Cooling front ends

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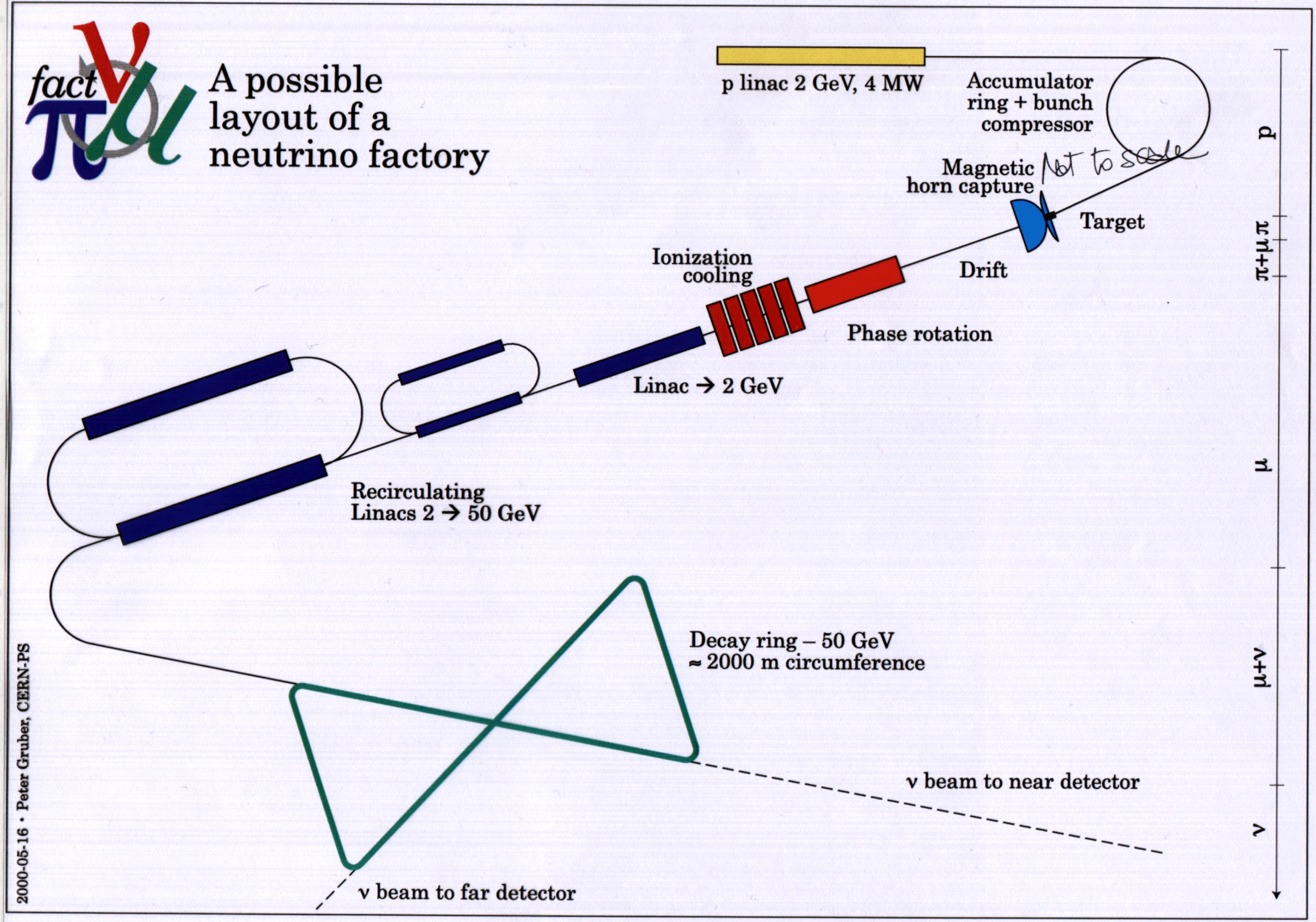
outline

- Aim
- General issues
- Two approaches studied at CERN
  - layout
  - performances
  - comparison
- Conclusions, future work
- Feed back


A possible layout of a neutrino factory
p linac 2 GeV, 4 MW
Accumulator ring + bunch compressor
Magnetic horn capture
Not to scale
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
p
π
π+μ
μ
μ+ν
ν
2000-05-16 • Peter Gruber, CERN-PS

proton-pion-muon budget

Muons in the decay ring

intensity : 10^{20} to 10^{22} muons/year
energy :50 GeV
transverse acceptance : 1.5 pi cm rad
longitudinal acceptance : 15 pi cm dp/p (i.e. 0.053 pi eV sec)

Protons from CERN driver

4 MW, 2 GeV, 10^{23} proton/year (1year=10^{7} sec)

need at least 0.1% muon/proton

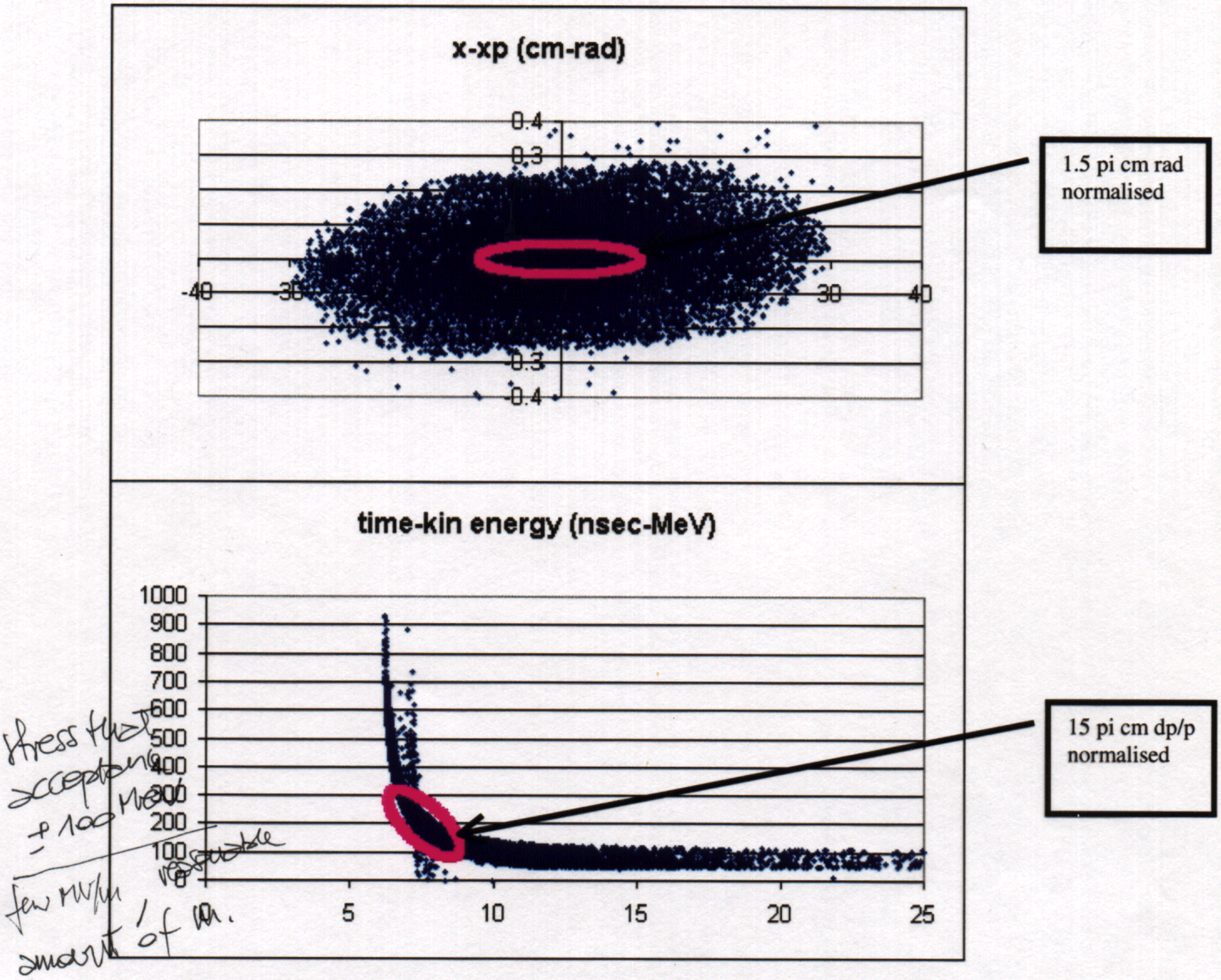
Pions from the target (FLUKA 2.6 cm Hg re-scaled to 30 cm)

0.17 pions+/protons
0.04 pions-/protons

need at least 0.01 muon/pion

after the target

2 GeV proton beam instantaneously impinging on the target
FLUKA calculations of 2.6 cm long Hg target + 20T solenoid



6% of the pions are within the downstream decay ring acceptance but then....

we need to let the pions decay and we need to accelerate the muons to 50 GeV

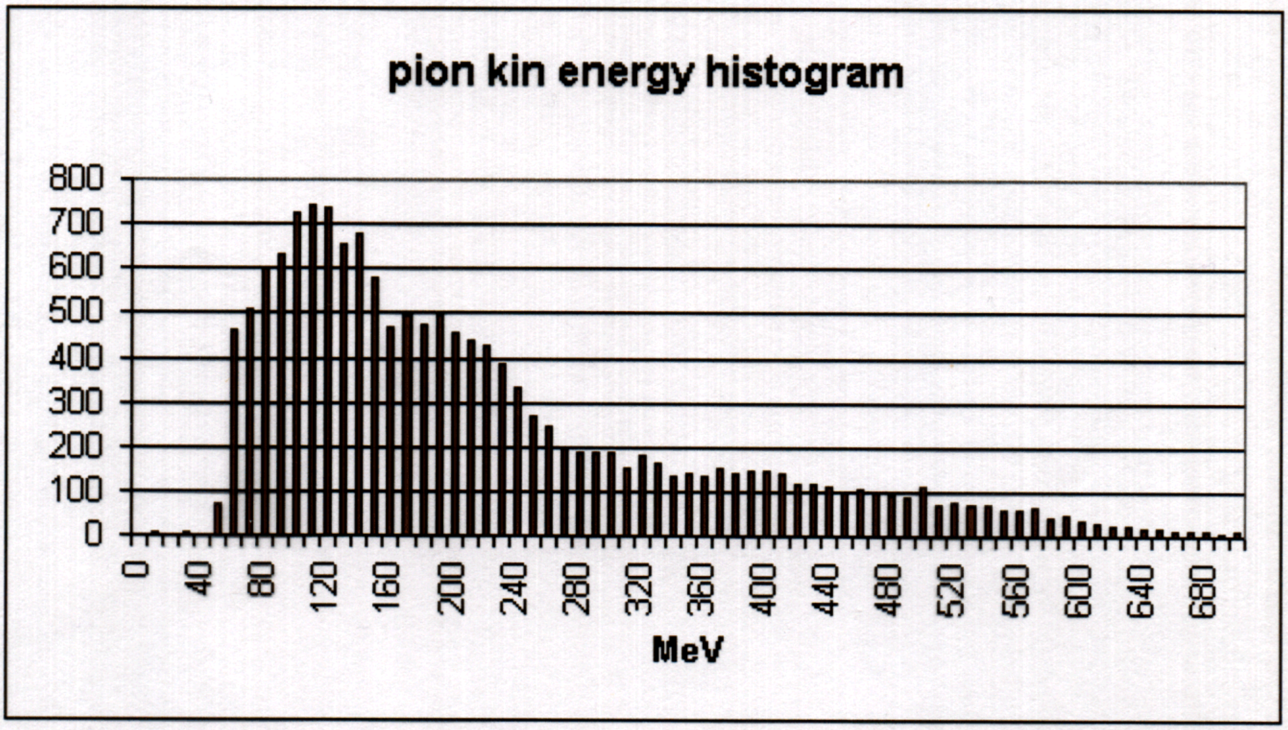
- the transverse emittance increases because of
    - decay (factor 1.5-2)
    - chromatic effects of the transport system
    - RF

- the longitudinal emittance increases because of
    - decay
    - different path length in the transport system
    - ??

- muon losses due to decay before arriving in the storage ring

need to cool the beam

pion beam energy histogram



peak of energy 120MeV
big energy spread.

longitudinal plane
how to reduce the energy spread

1. Do something a.s.a.p. : start operating on the pions just after the target .

   need high field in high radiation area
   frequency range > 100MHz
   max enhancement of polarisation

very little work at CERN

2. let the pions decay : drift of the order of tens of meters

   do not need high field
   frequency range> 10MHz

40-80 MHz scheme

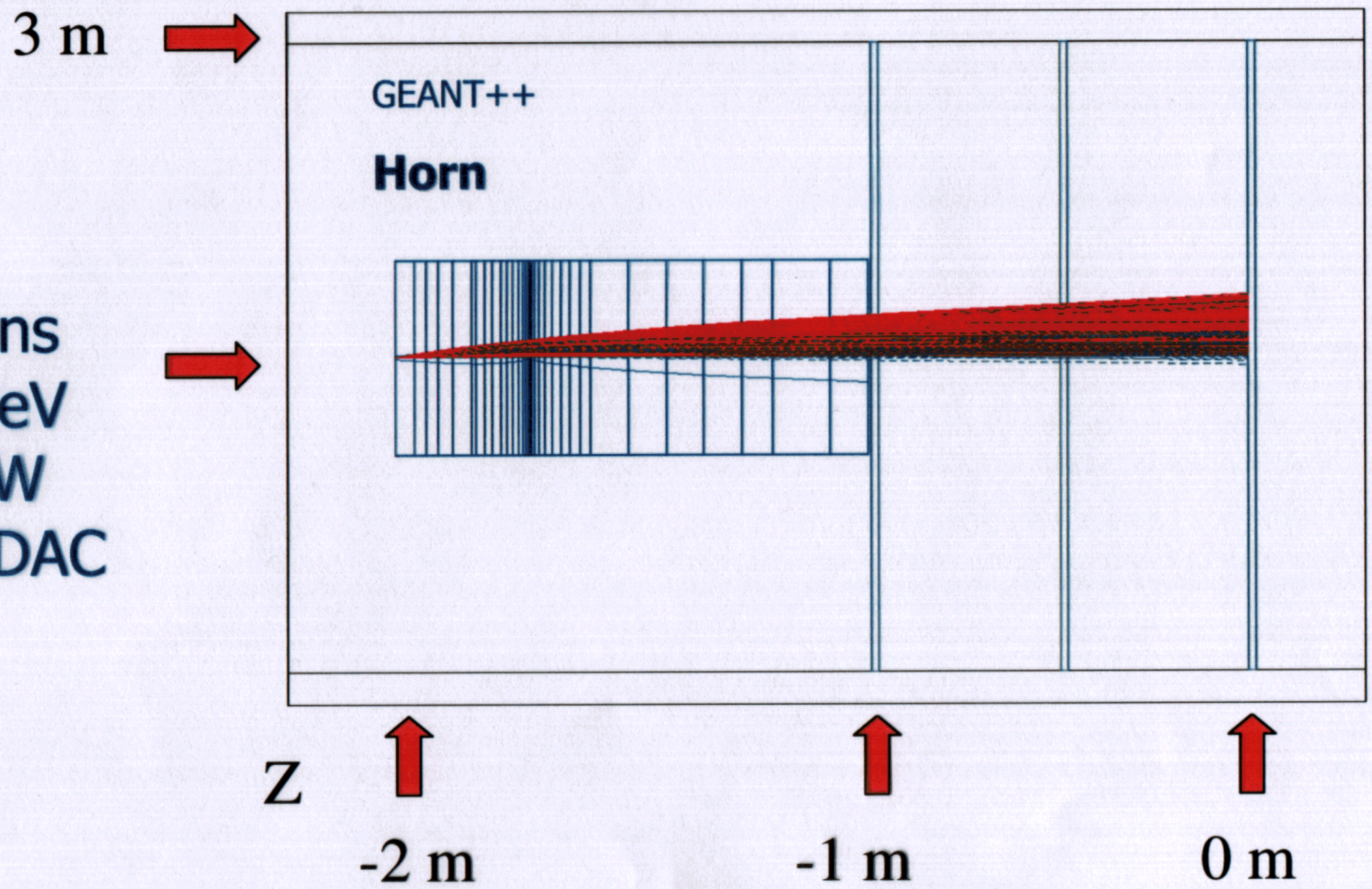
3. let the muon beam build up a strong correlation energy-time : drift of the order of hundreds of meters

   "quasi-DC" device to counter-match the correlation

Induction Linac scheme

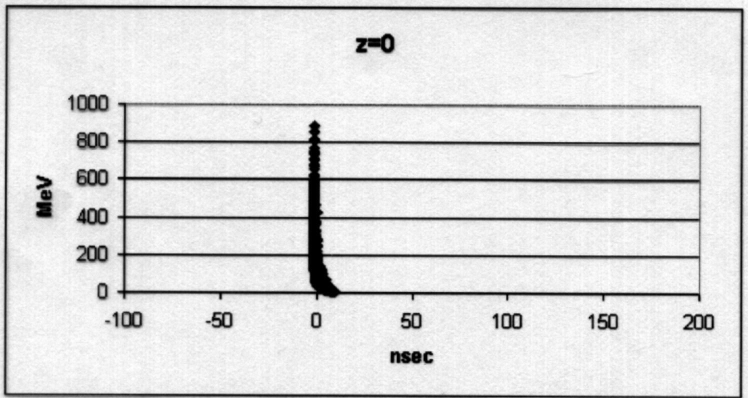
Target sketch

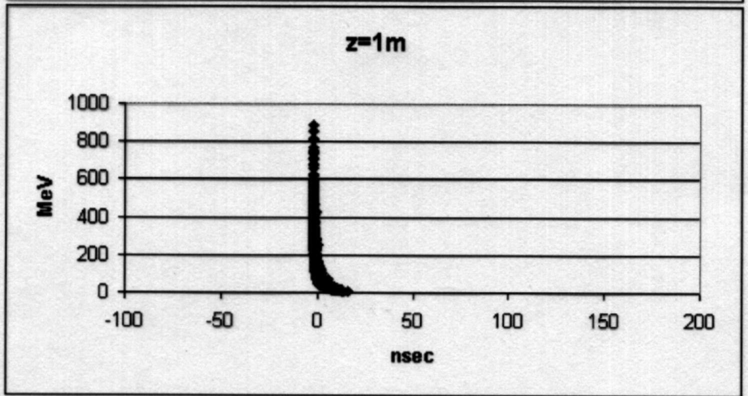
Protons
@2 GeV
4 MW
from PDAC



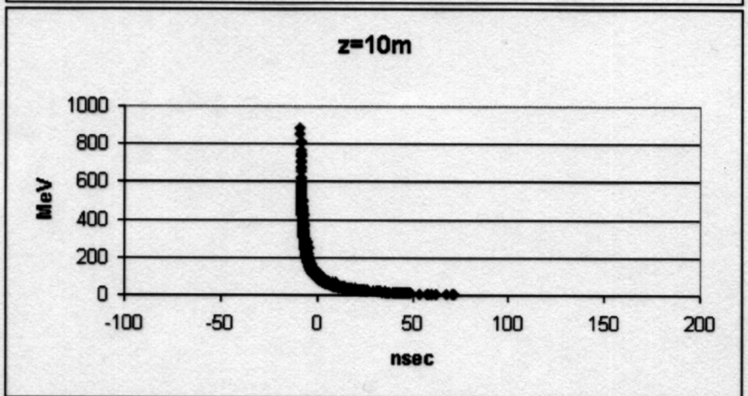
longitudinal phase plane vs. drift length

no decay
solenoidal focusing

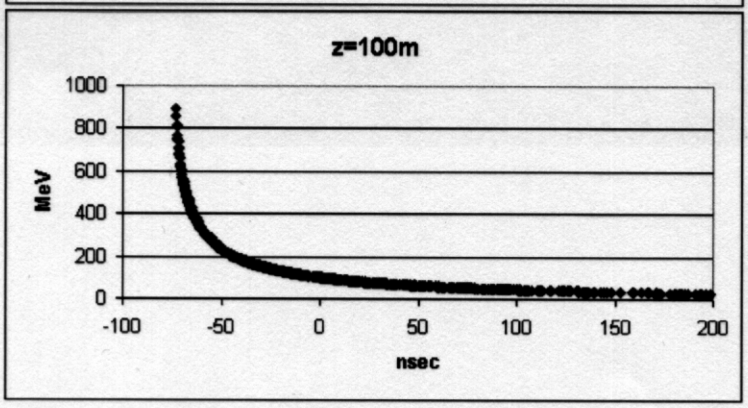




±100 MeV fits in 100MHz



±100 MeV fits in 10MHz

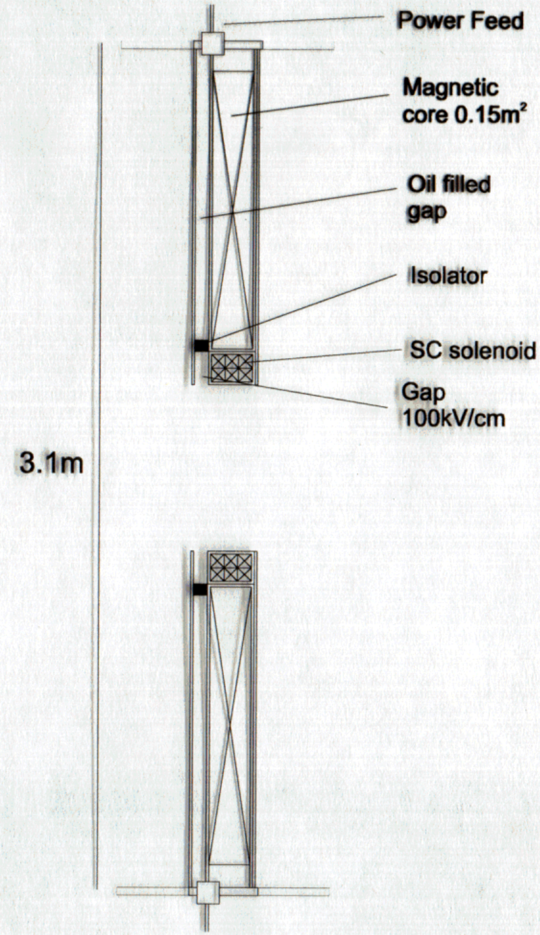


±100 MeV fits in 1MHz

CERN

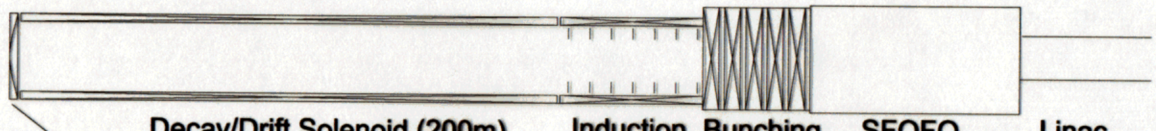
Induction Linac

Bz on Axis	1.4 T
Aperture	0.6 m
Pulse length	300 ns
Power Consumption	16.5 MW



Zero order induction linac cell - RS 18/01/2000

induction linac solution
(CERN-NFWG-note 14,17)

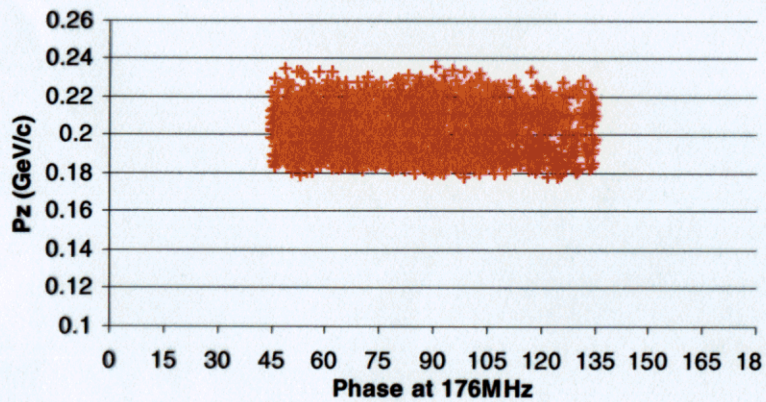


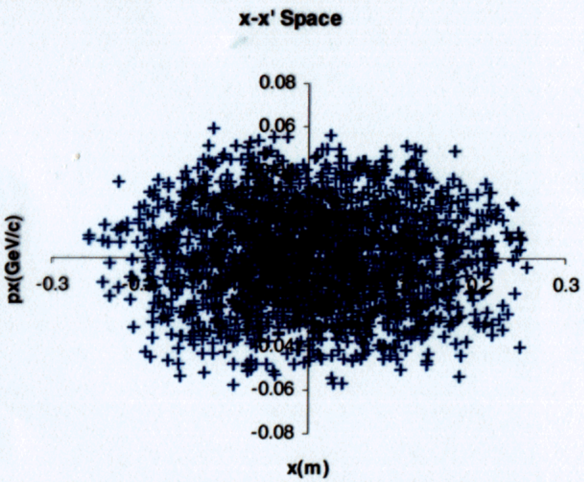
		Decay	Rotation	Bunching	Cooling	Acceleration
Length	[m]	200	50	37	80	
Diameter	[cm]	60	60	60	60	
Focalisation	[T]	1.4	1.4	2.0	3	
Frequency	[MHz]	-	I.L.	176	176	
Gradient	[MV/m]	-	±2	2	15	

CERN

Buncher

- Very conservative. 2MV/m @ 176 MHz (no dual freq).
- Cooling type Pill-Box windowed cavities.
- Assumed 60 cm aperture as power in each Cu cavity only ~60 kW pulsed ~2 kW average (not considering Be conductivity).
- Only 37 m long (only 8m of RF).
- Solenoids between cavities (not around).

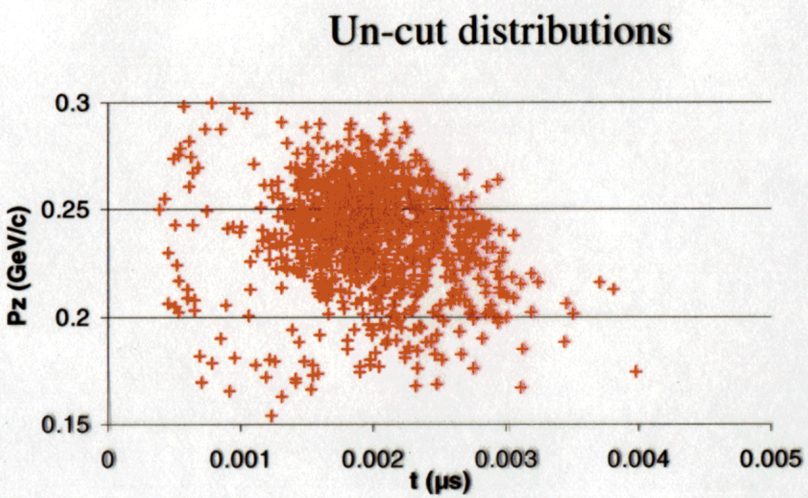


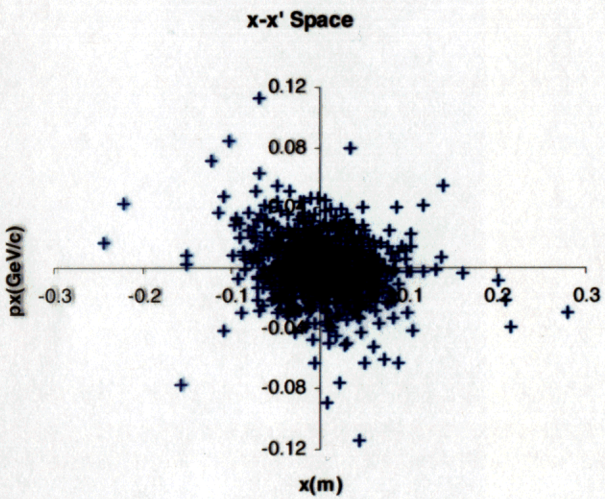


cooling in quotes because cooling rf, etc

Cooling

- Using an old SFOFO from (sf03-1.94).
- 3 T on-axis and 15MV/m in the cavities.
- Not suited to the rep-rate of the CERN base-line due to power consumption (>100 kW average per cavity).
- 45% of input muons make the output cut.
- Emittance from 17.3 -> 5.3 mm.rad (rms-norm-LBL).

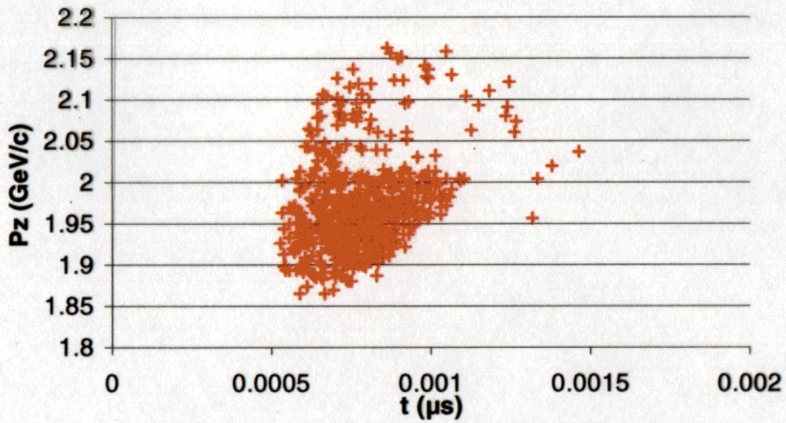


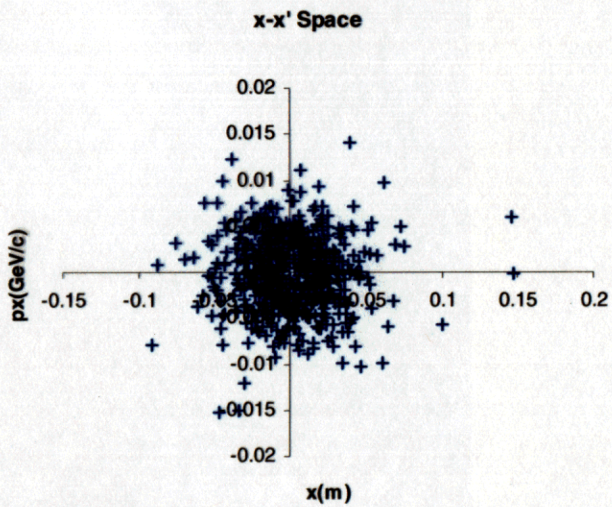


Acceleration

CERN

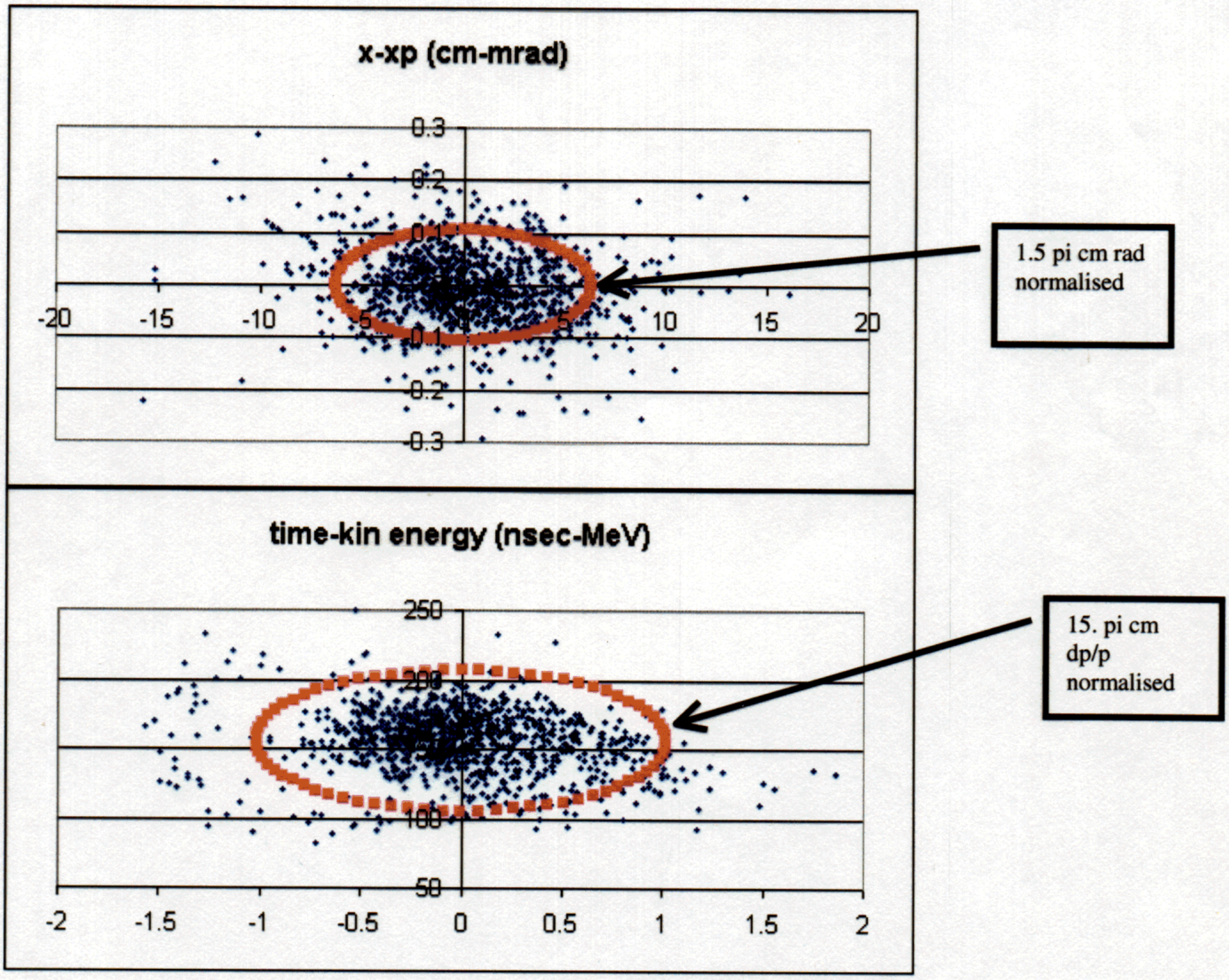
- Not yet properly simulated.
- Beam accelerated in Pill-box cavities with “ideal” solenoids between.
- Use 176MHz at 45° to accelerate the long bunches.
- Transverse emittance is good, long. emittance ???





induction linac solution
end of cooling

ICOOL calculation, particle regenerated at each section, magnetic distribution from current sheets, IL electrostatic field

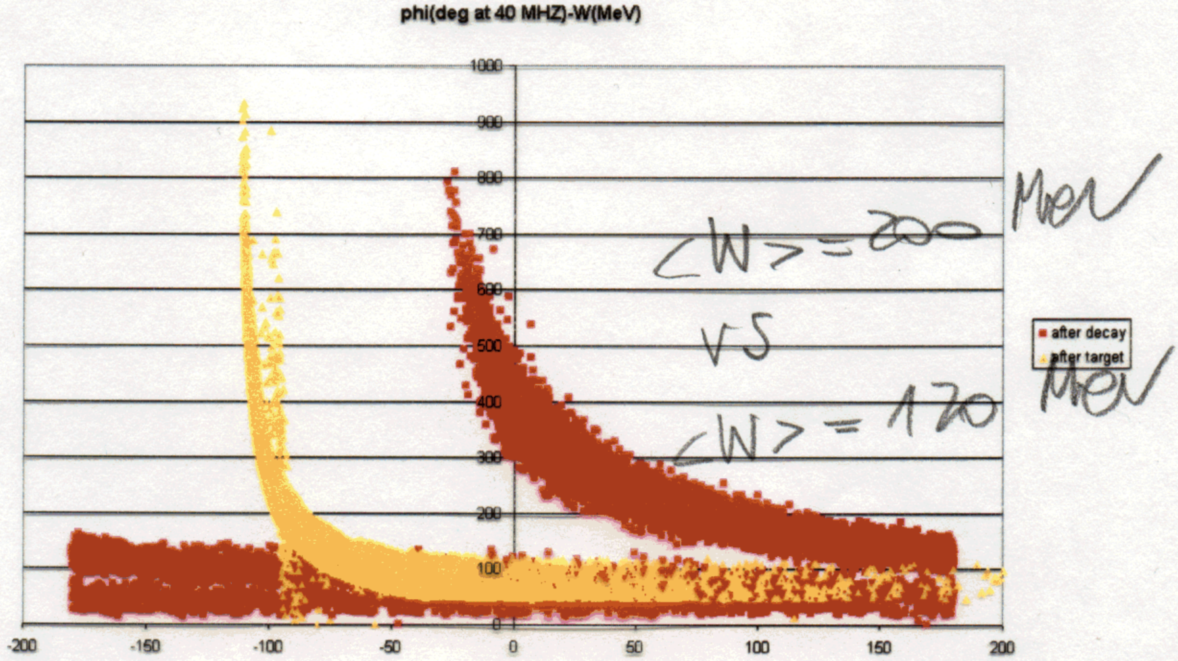


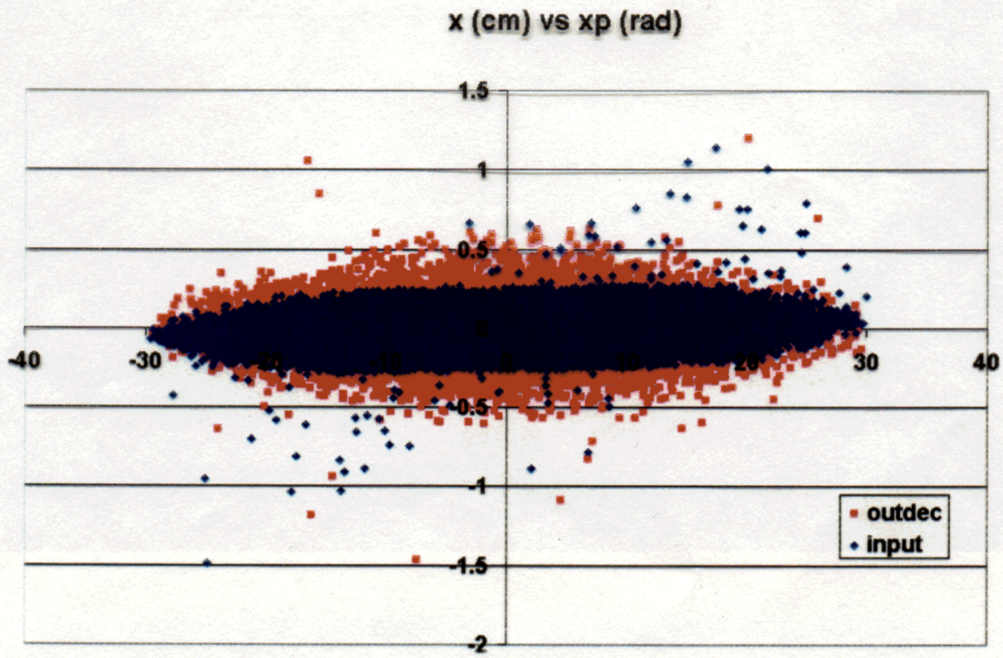
0.04 muon/pion

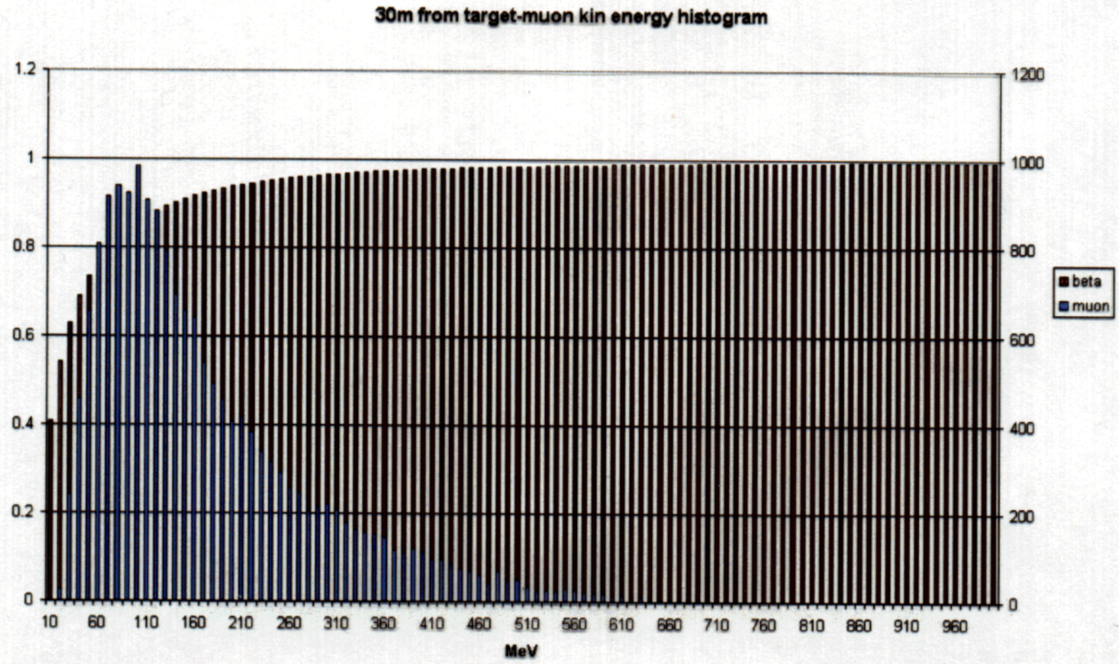
40-80 MHz solution
(CERN-NFWG-note 20)

	Decay	Rotation	Cooling I	Acceleration	"Cooling II"	Acceleration
Length [m]	30	30	46	32	112	≈450
Diameter [cm]	60	60	60	60	30	20
Focalisation [T]	1.8	1.8	2.0	2.0	2.6	2.6
Frequency [MHz]		40	40	40	80	80-200
Gradient [MV/m]		2	2	2	4	4-10
Kin Energy [MeV]				280	300	2000

30 m long 1.8 Tesla solenoid, 60 cm bore diametre

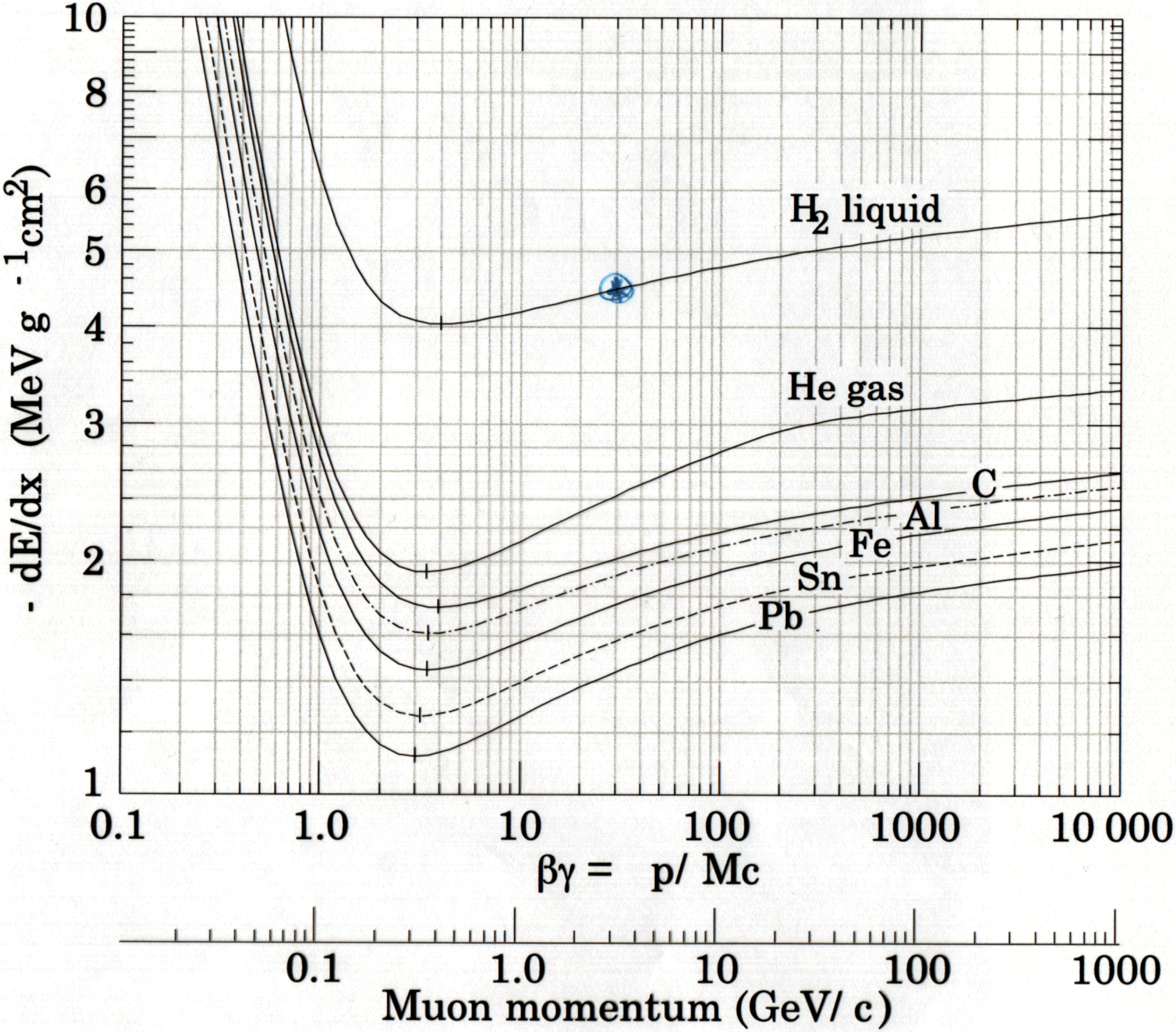






DEBUNCHING per METRE at 40 MHz

average energy (MeV) \ energy spread	±50 MeV	±100MeV
150	4.7°	12.7°
250	1.4°	3.3°
350	0.6°	1.4°



10
8
6
5
4
3
2
1
- dE/dx (MeV g⁻¹cm²)
H2 liquid
He gas
C
Al
Fe
Sn
Pb
0.1
1.0
10
100
1000
10 000
βγ = p/ Mc
0.1
1.0
10
100
1000
Muon momentum (GeV/ c)

Bethe Bloc + where we are

RF	
200	kin
286	cp
300	kin
391	kin

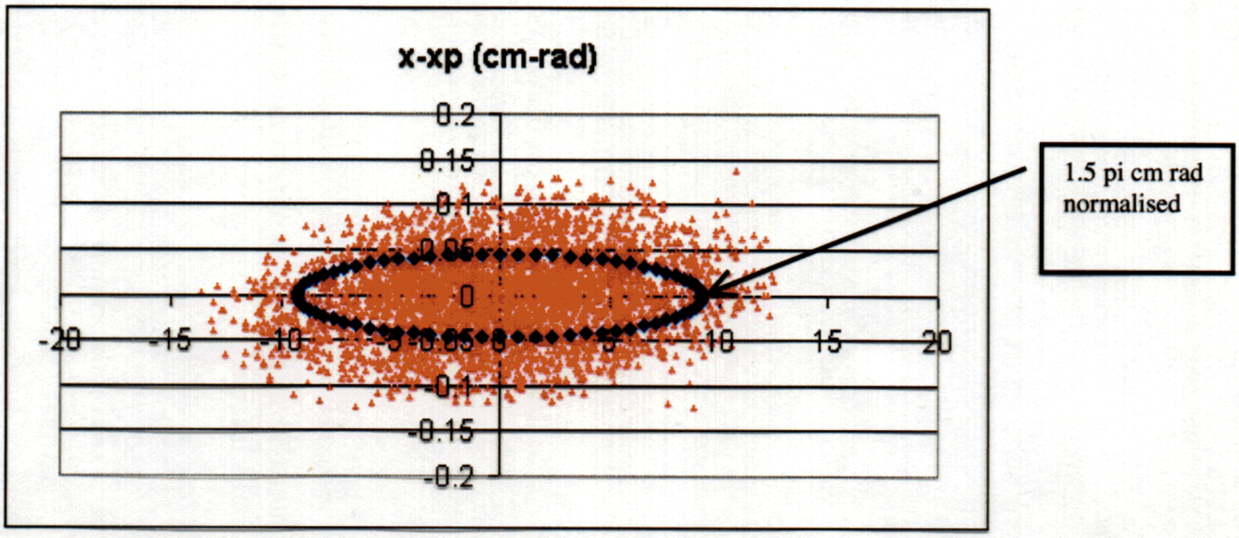
IL	
200	cp
120	kin

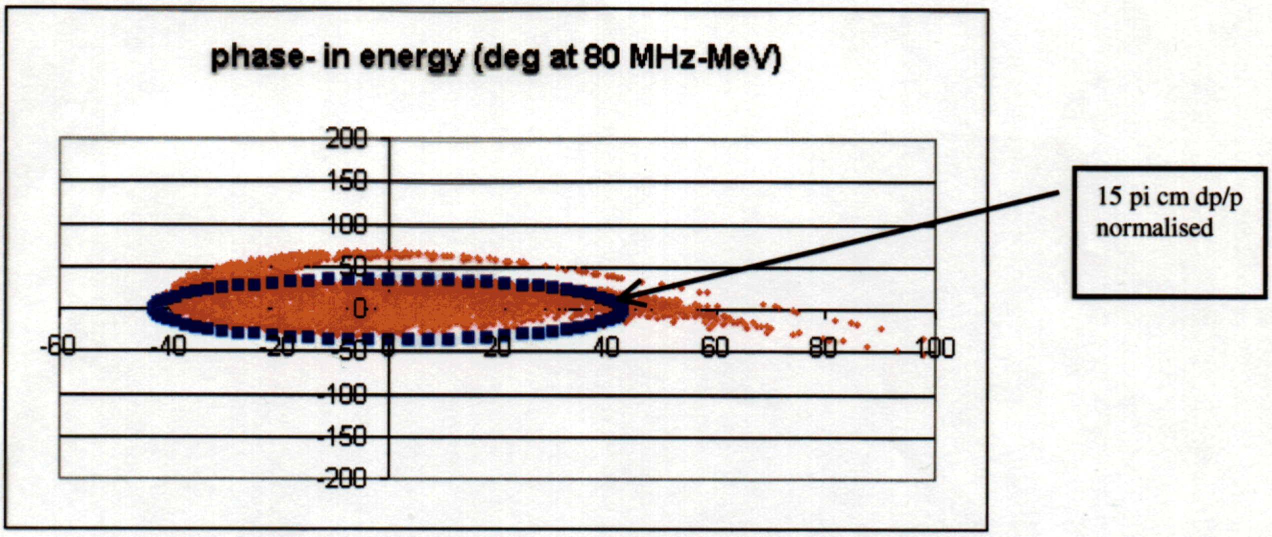
Cooling at higher energies

- more difficult (need more abs) goes against philosophy of doing things fast
- higher ΔW acceptance
- some longitudinal cooling

40-80MHz solution
end of COOLING

CERN-PATH calculations, beam from the target, ideal magnetic field and electromagnetic RF field. (Cross-checked with ICOOL till cooling stage I)





10% muon/pion at the end
4-5% muon/pion in the decay ring acceptance

NEED MORE (EFFICIENT) TRANSVERSE COOLING induction linac vs. 40-80 MHZ solution

COMPARISON AT THE END OF COOLING

	INDUCTION LINAC	40-80 MHz
length (m)	367	250
number of particles in Acceptance (*)	0.04 muon/pion	0.04 muon/pion
power needed (ESTIMATE)	16 MW (IL)+ 15MW (176 MHz)	7. MW (40MHz)+ 7 MW (80 MHz)
dependence on driver :		
pulse length	no	less than 3 nsec
number of pulses	yes	no

(*) = 1.5 pi cm rad normalised ; 15 pi cm dp/p normalised

CONCLUSION AND FUTURE WORK

- Two schemes for pion and muon collection have been simulated : one employs an Induction Linac , the other 40 MHz RF cavities for phase rotation
- The 40-80 MHz scheme seems to better match the CERN driver (lower current from the proton linac, less critical space charge effects in the accumulator)

- Continue studying both schemes and try to improve their performances
- Sensitivity study of the schemes to identify weak points and possible improvement
- Consider other schemes (high frequency RF)