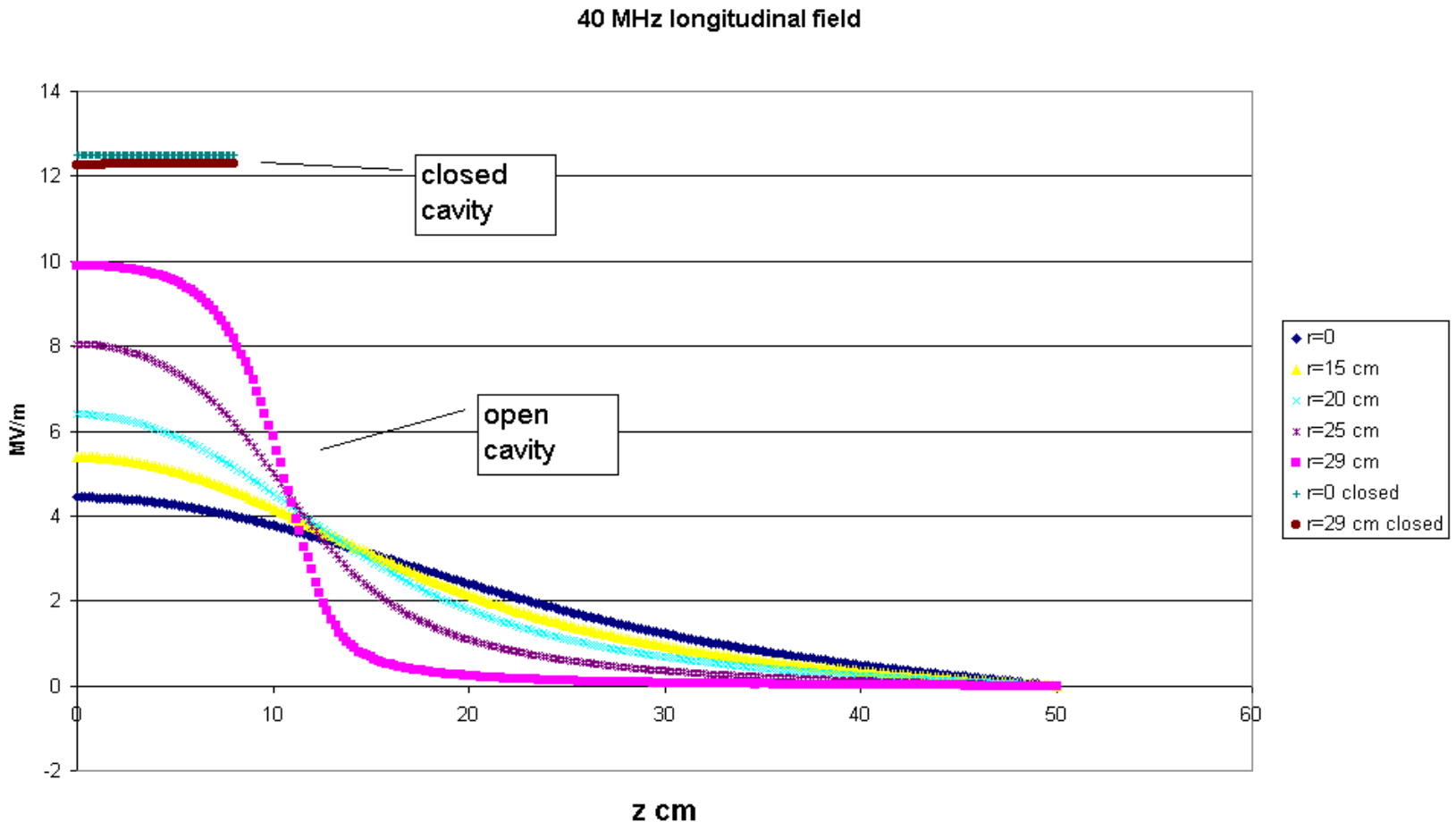


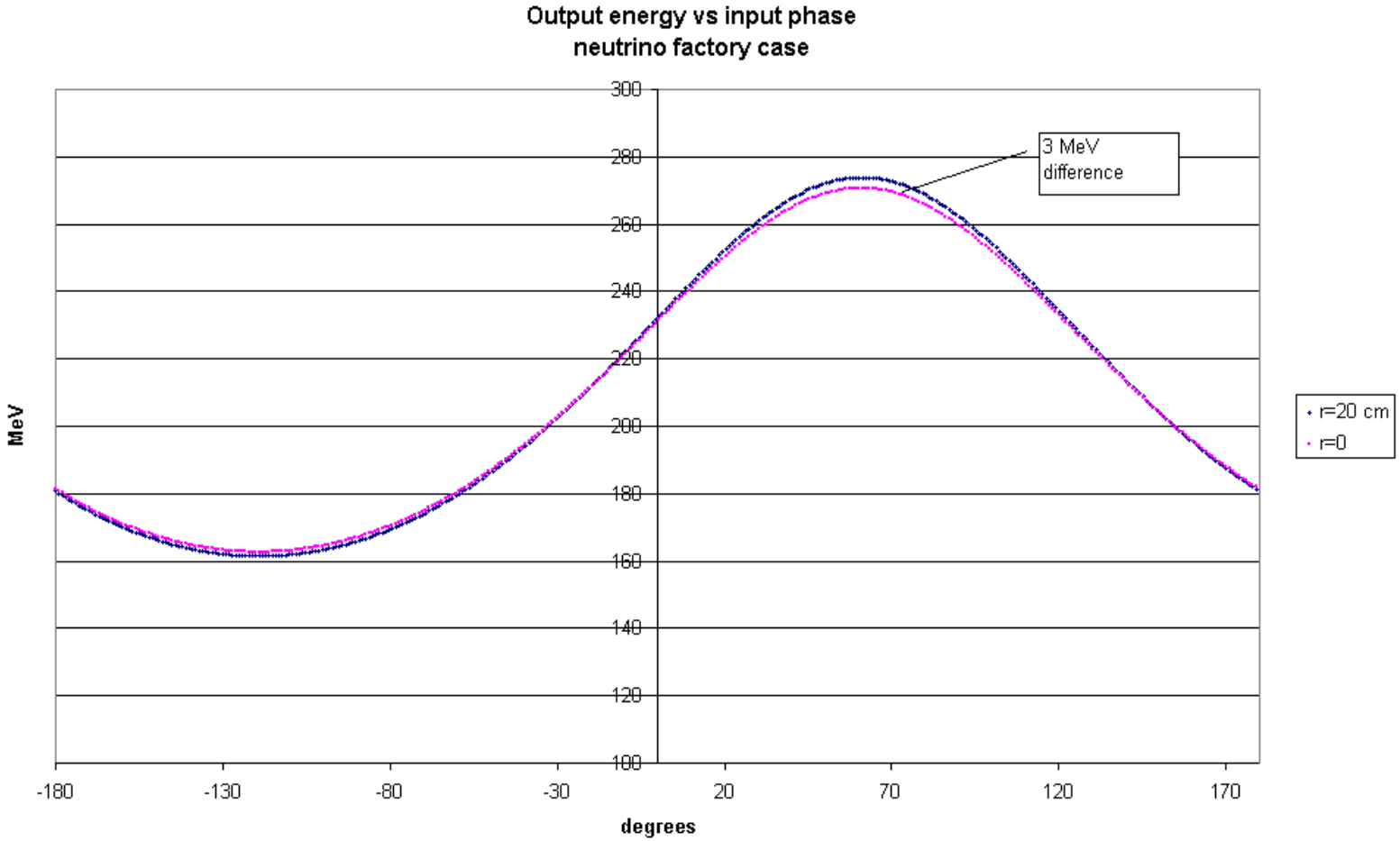
44 MHz-cavities for muon capture and bunch rotation with open gap

Outer rad. = 164cm
Gap length = 16cm
Cavity length = 100 cm

E_{MEAN} = 2MV/m
Z_{TT} = 5.7 MΩ/m
P = 0.70 MW/m
Q = 53000
T_{FILL} = 470 μs
P_{MEAN} ~ 100 kW/m




40 MHz longitudinal field
14
12
10
8
6
4
2
0
-2
MV/m
0
10
20
30
40
50
60
z cm
closed cavity
open cavity
r=0
r=15 cm
r=20 cm
r=25 cm
r=29 cm
r=0 closed
r=29 cm closed


Output energy vs input phase
neutrino factory case
MeV
degrees
300
280
260
240
220
200
180
160
140
120
100
-180
-130
-80
-30
20
70
120
170
3 MeV
difference
r=20 cm
r=0

Other important on-going Activities:

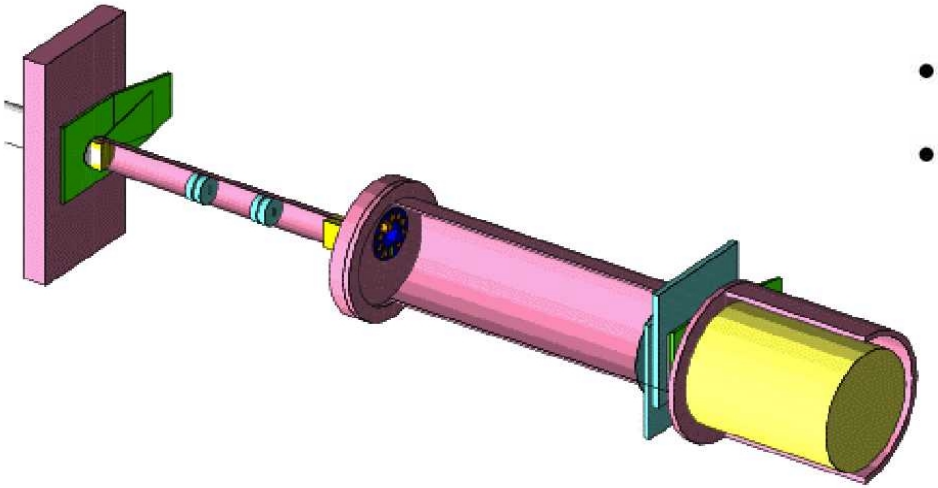
MUSCAT

Meetings on Instrumentation and Cooling Experiments (only started recently)

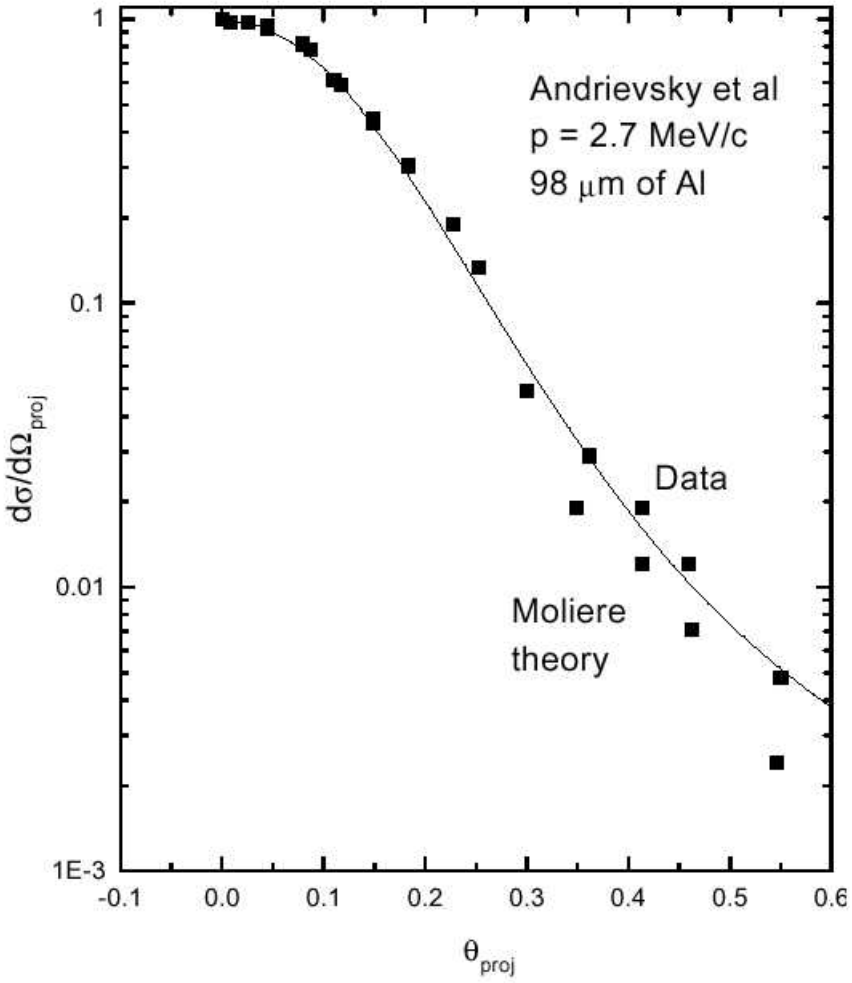
MUon SCATTering experiment

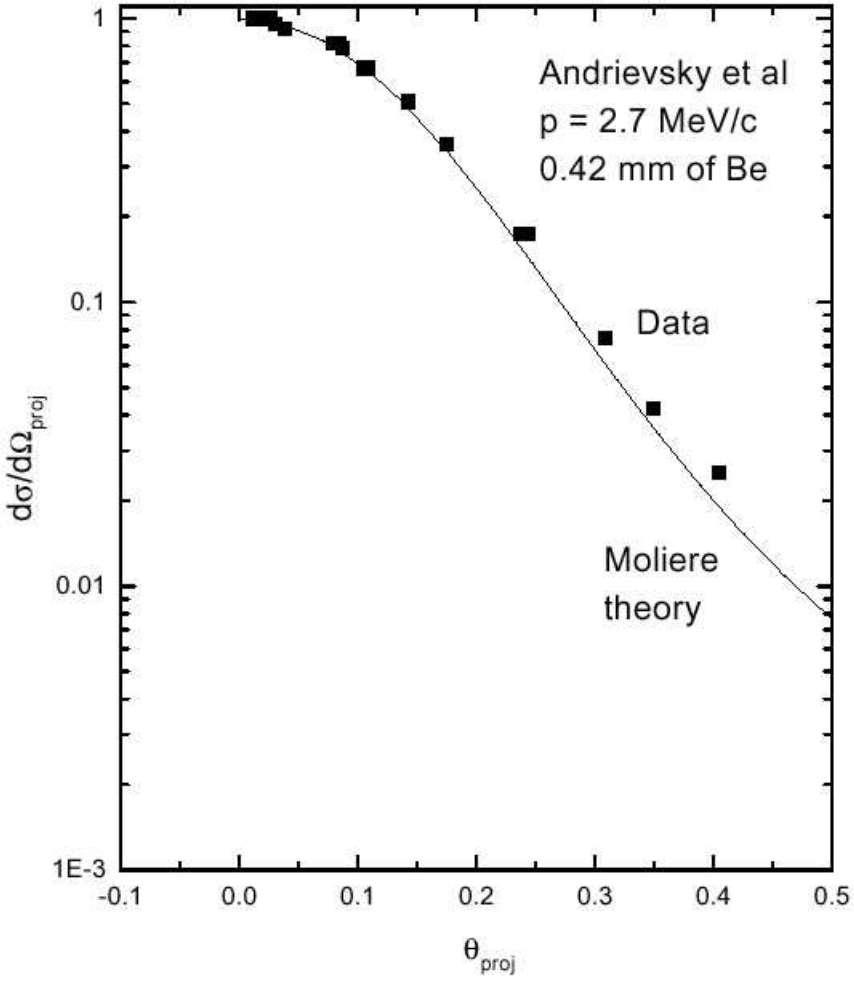
(RAL, TRIUMF, CERN et al.

- Multiple scattering of muons is important input parameter for cooling simulations
- Only 55year old electron data available
- First measurement with muons
  - Compare with existing (e^-) data and Moliere theory
  - Increase precision
  - Input for new scattering models

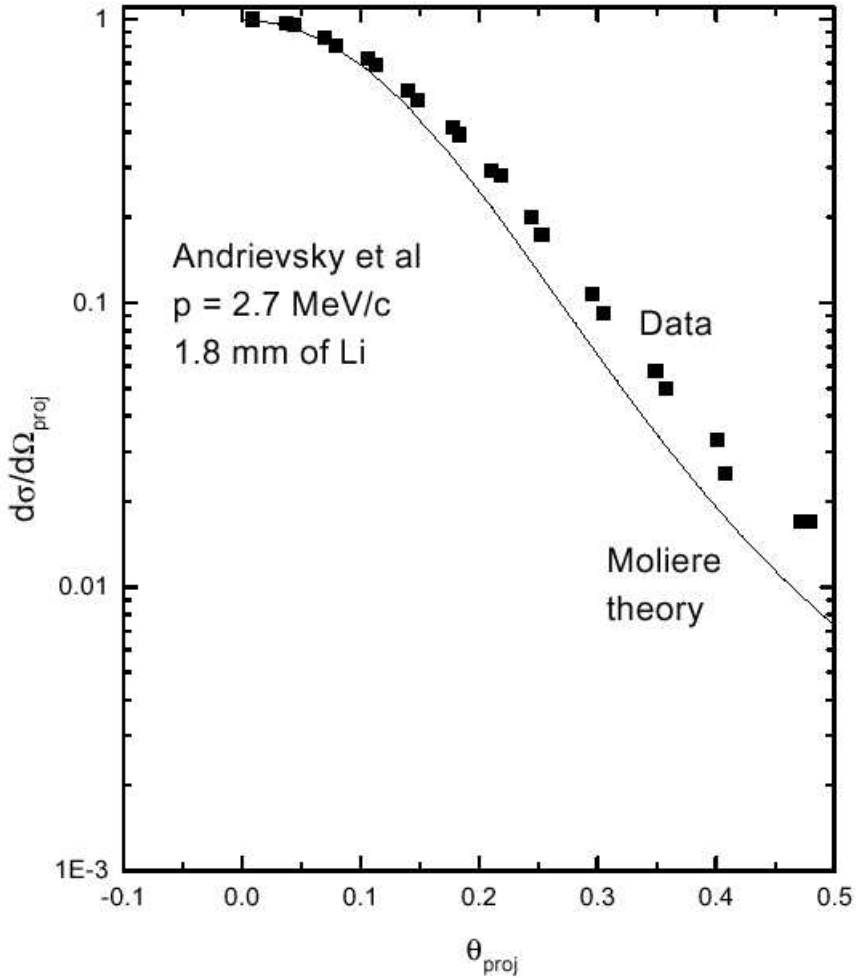


Scattering Experiment and Theory





Scattering Experiment and Theory

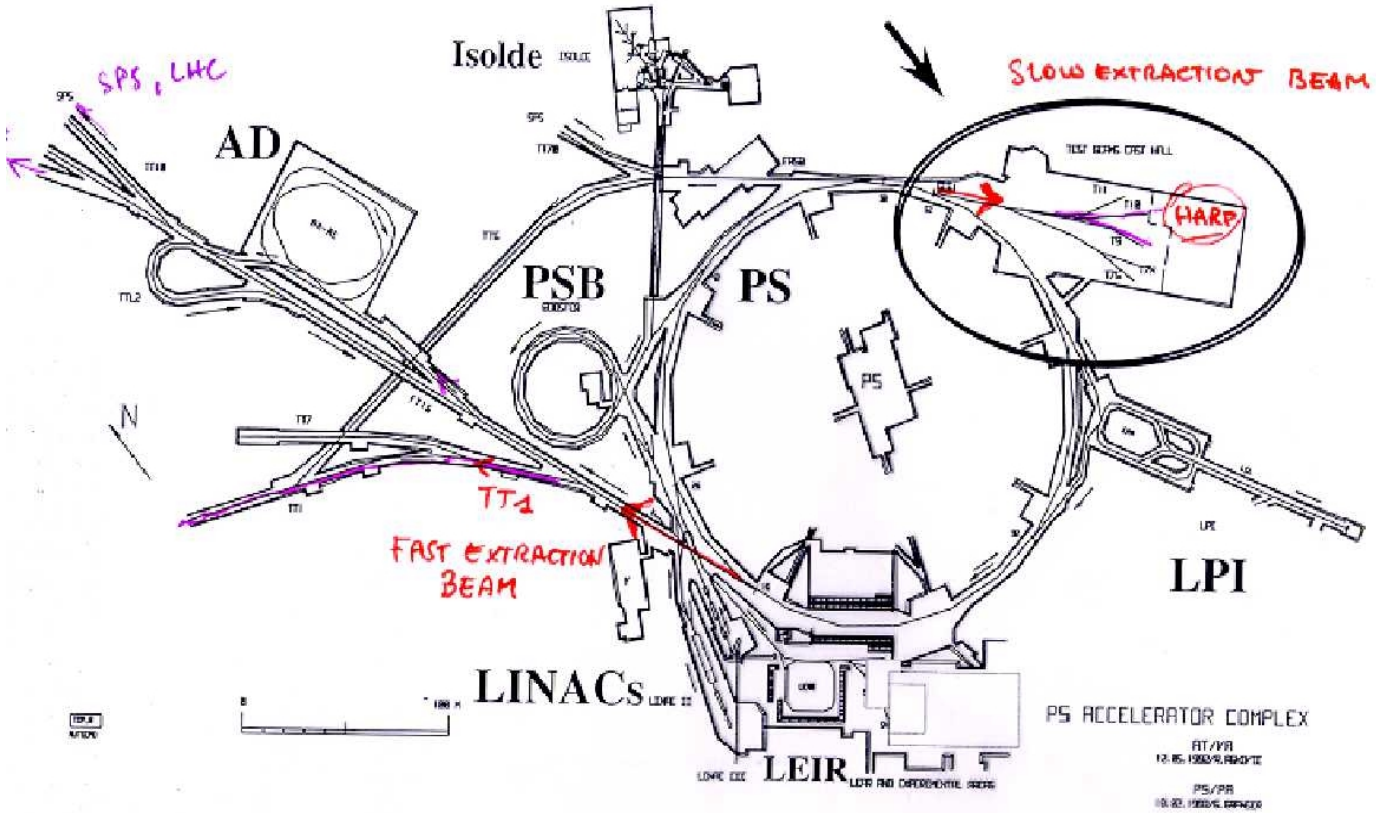


2.7 MeV/c electrons on

- 98μm of aluminium
- 0.42mm of beryllium
- 1.8mm of lithium

from: Andrievsky et al,
J. Phys 6 (1942) 278

The PS Accelerator Complex and possible Locations for a Muon Beam



⇒ *A cooling experiment is very important to demonstrate* ⇐

the feasibility of the technical choices made

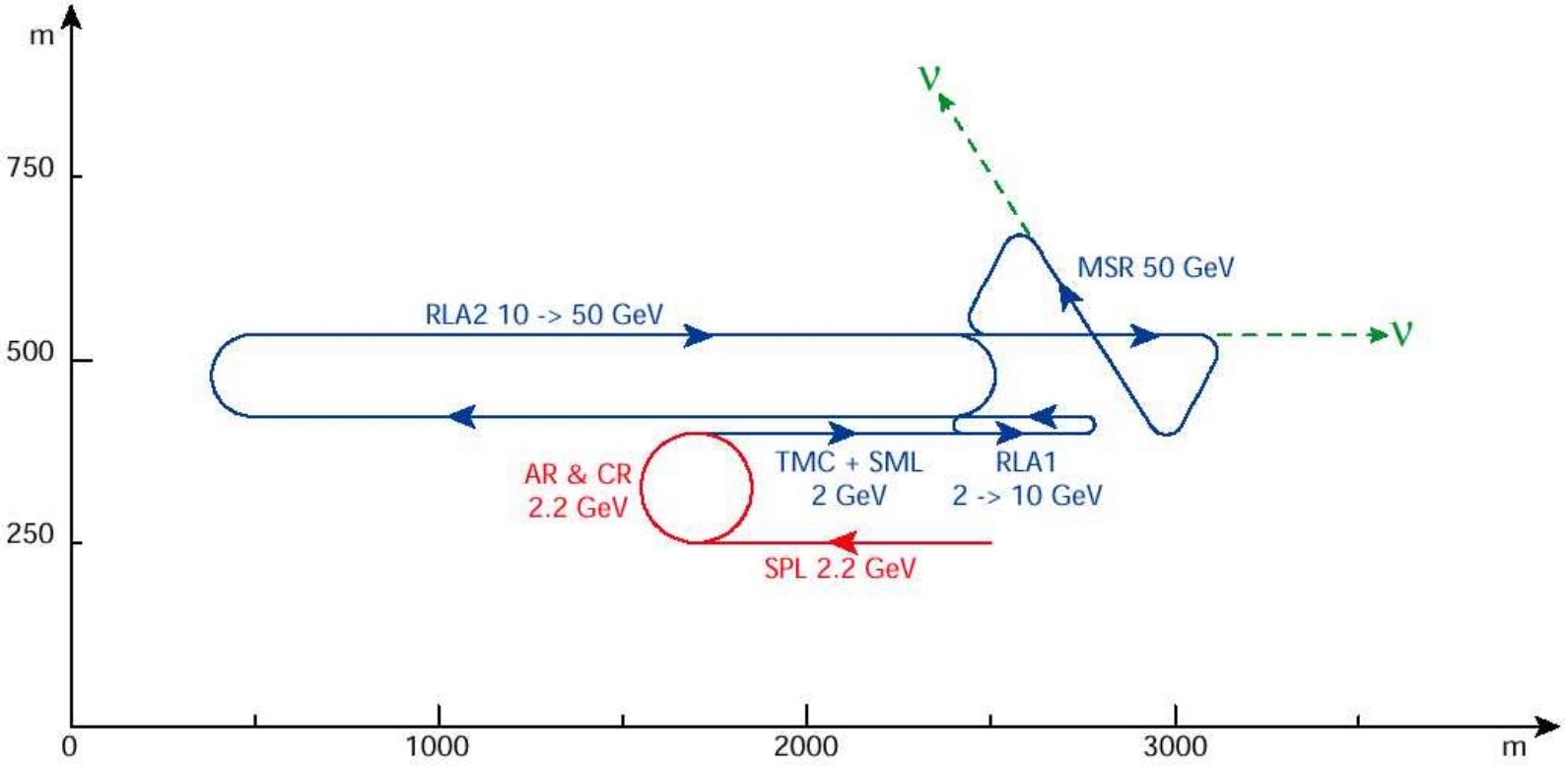
	RLA1	RLA2
Injection energy, GeV	2	10
Extraction energy, GeV	10	50
Number of turns	4	4
Length of linacs (2), m	680	3813
Rf frequency, MHz	352	352
Bending radius in arc, m	5	25
Mean arc radius, m	20	100
Circumference, m	806	4442
Peak voltage gradient per linac, MV/m	7.4	7.4
Normalised admittance, mm rad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

Preliminary Layout of Neutrino Factory (drawn to scale)



SPL: Superconducting Proton Linac
AR: Accumulator Ring
CR: Compressor Ring
TMC: Target + pion/Muon Collection
SML: Superconducting Muon Accelerator
RLA: Recirculating Linear muon Accelerator
MSR: Muon Storage Ring

The neutrino factory is likely to serve experiments at the:

Gran Sasso

and a long baseline neutrino experiment at a

new site *at a distance of some 3000 km*

Candidates: Spain, Norway, Finland

Criteria:

distance from CERN,

depth

background,

existing infrastructure

access

local community

La Palma (Canary islands), astronomical observatories, Tunnels (l km long) under 800m of basaltic stone

CUPP (Centre for Underground Physics **Pyhäsalmi),** Cosmic ray observatory, 960m to 1200m 2296 km from CERN

Svalbord / Spitzbergen

Michel Mayoud /Mark Jones / Aude Wiart are working on the position of the decay ring:

neutrino beam to near detector	Gran Sasso
neutrino beam to far detector	Svalbord
	La Palma
	Pyhäsalmi

Acknowledgements

The work presented here is the result of the effort of the Neutrino Factory Working Group at CERN.

Special help has been received from R. Cappi, R. Edgecock, F. Gerigk, P. Gruber, K. Hanke, A. Lombardi, E. Keil, N. Mokhov and H. Wenninger.

The help of other European laboratories (CEA, FZJ, GSI, IN2P3, INFN and RAL) and of members of the American Neutrino Factory and Muon Collider Collaboration is gratefully acknowledged.

Conclusions

- *There is a scheme for a neutrino factory that seems well adapted to CERN. It is by no means final and requires still a lot of work in order to assess the feasibility.*

- *It is intended to continue this study and to fill in the remaining gaps. Future work may well show that some elements of this scenario need substantial modification or even replacement by other components.*

- *The results of the HARP experiment expected for next year may also provoke some modifications.*

- *The next steps ought to be:*

  - *the refinement of simulations, engineering designs and a*
  - *cooling experiment for which we need a strong international collaboration*