Additional installations for a neutrino physics facility

H. Haseroth, CERN

What kind of neutrino physics facilities are we talking about?

Superbeam

Betabeam

Neutrino factory

What is a Superbeam?

A Superbeam is a “conventional” ν-beam where the νs are produced by π (and K) decay but at a much higher intensities

What is a Beta beam?

A β - beam is a beam where the neutrinos are produced by β-decay of radioactive nuclei (e.g. ^{6}He and ^{18}Ne)

What is a Neutrino Factory?

A Neutrino Factory is a machine where the ν-beam is produced by μ decay, which are in turn produced by the decay of πs
The μ beam is of good quality and may
open the way to μ colliders (the ultimate high energy for lepton colliders)

What is needed for a Superbeam and/or for a Neutrino Factory?

Target
Collection device
Decay channel
Cooling
Large acceptance accelerators
Power efficiency

Some exotic ideas:

- Friction cooling
- High pressure rf cavities
- Neutrino lasers (Scientific American, April 2004 p 36; Phys Rev C, vol 31, p 1468

I shall not talk about:

A neutrino Beta-beam facility at CERN (Mats Lindroos)
Detectors

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.

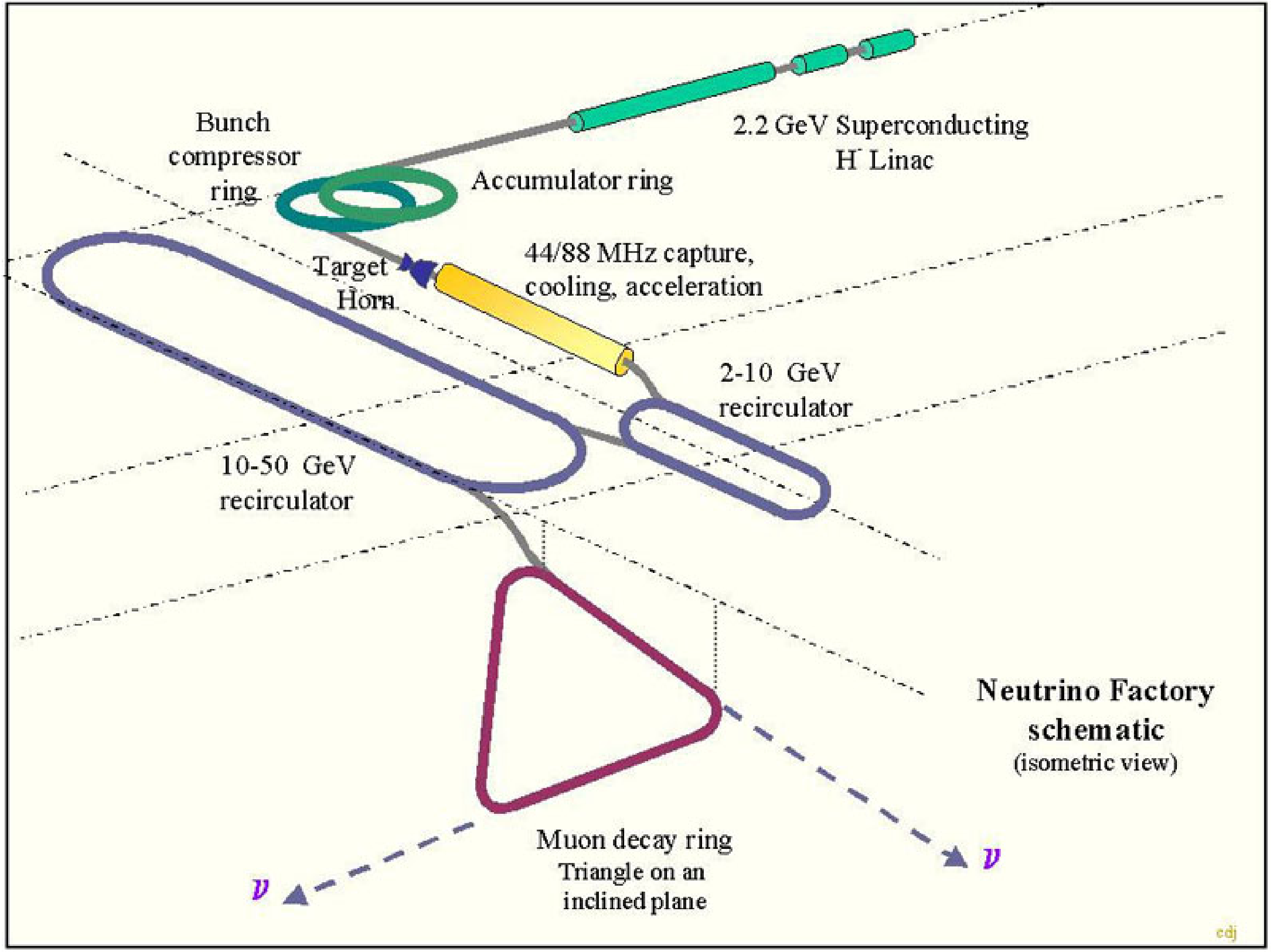
You may stop here for a Superbeam

⇒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 (?)

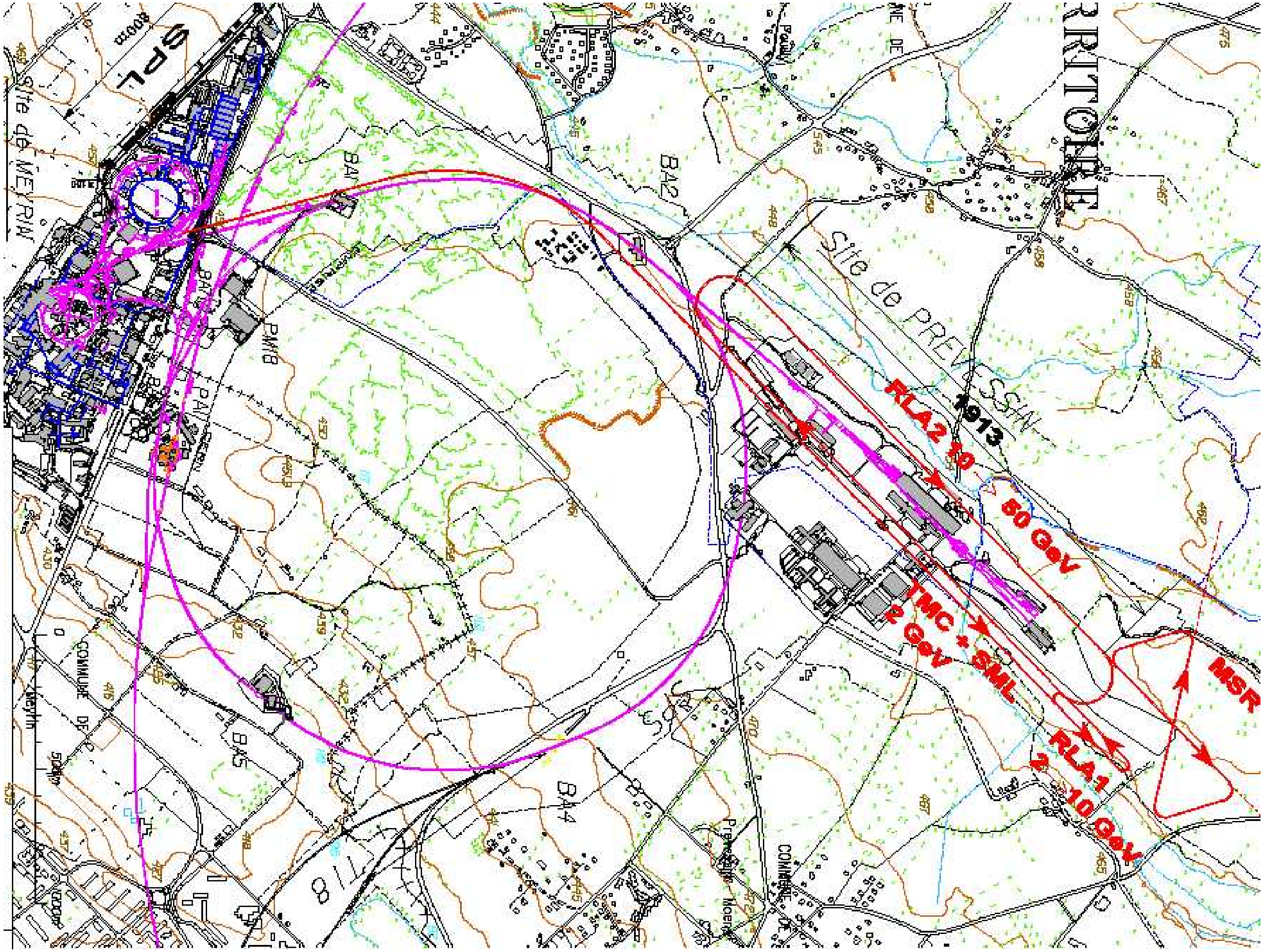
⇒Muons are injected into a storage ring (decay ring), where they decay in long straight sections in order to deliver the desired neutrino beams.

CERN Scheme



Bunch compressor ring
Accumulator ring
2.2 GeV Superconducting H⁻ Linac
Target Horn
44/88 MHz capture, cooling, acceleration
2-10 GeV recirculator
10-50 GeV recirculator
Neutrino Factory schematic
(isometric view)
Muon decay ring
Triangle on an inclined plane
ν
ν
cdj

Preliminary Layout of Neutrino Factory



The Proton Driver

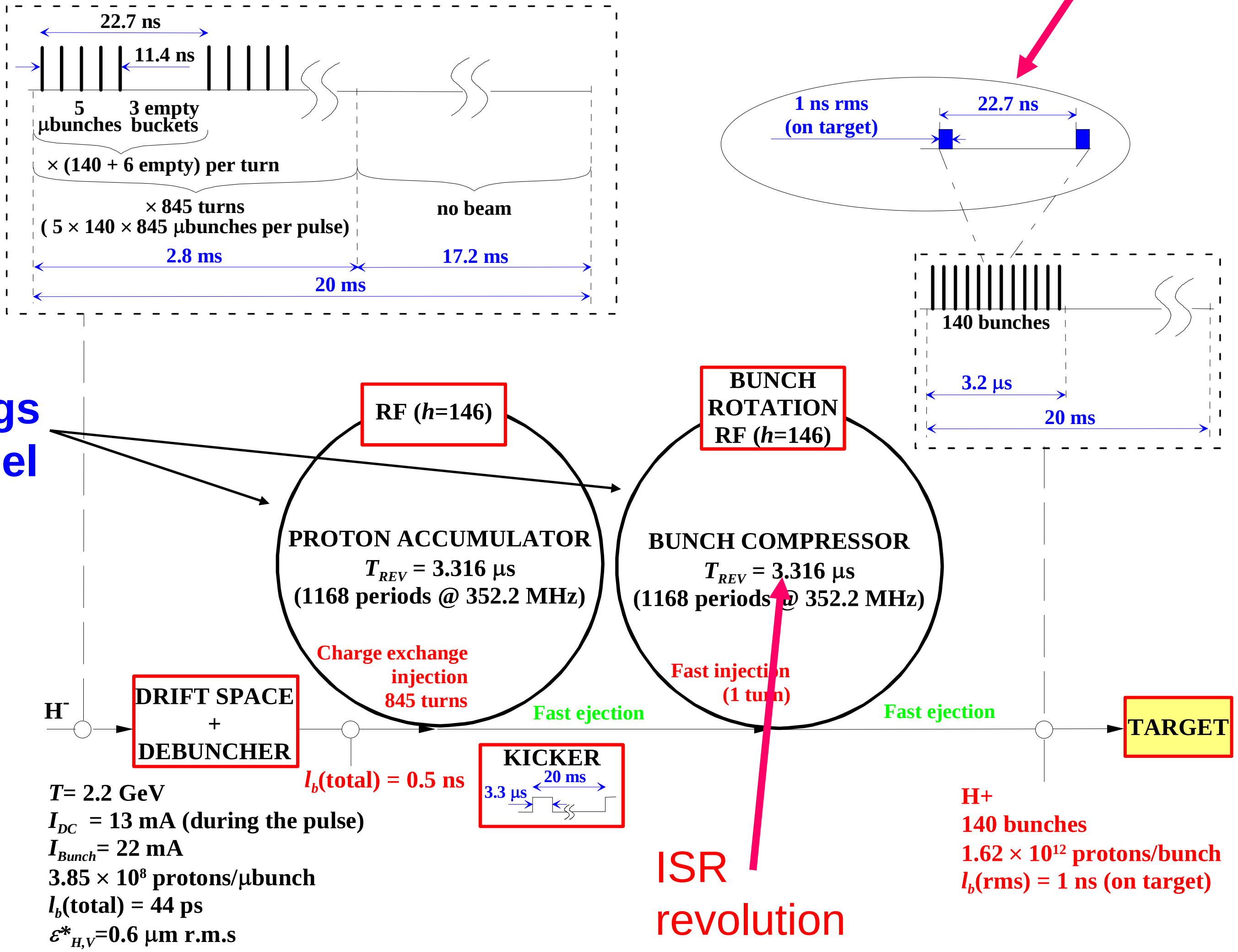
Technological challenges: **High power is a challenge in terms of beam losses, which can yield undesired activation of the machine components making hands-on maintenance impossible.**

In the CERN scheme of an H- linac with charge exchange injection into an accumulator ring the stripping foil needs very close attention.

A common problem of all proton drivers is the production of very short bunches in order to reduce finally the energy spread of the muons with a scheme called "debunching" amongst linac experts ("phase rotation" for neutrino people)

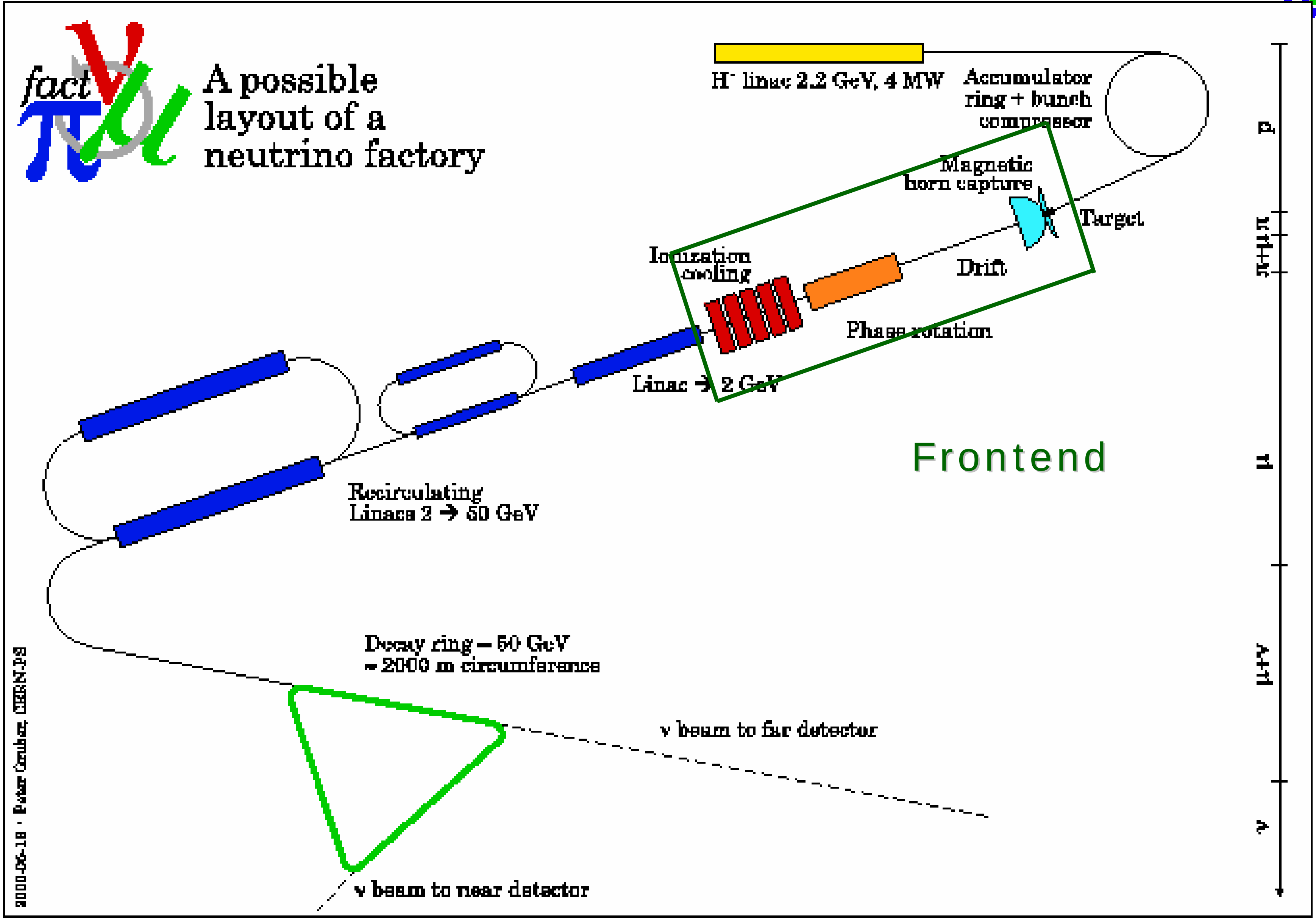
Accumulator and Compressor Rings ("PDAC")

44 MHz



2 synchrotron rings in the ex-ISR tunnel

ISR revolution time


A possible layout of a neutrino factory
H⁻ linac 2.2 GeV, 4 MW
Accumulator ring + bunch compressor
Magnetic horn capture
Target
Ionization cooling
Drift
Phase rotation
Linac → 2 GeV
Frontend
Recirculating Linacs 2 → 50 GeV
Decay ring – 50 GeV ≈ 2000 m circumference
ν beam to far detector
ν beam to near detector
2000-06-18 · Peter Gruber, CERN-PS
p
π+μ
μ
μ+ν
ν

Targetry

(American word invention, my apologies to English language purists…)

Areas of application:

Neutrino physics

Studies of rare processes initiated by muons

Studies of materials with neutron beams from a spallation source

Accelerator production of tritium

Accelerator transmutation of waste

Accelerator test facilities for fusion reactor materials
etc…

Some of the problems:

Survival of components against melting/vaporization

Survival of components against beam-induced pressure waves, in the case of pulsed proton beams

Survival of components against radiation damage

Passive solid targets (or rotating-wheel targets), typically water cooled, have been used in most applications with not more than 1-MW beam power. But for beam power in excess of 1 MW such passive solid targets become very problematic in view of the challenges listed above. This has led to consideration of flowing liquid targets: mercury, molten lead, molten Pb/Bi, *etc.*

Liquid target systems still require solid-walled containment vessels and beam windows that isolate the target region from the rest of the accelerator complex. Experience has shown that if a liquid target is confined inside a metal pipe in the region of the interaction with a pulsed proton beam, then the beam-induced pressure waves can cause pitting (associated with cavitation during the negative-pressure phases of the waves) and possible failure of the solid wall.

Such concerns indicate that it would be preferable to have a flowing liquid target in the form of a free jet, at least in the region of interaction with the proton beam.

Action taken:

The 2003 Targetry Workshop

High-power Targetry
for
Future Accelerators

Ronkonkoma, NY
September 8-12, 2003

BROOKHAVEN NATIONAL LABORATORY

Harold G. Kirk
Brookhaven National Laboratory

Facility	Status	Target Material	Beam Pulse Duration (ms)	Beam Pulse Rep Rate (Hz)	Energy (GeV)	Time Ave Power in Beam (MW)	Peak Time Ave Power Density (MW/m^3)	Peak Energy Density (MJ/m^3/pulse)
BNL Neutrino Superbeam	Under Study	C-C Composite	2.6	2.5	28	1	4,060	1,630
ESS - short pulse	Under Study	Hg	1.2	50	1.334	5	2,500	50
ESS - long pulse	Under Study	Hg	2,000	16.7	1.334	5	2,500	150
EURISOL	Under Study	Hg	3	50	2.2	4	100,000	2,000
IFMIF	Under Study	Li	CW		0.04 (D_2)	10	100,000	NA
JPARC - Hadron beam line	Under Construc	Ni	7.E+05	0.3	50	0.75	7,600	5,300
JPARC - Neutrino beam line	Under Study	C	5	0.3	50	0.75	83	300
LANSCE - APT irradiation tests	Dismantled	W	1,000	20	0.8	0.8	800	40
LANSCE - Lujan	Existing	W	0.25	20	0.8	0.1	350	18
LANSCE - Mats Test Station	Under Study	Pb-Bi	1,000	120	0.8	0.8	2,400	20
LEDA as fusion mats test facility	Under Study	Li	CW		0.04 (D_2)	2	100,000	NA
MiniBoone	Existing	Be	150	5	8	0.032	120	24
NLC - conventional	Under Study	W Re	0.26	120	6.2	0.086	334,800	2,790
NLC - undulator	Under Study	Ti alloy	0.26	120	0.011	0.126	1,110,000	9,200
NuMI	Existing	C	8.6	0.53	120	0.4	318	600
Pbar	Existing	Inconel 600 + ...	1.6	0.5	120	0.052	7,650	15,300
RIA	Under Study	Li, Be, Hg, W, ...	CW		1-96 (p to U)	0.4	< 4,000,000	NA
SINQ/Solid Target	Existing	Pb, SS-clad	CW		0.575	0.72	720	NA
SINQ/MEGAPIE	Under Construc	Pb-Bi	CW		0.575	1	1,000	NA
SNS	Under Construc	Hg	0.7	60	1	2	800	13
US Neutrino Factory	Under Study	Hg	0.003	15	24	1	3,800	1,080

Conclusions of the High-power Targetry Workshop for Future Accelerators, Ronkonkoma, NY September 8-12, 2003

- New physics opportunities are demanding more intense proton drivers.
- 1 MW machines are ~~almost~~ here! 4 MW machines are planned.
- Targets for 1 MW machines exist but are unproven.
- But no convincing solution exists yet for the 4 MW class machines.
- Worldwide R&D efforts underway to develop targets for these new machines.
- A key workshop concern was the lack of worldwide support facilities where promising new ideas can be tested.

BROOKHAVEN NATIONAL LABORATORY

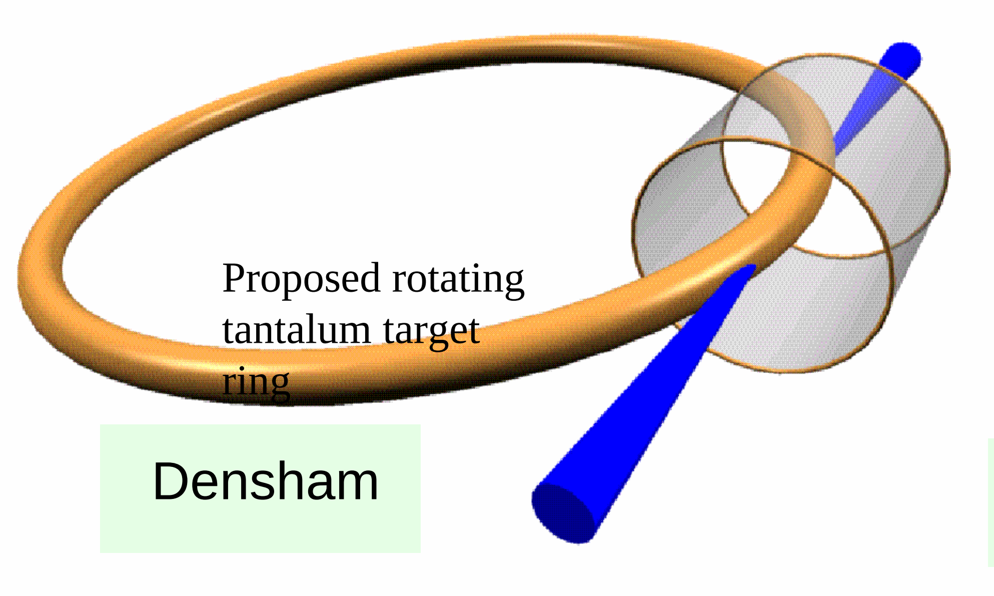
Harold G. Kirk

Targetry

Many difficulties: enormous power density
⇒ lifetime problems
pion capture

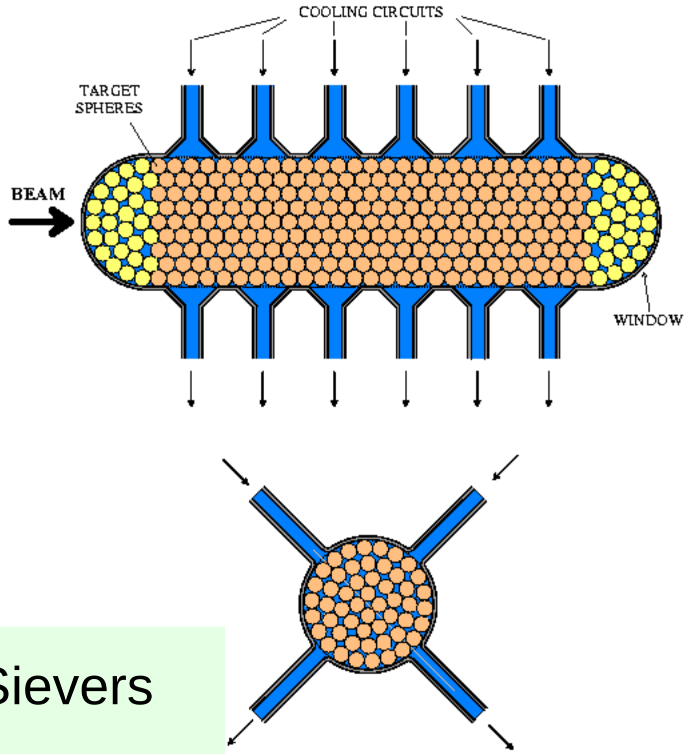
Replace target between bunches:

Liquid mercury jet or rotating solid target



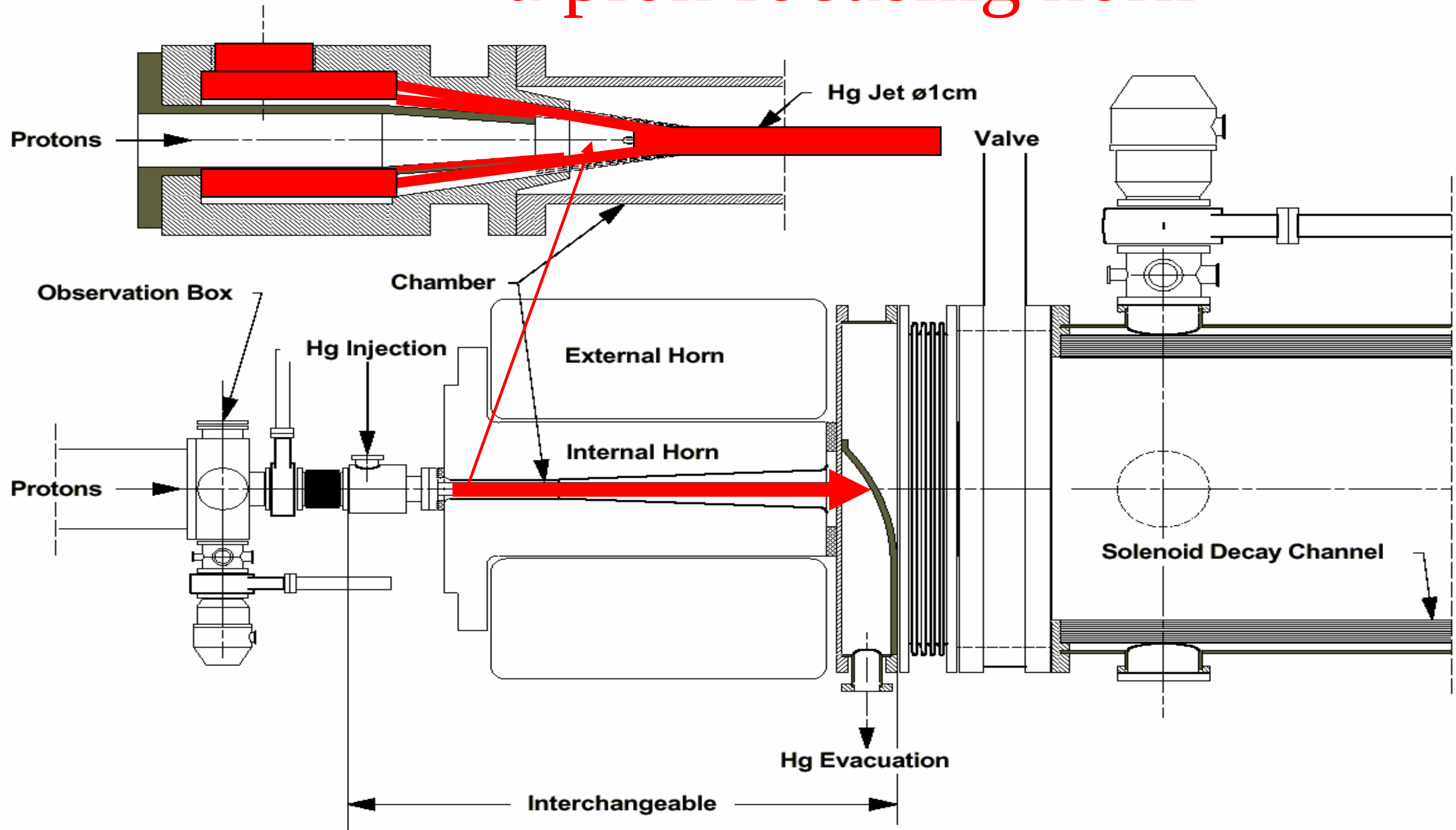
Densham

Stationary target:



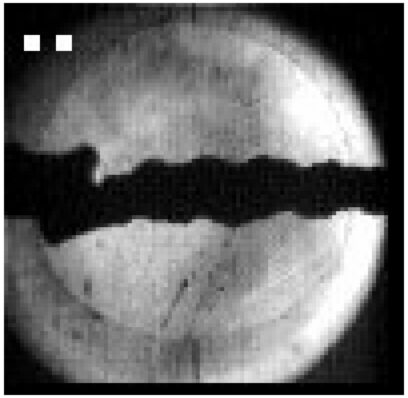
Sievers

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



H. Ravn

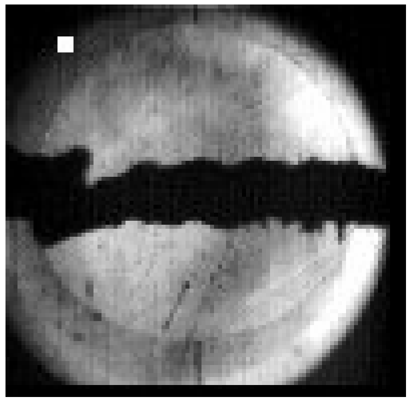
Jet test a BNL E-951



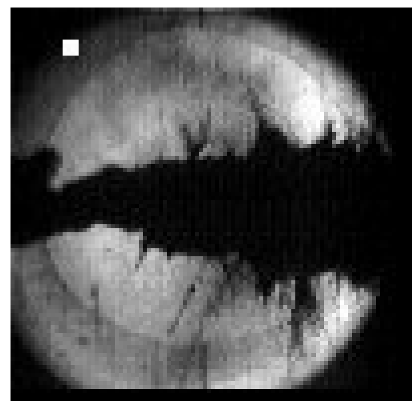
Event #11 25th April 2001

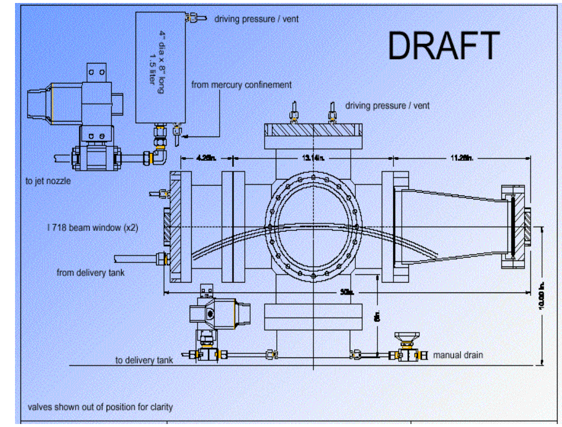
K. Mc Donald, H. Kirk, A. Fabich

Protons

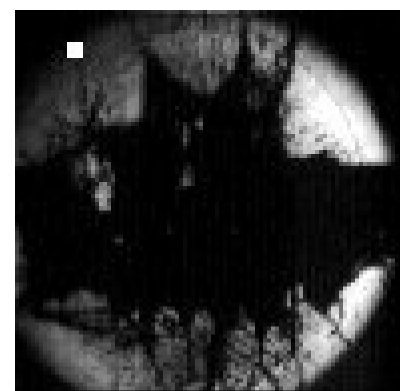


- 1cm diameter Hg Jet
- 24 GeV 4 TP Proton Beam
- No Magnetic Field





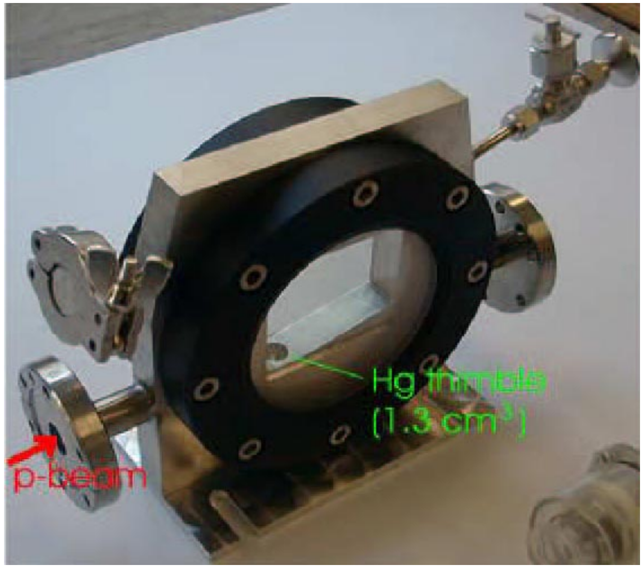
Picture timing [ms]
0.00
0.75
4.50
13.00

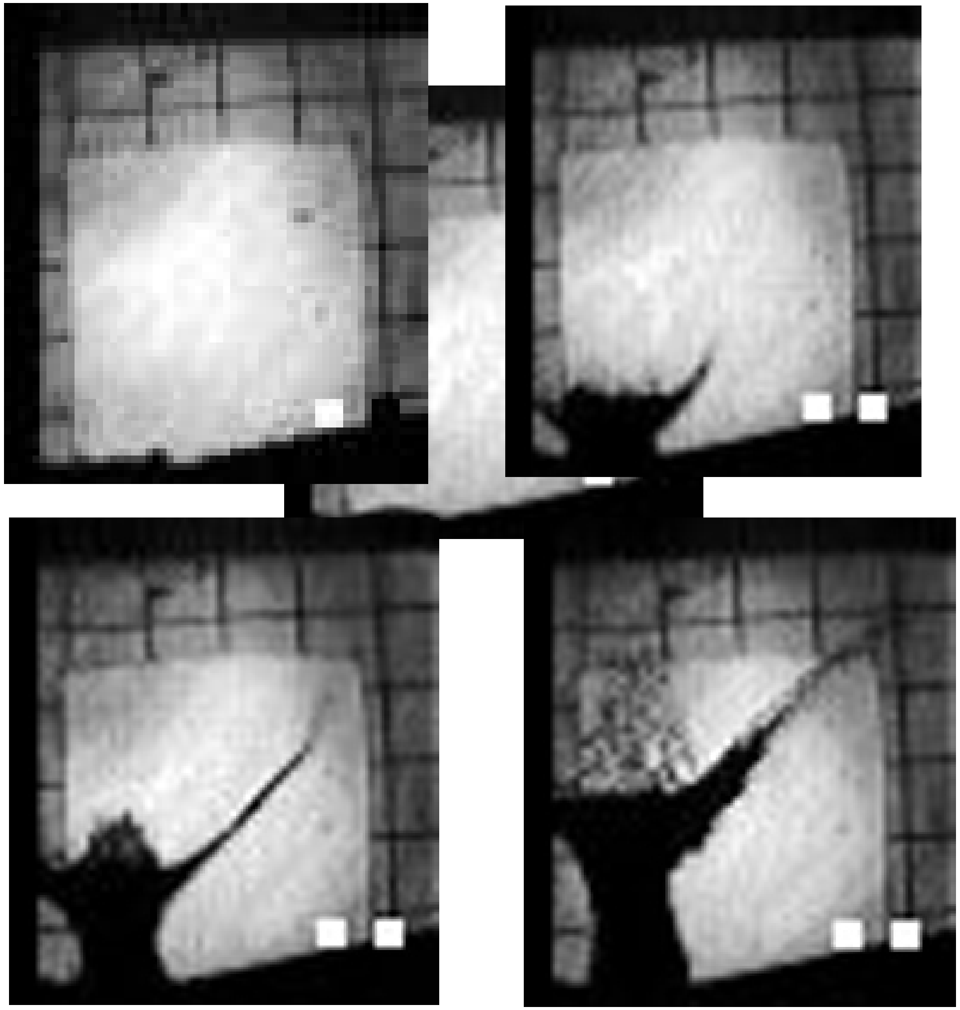


P-bunch: 2.7×10^{12} ppb
100 ns
$t_o = \sim 0.45$ ms

Hg- jet : diameter 1.2 cm
jet-velocity 2.5 m/s
perp. velocity ~ 5 m/s

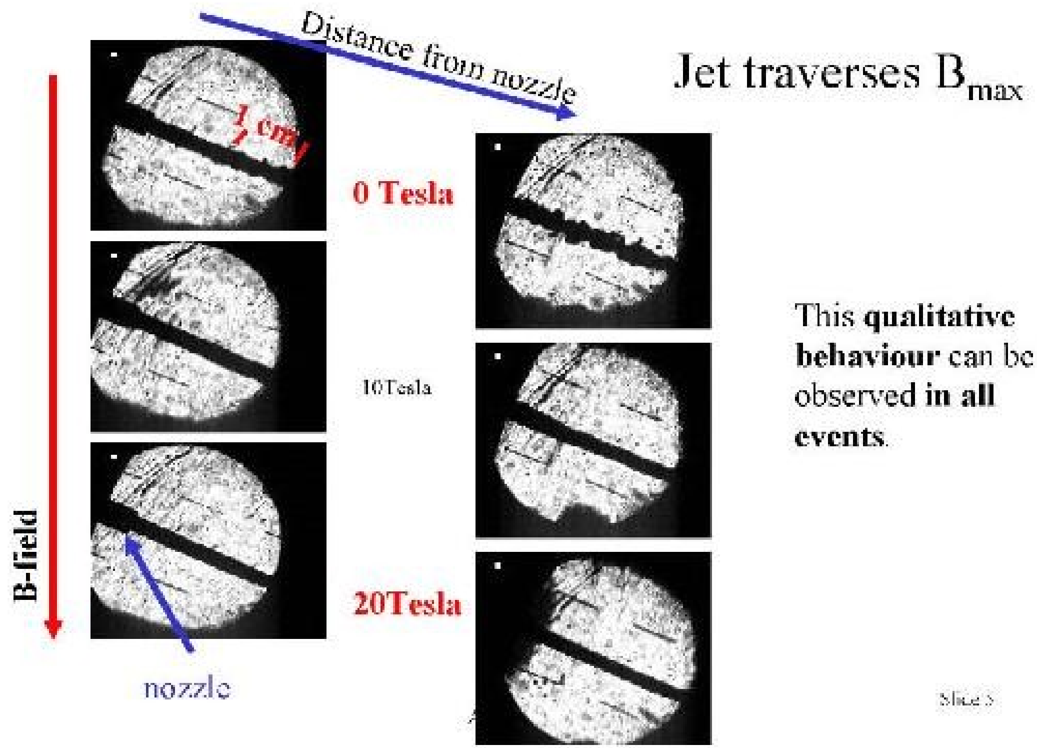
CERN Passive Hg Thimble Test





Exposures to a BNL AGS 24 GeV
2 TP beam. T=0, 0.5 , 1.6 and 3.4 ms.

CERN/Grenoble Hg Jet Tests



- 4 mm diameter Hg Jet
- v = 12 m/s
- 0, 10, 20T Magnetic Field
- <u>**No**</u> Proton Beam

A. Fabich, J. Lettry
Nufact'02

Key E951 Results

- Hg jet dispersal proportional to beam intensity
- Hg jet dispersal ~ 10 m/s for 4 TP 24 GeV beam
- Hg jet dispersal velocities ~ ½ times that of “confined thimble” target
- Hg dispersal is largely transverse to the jet axis -- longitudinal propagation of pressure waves is suppressed
- Visible manifestation of jet dispersal delayed 40 μs

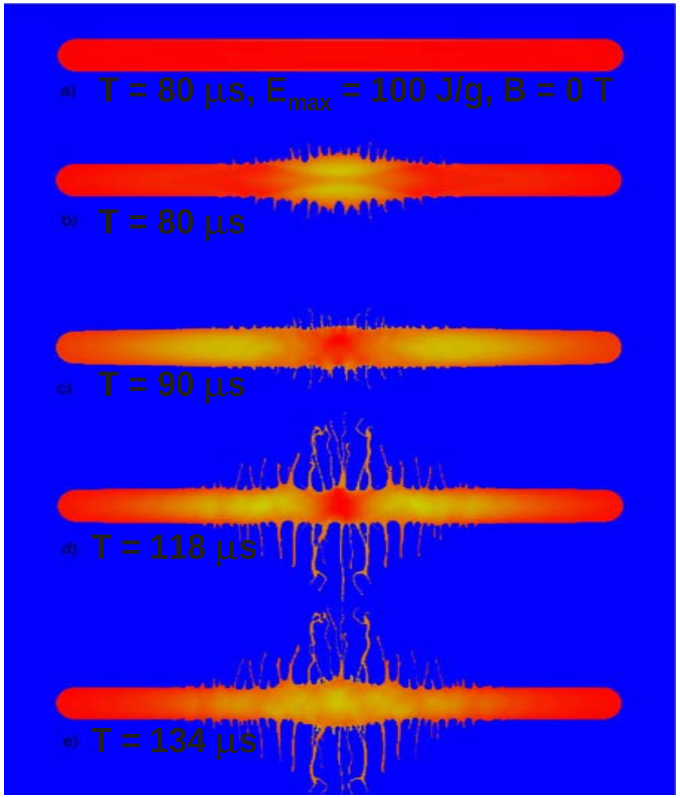
Key Jet/Magnetic Field Results

The Hg jet is stabilized by the 20 T magnetic fieldMinimal jet deflection for 100 mrad angle of entry

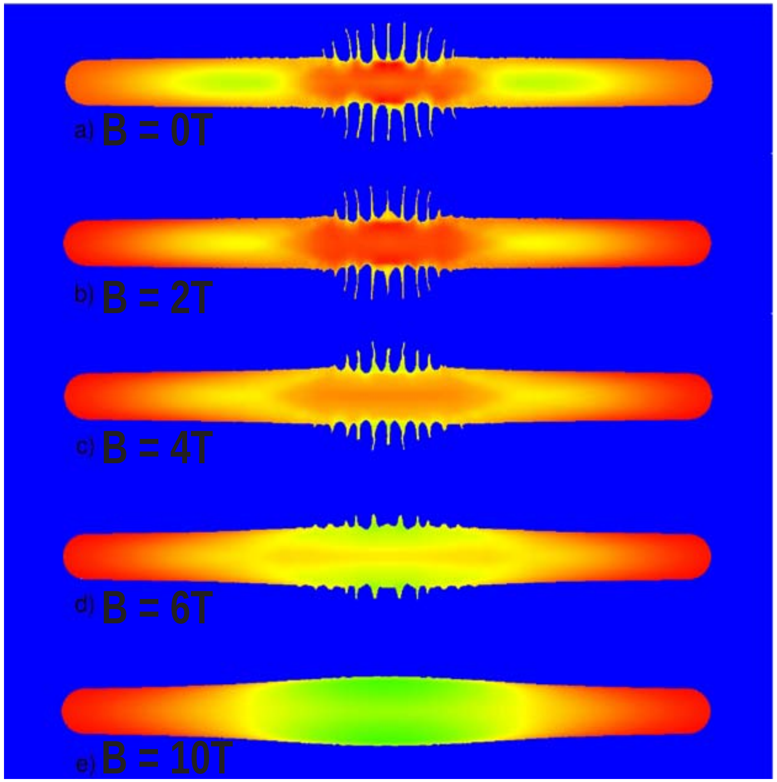
Jet velocity reduced upon entry to the magnetic field

Wanted:Tests with beam AND magnetic field

Simulations at BNL (Samulyak)



Gaussian energy deposition profile
Peaked at 100 J/g. Times run from
0 to 124 μs.

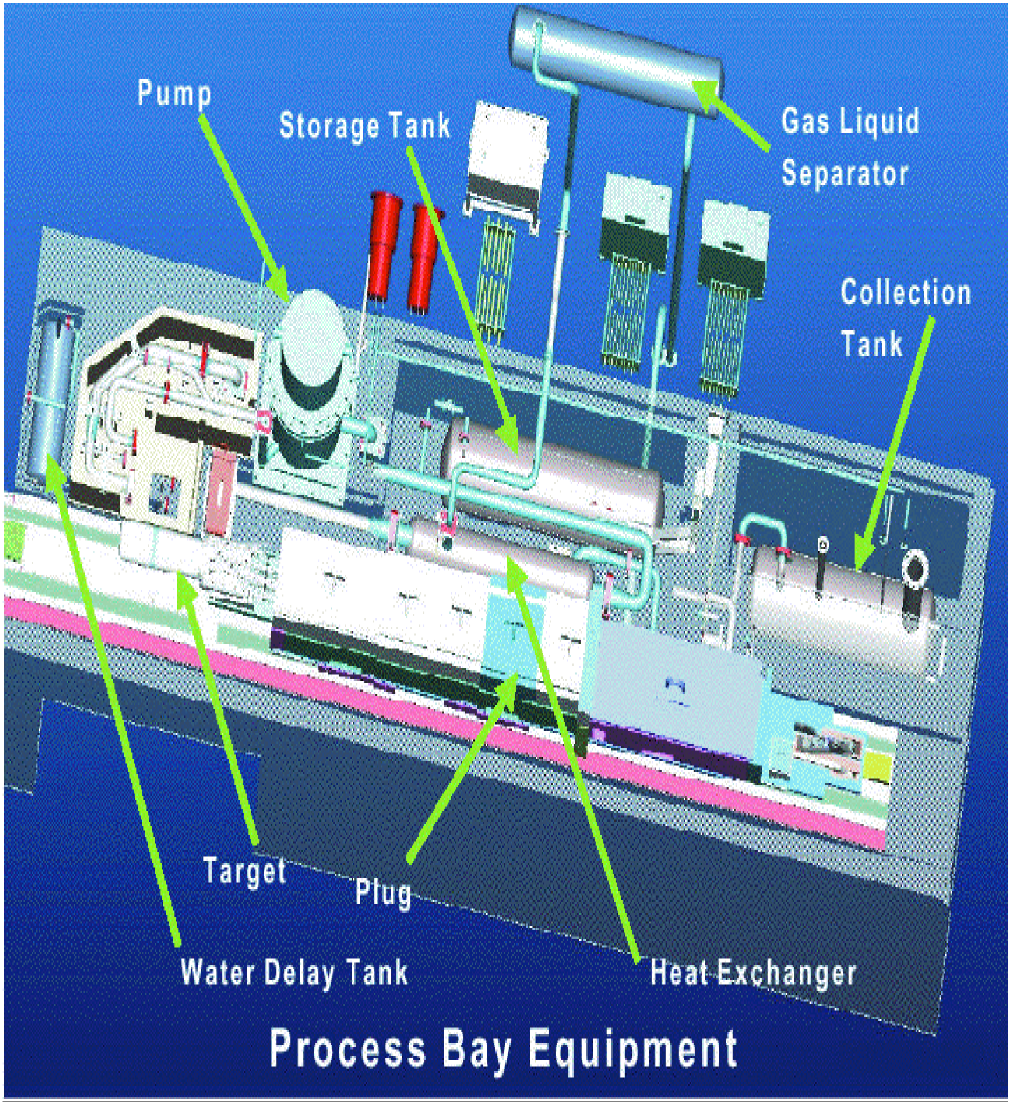


Jet dispersal at t=100 μs with magnetic
Field varying from B=0 to 10T

Hg-jet system

H. Ravn

- 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



Pion Capture

Pion Capture and decay channel

1. Solenoid, 10-20 Tesla

 US consider they have a long life (>>1 year) design

2. Horn (CERN)

NEEDED for π^+ and π^- separation (Superbeam)

 Problems with:

Heat dissipation, Radiation damage, Stress
Possible 6 week life
Studies will continue

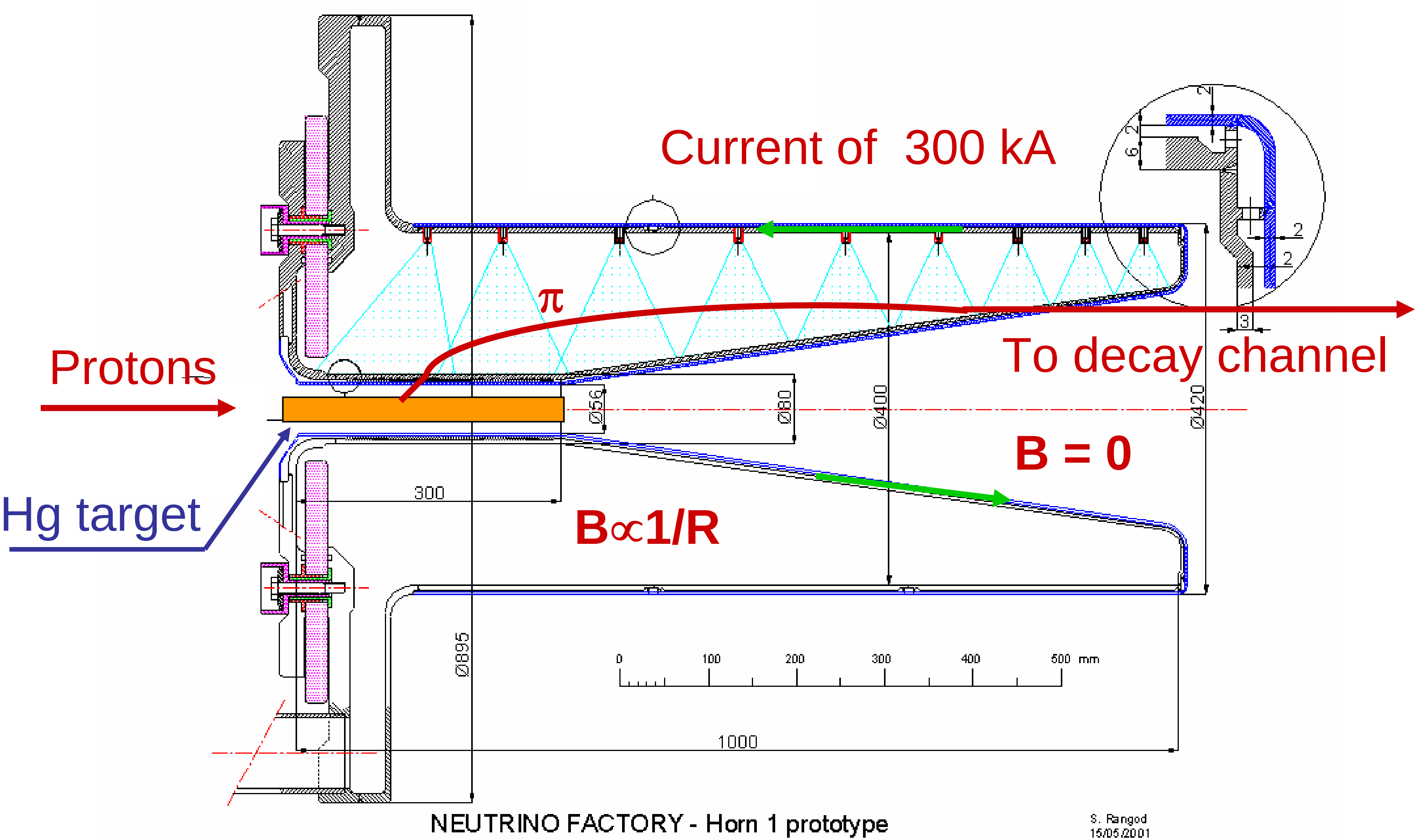
The typical length of this channel is 30 m, to allow most of the pions to decay into muons.

We need the HARP results:

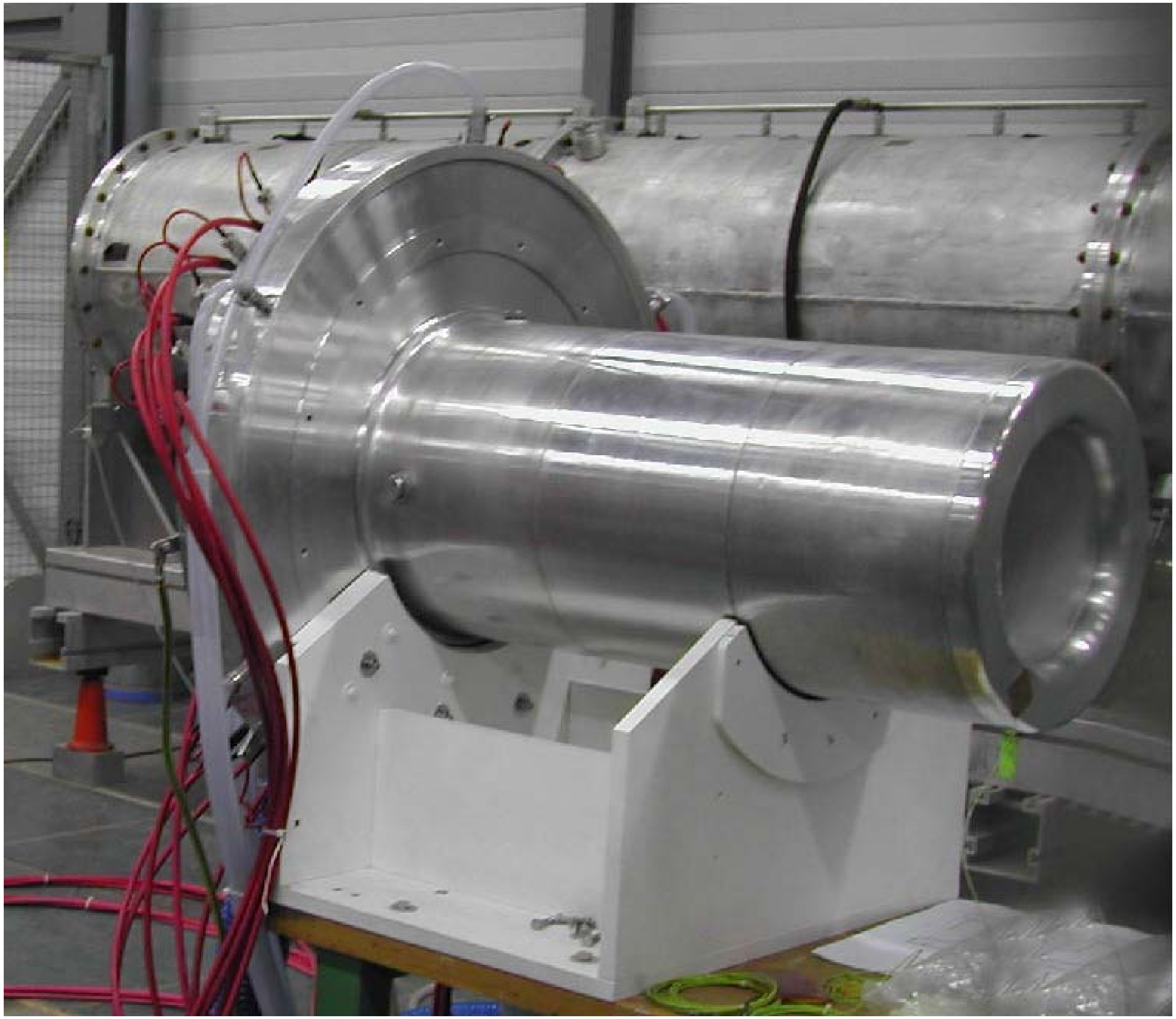
- ***For optimising the p-driver energy and the optimum focusing***

- ***In particular for the π^- production***

Horn focusing system



Horn prototype ready for tests



Main Parameters

•Radius of the waist	40 mm
•Peak current	300 kA
•Repetition rate	50 Hz
•Pulse length	93 μs
•Voltage on the horn	4200 V
•rms current in the horn	14.5 kA
•Power dissipation (by current)	39 kW
•Skin depth	1.25 mm

•Total length	1030 mm
•Outer diameter	420 mm
•Max diameter (electrical connection flange)	895 mm
•Free waist aperture	56 mm
•Waist outer diameter	80 mm
•Average waist wall thickness	6 mm
•Double skin thickness	2 mm

Phase rotation and cooling

Phase rotation

Phase rotation in the CERN scheme is achieved with rf cavities operating at 88 MHz.

The American scheme (Study 2) is using induction linacs. Now a 200 MHz rf capture system is being worked on.

In both cases one lets the muon beam generated via the very short (1 ns rms) proton bunch spread out in the longitudinal direction and use the corresponding time-position correlation to correct the energy of the muons with a time-varying electric field.

Cooling / Cooling Rings

To perform cooling, the beam is sent through (liquid hydrogen?) absorbers, reducing the transverse and longitudinal momenta.

Subsequent reconstitution of the longitudinal momentum occurs with RF cavities.

Basically the cooling channel is a linear accelerator with (liquid hydrogen) absorbers.

The cooling channel will be fairly long and expensive, hence the interest in “ring coolers”, where cooling is done over many revolutions.

200 MHz cavities (LBNL) as for MICE

Muon Ionisation Cooling Experiment

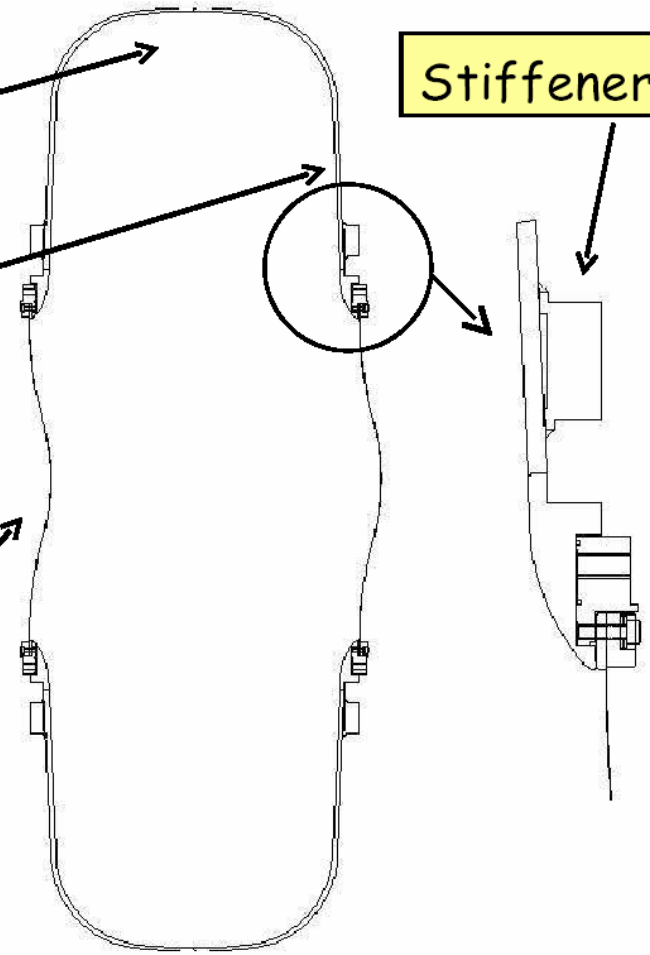
(Scientifically approved at RAL)

Spherical section at the equator to ease addition of ports (± ~ 6°)
Elliptical-like (two circles) nose to reduce peak surface field

2° tilt angle

6-mm Cu sheet allows for uses of spinning technique and mechanical tuners

De-mountable Pre-curved Be windows to terminate RF fields at the iris



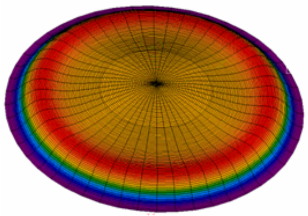
Stiffener ring

Nov. 1st 2003

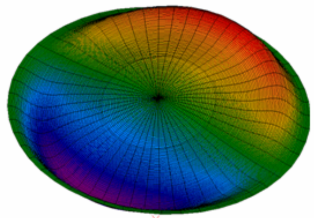
Mechanical cleaning of the cavity inner surface (right) after e-beam welding of the stiffener ring (above)

Real science in the Be windows simulations

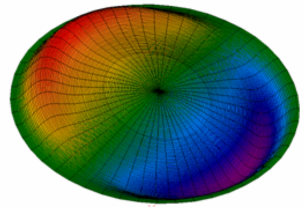
(Also for the LH2 absorber windows)



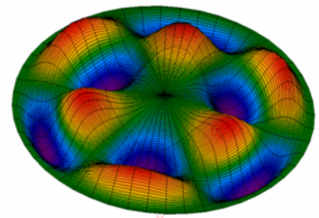
1st mode shape of the 3-D model



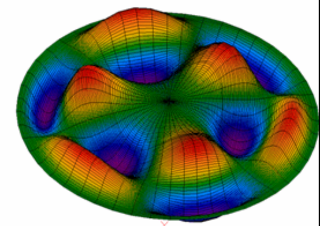
2nd mode shape of the 3-D model



3rd mode shape of the 3-D model

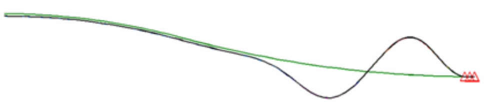


4th mode shape of the 3-D model

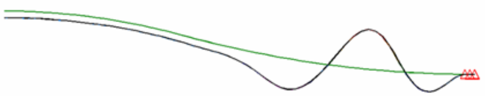


5th mode shape of the 3-D model

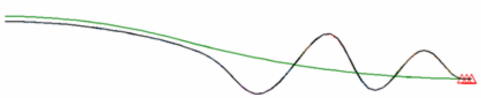
1st mode shape of the 2-D model



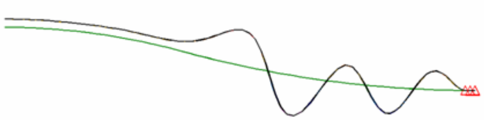
2nd mode shape of the 2-D model



3rd mode shape of the 2-D model



4th mode shape of the 2-D model

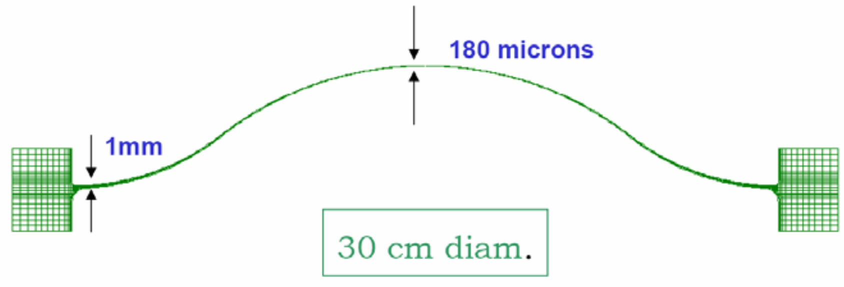


5th mode shape of the 2-D model

	0.25mm thk		0.38mm thk		0.5mm thk	
	2-D axisy model	3-D plate model	2-D axisy model	3-D plate model	2-D axisy model	3-D plate model
1st freq.	463 Hz.	482 Hz	559 Hz	582 Hz	635 Hz	660 Hz
2nd freq.	1878 Hz	586 Hz	2190 Hz	703 Hz	2449 Hz	793 Hz
3rd freq.	2343 Hz	586 Hz	2782 Hz	704 Hz	3140 Hz	793 Hz
4th freq.	3254 Hz	820 Hz	3890 Hz	1050 Hz	4423 Hz	1250 Hz
5th freq.	3849 Hz	820 Hz	4690 Hz	1050 Hz	5433 Hz	1250 Hz

Summary of the natural frequency runs

Liquid Hydrogen Absorbers



Acceleration

D. Hartill: 200 MHz sc cavity (Cu sputtered with Nb, for preacceleration and RLAs) at Cornell

Requirements to acceleration

- The highest possible Eacc to minimize muon decay
- Large transverse and longitudinal acceptances

Both requirements favor the choice of SRF

$$P_d = \frac{Eacc^2}{(R/Q)Q_0}$$

- SRF cavities have a high Q_0
- SRF can achieve high gradients with modest RF power
- SRF cavities accommodate a larger aperture without a large penalty for the low R/Q

Why Nb-Cu cavities?

- Save material cost
- Save cost on magnetic field shielding (Rs of Nb-Cu less sensitive to residual mag. field)
- Save cost on LHe inventory by pipe cooling (Brazing Cu pipe to Cu cavity)

1.5GHz bulk Nb cavity (3mm) material cost: ~ $ 2k/cell
200MHz: X $(1500/200)^2 = 56 \rightarrow$ $ 112k/cell
Thicker material (8mm) needed: X 2.7 → $300k/cell

Nb Material cost for 600 cells: 180M$
Cu (OF) is X 40 cheaper: 5M$

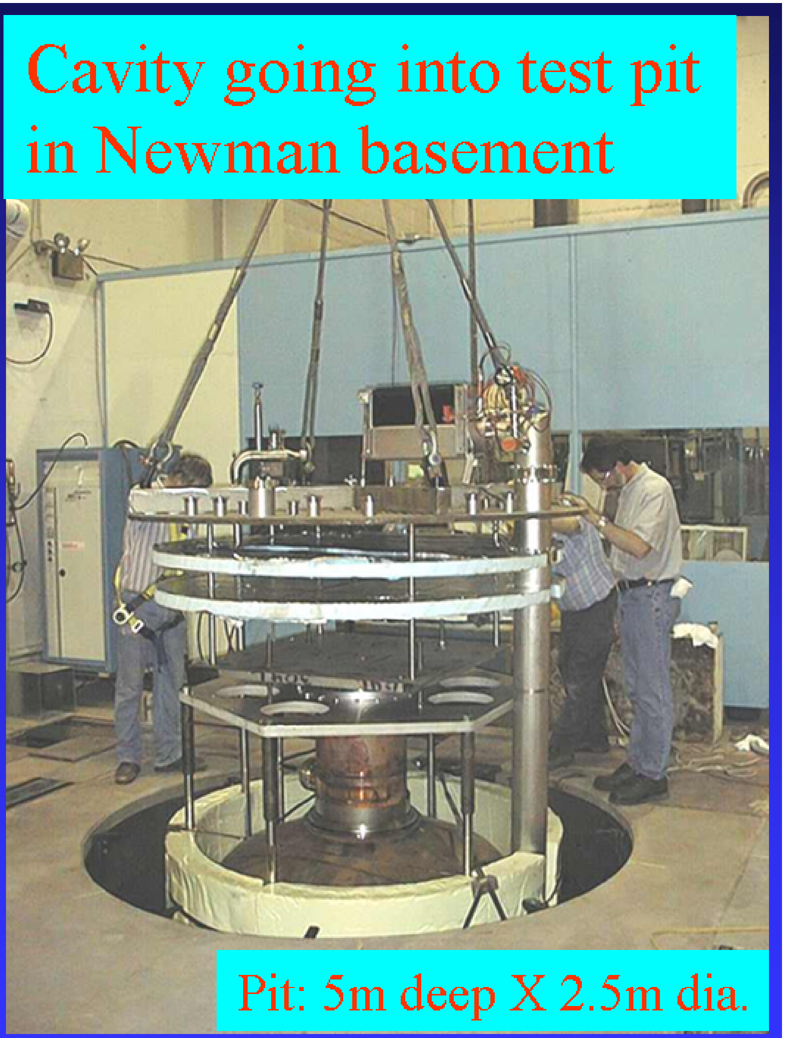
Sputtering at CERN

Electro-polished half cell

- DC voltage: 400-650 V
- Gas pressure: 2 mTorr
- Substrate T: 100 °C
- RRR = 11
- Tc = 9.5 K

Magnetron Nb film (1-2 μm) sputtering

RF test preparation at Cornell



Cavity returned to CERN for recoating with improved geometry - expect completion in March - retest 5/04

Acceleration with RLAs

After the cooling the muons have to be accelerated to energies between 20 and 50 GeV. Normal synchrotrons are too slow and the decay losses of muons would not be tolerable (the muon's life time is only 2.2 μs). So-called recirculating linacs (RLA) are a good compromise between cost and speed.

One interesting proposal should nevertheless be mentioned here: the possible use of a rapidly pulsed synchrotron, which seems feasible by making use of the fairly low repetition rate, at least in the US scheme.

Alternative: Acceleration with FFAGs!

Large Acceptance

Both longitudinal and transverse

Fast acceleration due to fixed magnetic field

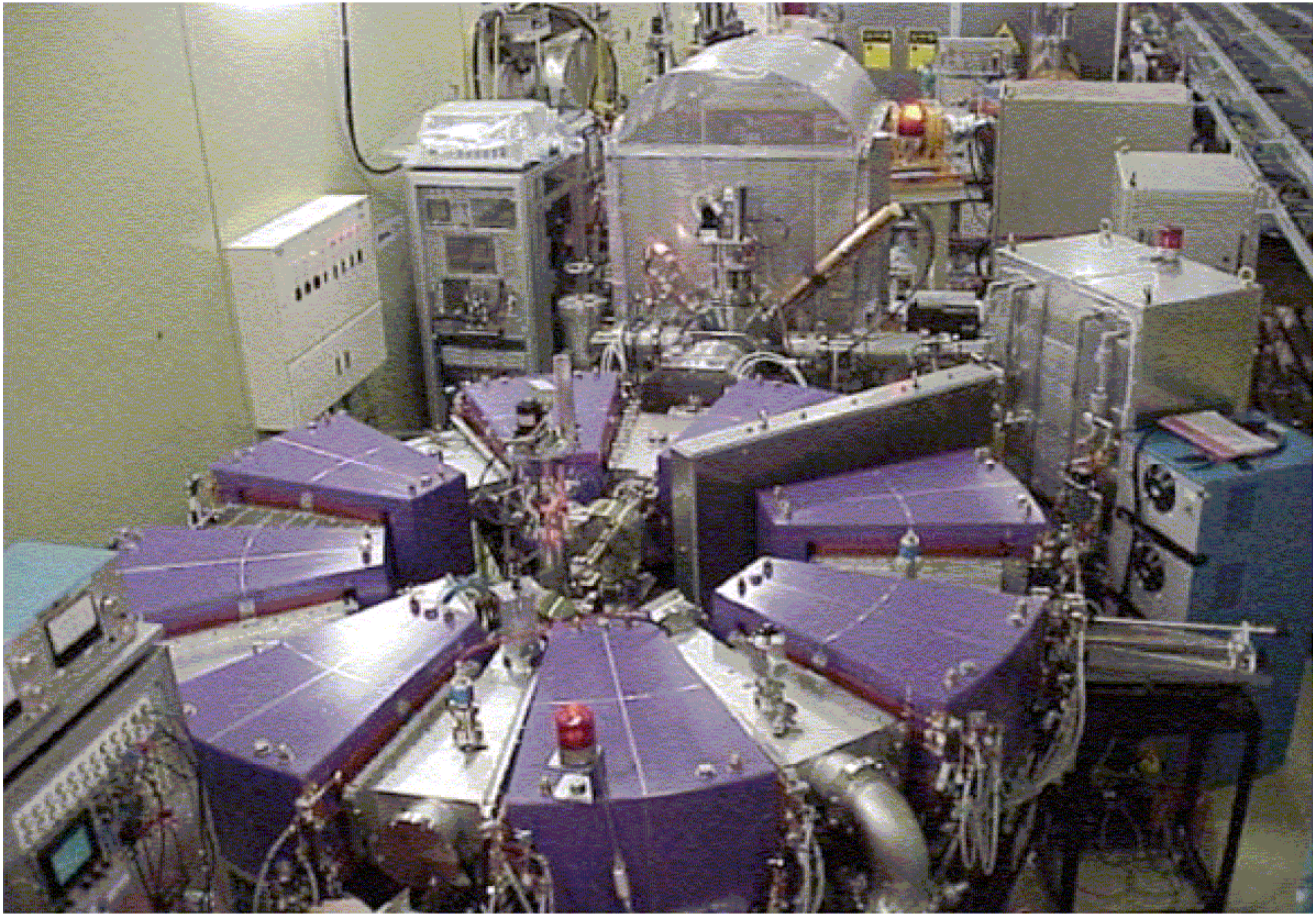
Suitable for Muon Acceleration

without cooling!

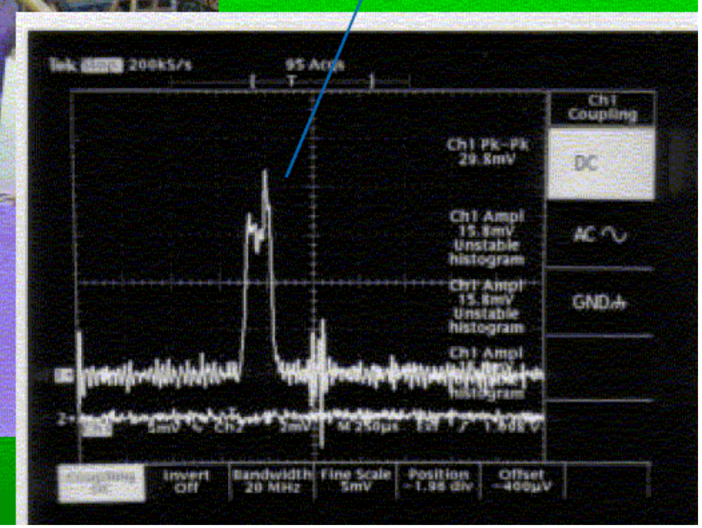
Built for protons in Japan:

PoP FFAG: 50 keV to 500 keV, about 1 m radius

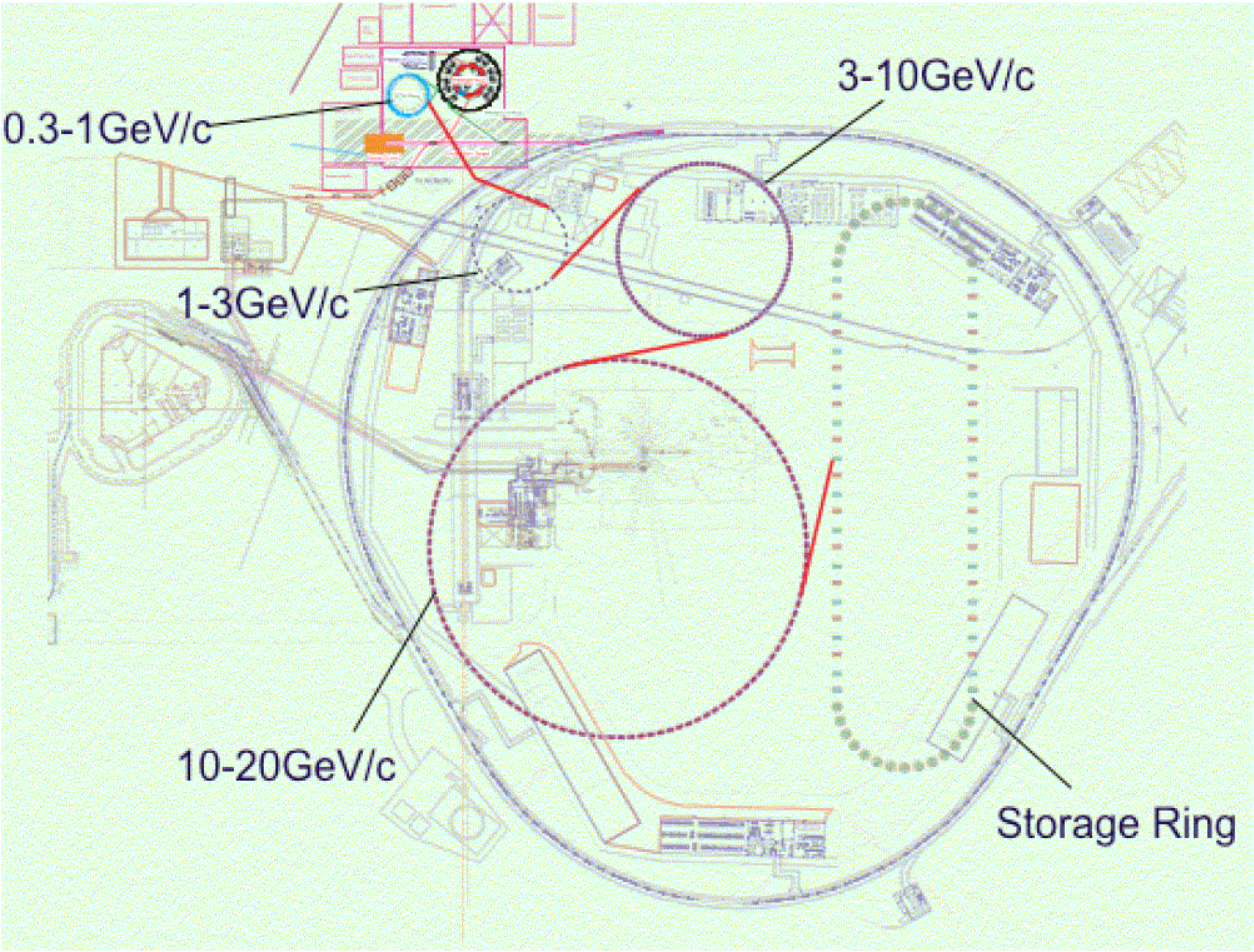
150 MeV is radius 5 m, rep rate 250 Hz



150-MeV FFAG



Layout of Neutrino Factory at J-PARC



Muon Colliders

Some time ago regarded by some people as science fiction, it must be noted that the advances in cooling theory and technology are so impressive as to consider this type of machine as a real possibility in the future.

High Energy Frontier…

Main problems in a Neutrino Factory:

(Proton driver)

Target

Collection

Cooling (Phase rotation)

Acceleration

Main problems with a superbeam:

High intensity linacs **NOT** a basic problem:

Work at Los Alamos, ESS, TRISPAL, CONCERT, EURISOL and SNS (the only one being build…)

Except for cost, halo and hands-on maintenance

You may need an accumulator (+stripper foil!)…

<u>But target and collection need experiments</u>

especially for a low energy proton beam (high Z target material required)

(Of course we are waiting for the detailed analysis of the HARP experiment)

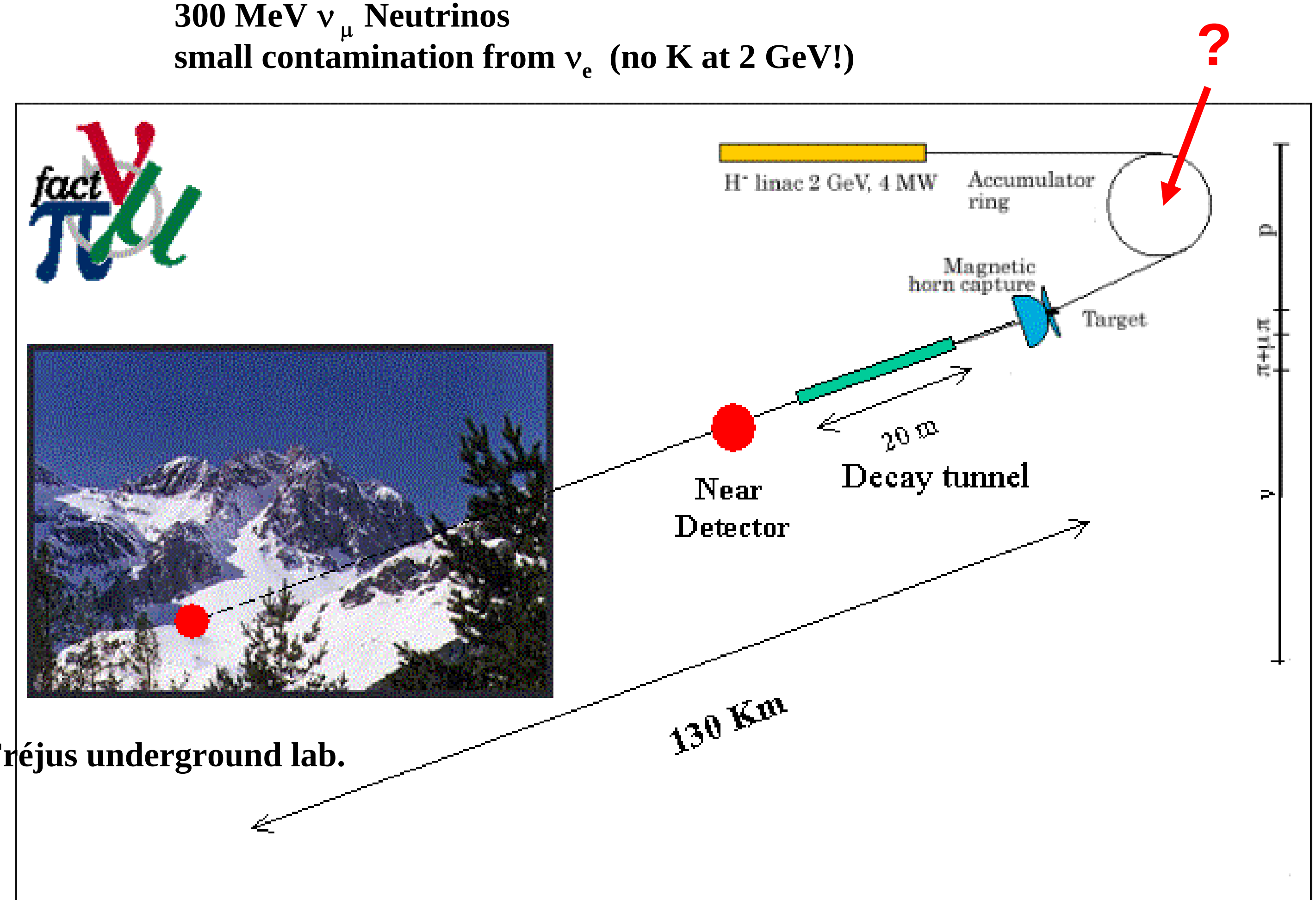
The Superbeam

Start with the SPL…

Where do you prefer to take shifts (Gilardoni)?

Sorry, this was for the Neutrino Factory…

300 MeV ν_μ Neutrinos
small contamination from ν_e (no K at 2 GeV!)



A possible layout of a Low Energy Neutrino Super Beam

Targets (recall!):

Difference between a neutron spallation source target and a “neutrino” target (pion escape…)

A neutrino target must be small: 1 to 2 cm in diameter

Material must be compatible with horn material

If this seems difficult…

Try funneling!

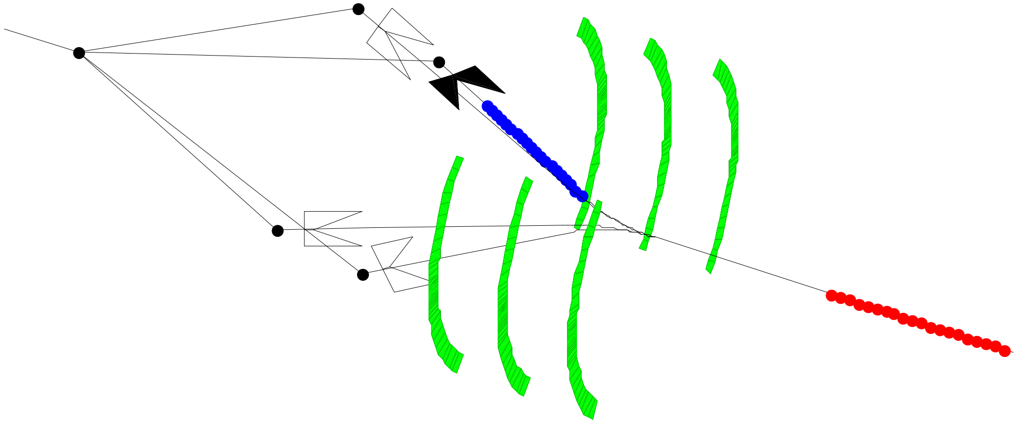
B. Autin, F. Meot, A. Verdier

What are the problems?

- Proton beam power: 4 MW
- Target to cope with high power
  (must be a high Z target because of the modest proton energy)
- Horn to be pulsed at: 50 Hz
  (Linac frequency)

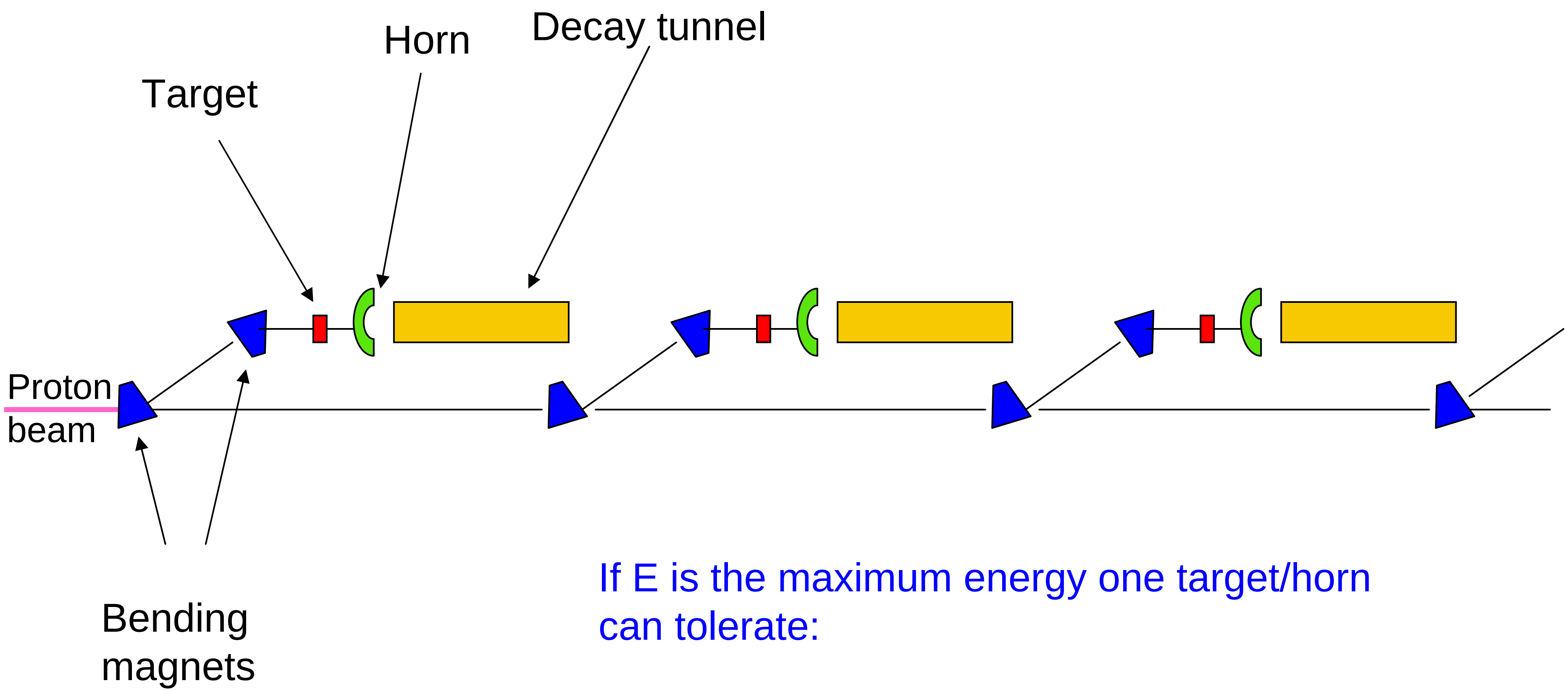
•It would be much simpler if we had only 1 MW and e.g. 12.5 Hz

Funneling step by step



Funneling maybe a nice idea for a Neutrino Factory,
however, you do not need funneling for a superbeam…

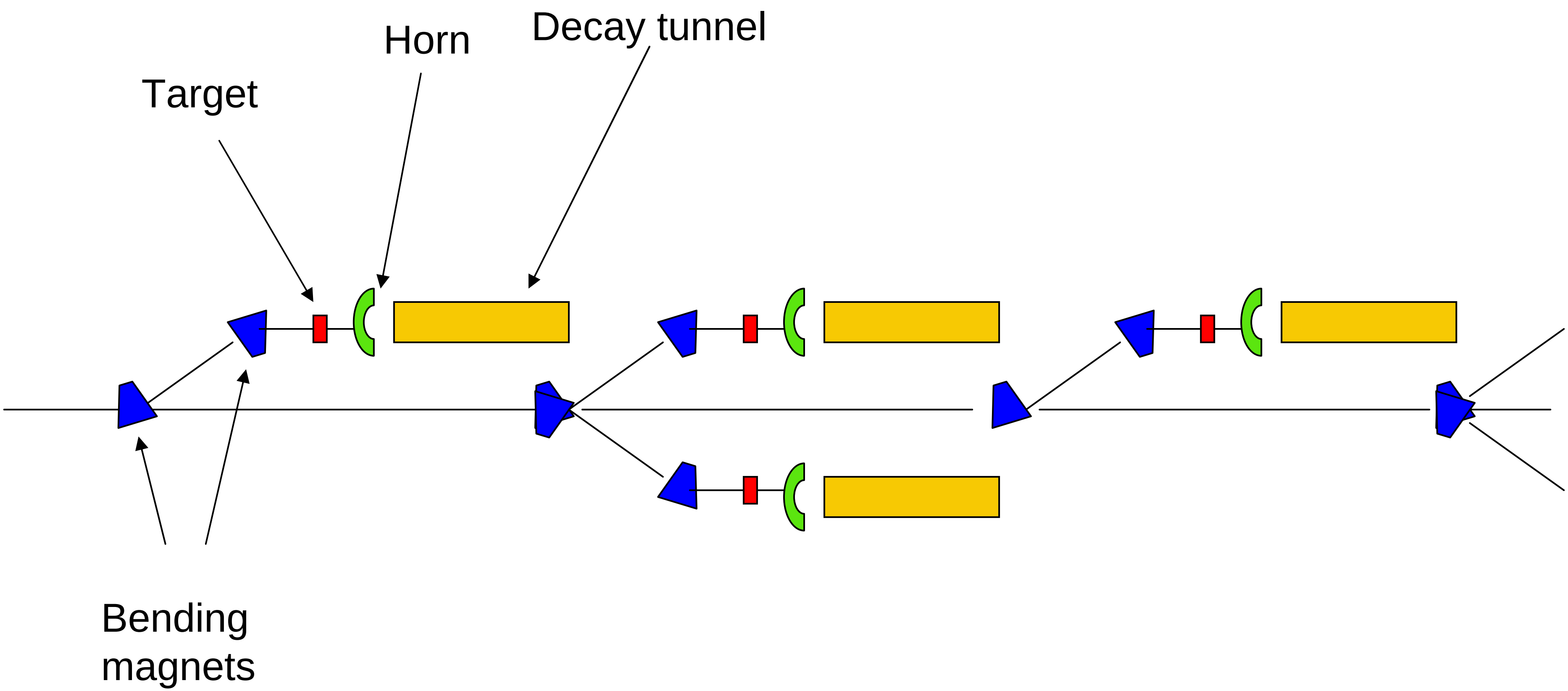
Schematic layout



If E is the maximum energy one target/horn can tolerate:

Do this n times to get n × E

Alternative layout



Of course

this means:

n targets,

n horns

n power supplies

n target stations with remote handling

but all are identical…

Nevertheless target experiments are important

- BNL et al. wish to perform a proof-of-principle test which will include:
  - A high-power intense proton beam (16 to 32 TP per pulse)
  - A high (> 15T) solenoidal field
  - A high (> 10m/s) velocity Hg jet
  - A ~1cm diameter Hg jet
- Experimental goals include:
  - Studies of 1cm diameter jet entering a 15T solenoid magnet
  - Studies of the Hg jet dispersal provoked by an intense pulse of a proton beam in a high solenoidal field
  - Studies of the influence of entry angle on jet performance
  - Confirm Neutrino factory/Muon Collider Targetry concept

Letter of Intent-- Isolde and nToF Committee

CERN-INTC-2003-033
INTC-I-049
23 October 2003
Updated: 31 Oct 2003

A Letter of Intent to
the ISOLDE and Neutron Time-of-Flight
Experiments Committee

Studies of a Target System for
a 4-MW, 24-GeV Proton Beam

J. Roger J. Bennett[1], Luca Bruno[2], Chris J. Densham[1], Paul V. Drumm[1],
T. Robert Edgecock[1], Helmut Haseroth[2], Yoshinari Hayato[3], Steven J. Kahn[4],
Jacques Lettry[2], Changguo Lu[5], Hans Ludewig[4], Harold G. Kirk[4],
Kirk T. McDonald[5], Robert B. Palmer[4], Yarema Prykarpatskyy[4],
Nicholas Simos[4], Roman V. Samulyak[4], Peter H. Thieberger[4],
Koji Yoshimura[3]

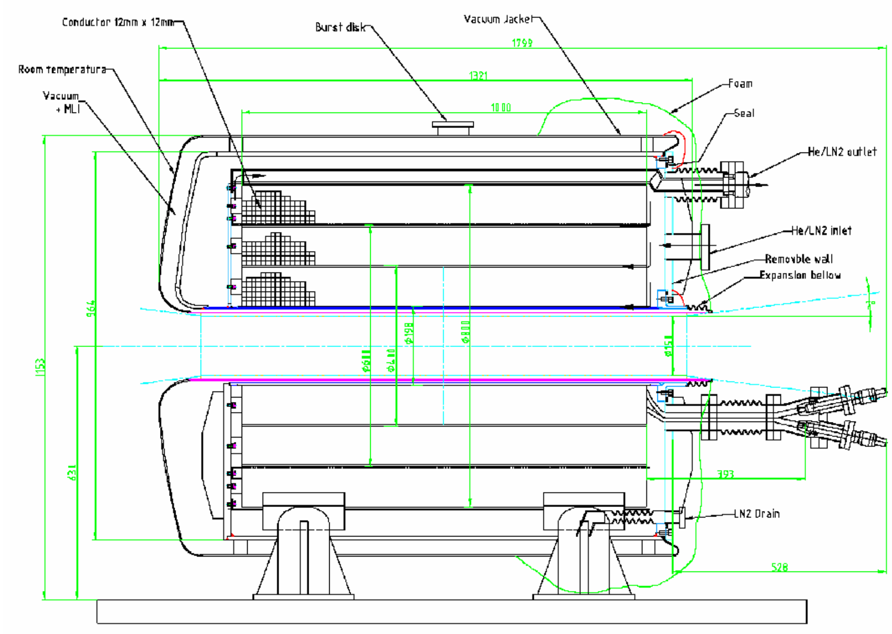
Spokespersons: H.G. Kirk, K.T. McDonald
Local Contact: H. Haseroth

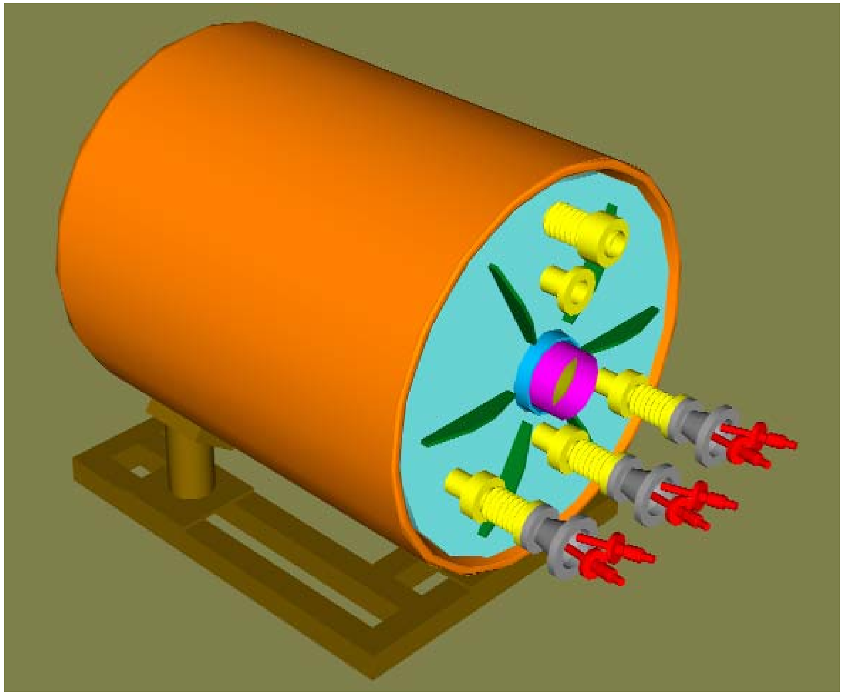
Participating Institutions

1) RAL
2) CERN
3) KEK
4) BNL
5) Princeton University

High Field Pulsed Solenoid

(being manufactured for $ 700 k)

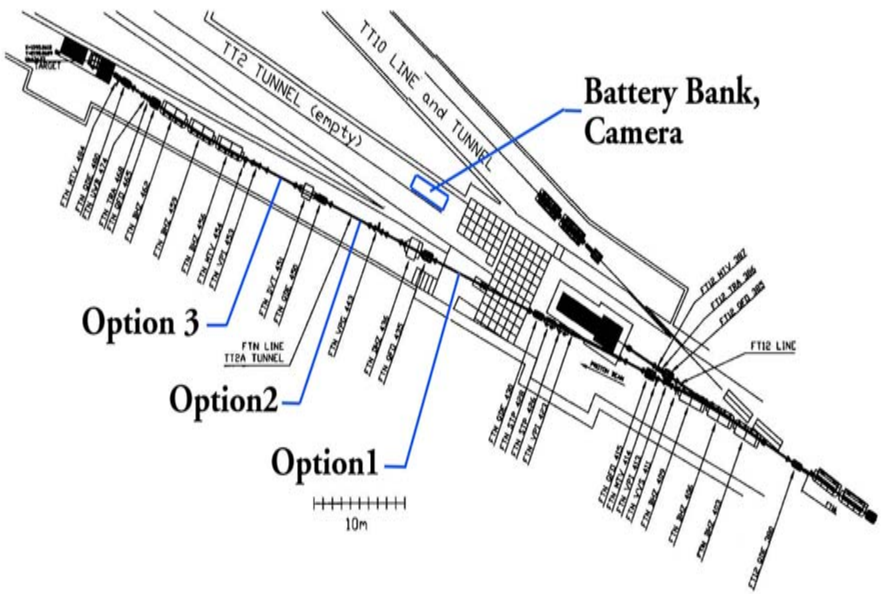


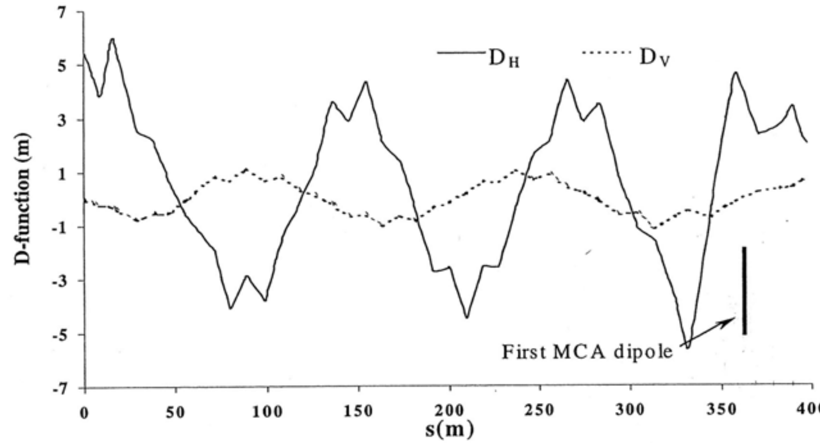


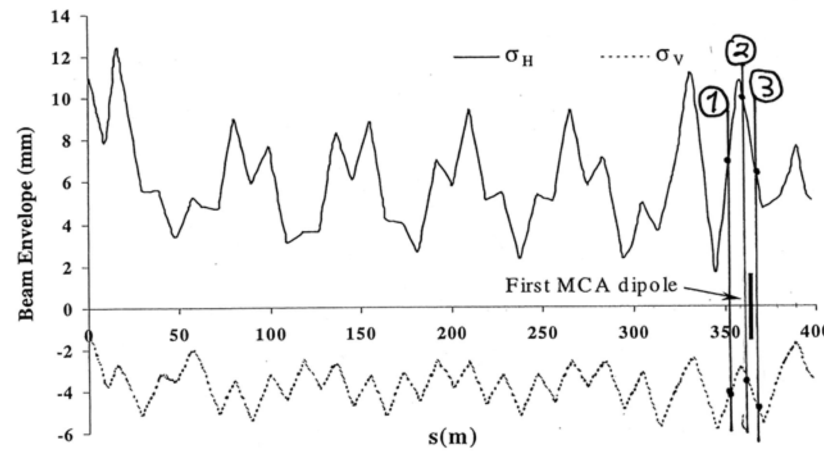
- 70º K Operation
- 15 T with 4.5 MW Pulsed Power
- 15 cm warm bore
- 1 m long beam pipe

Peter Titus, MIT

The TT2a Beam Line



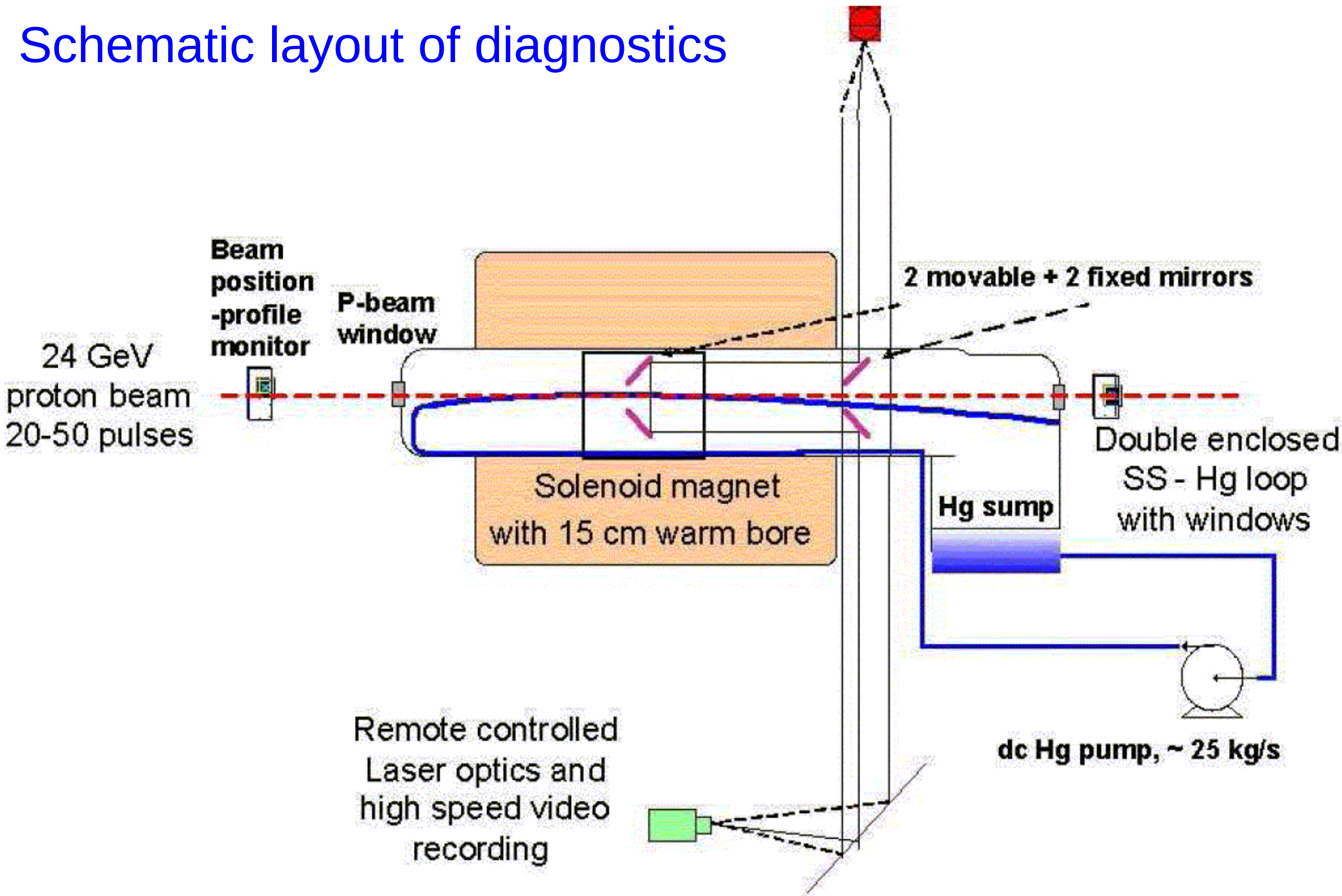




We propose running without longitudinal bunch compression allowing for a reduced beam spot size of ~ 2mm rms radius.

CERN, beam line towards nTOF

Schematic layout of diagnostics



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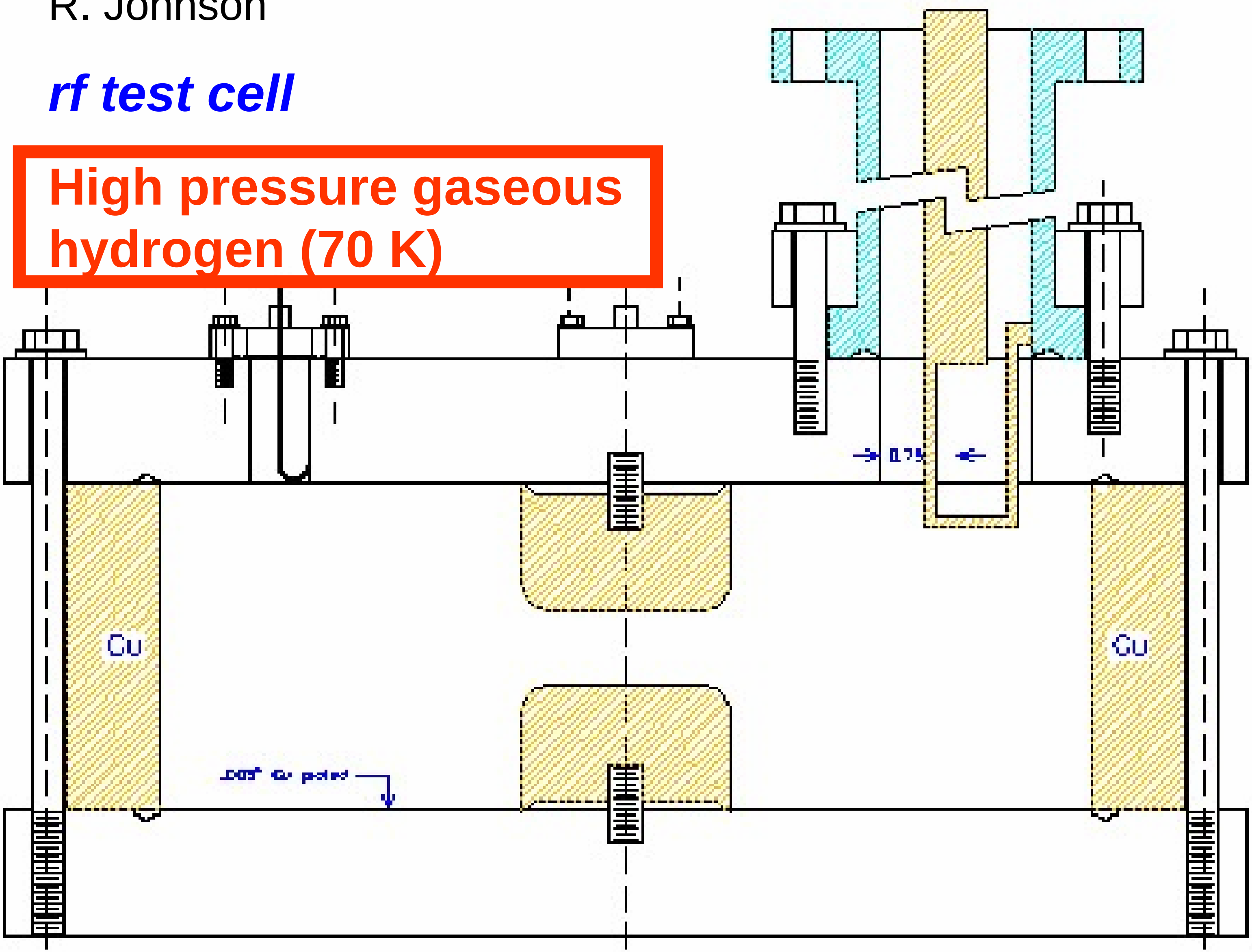
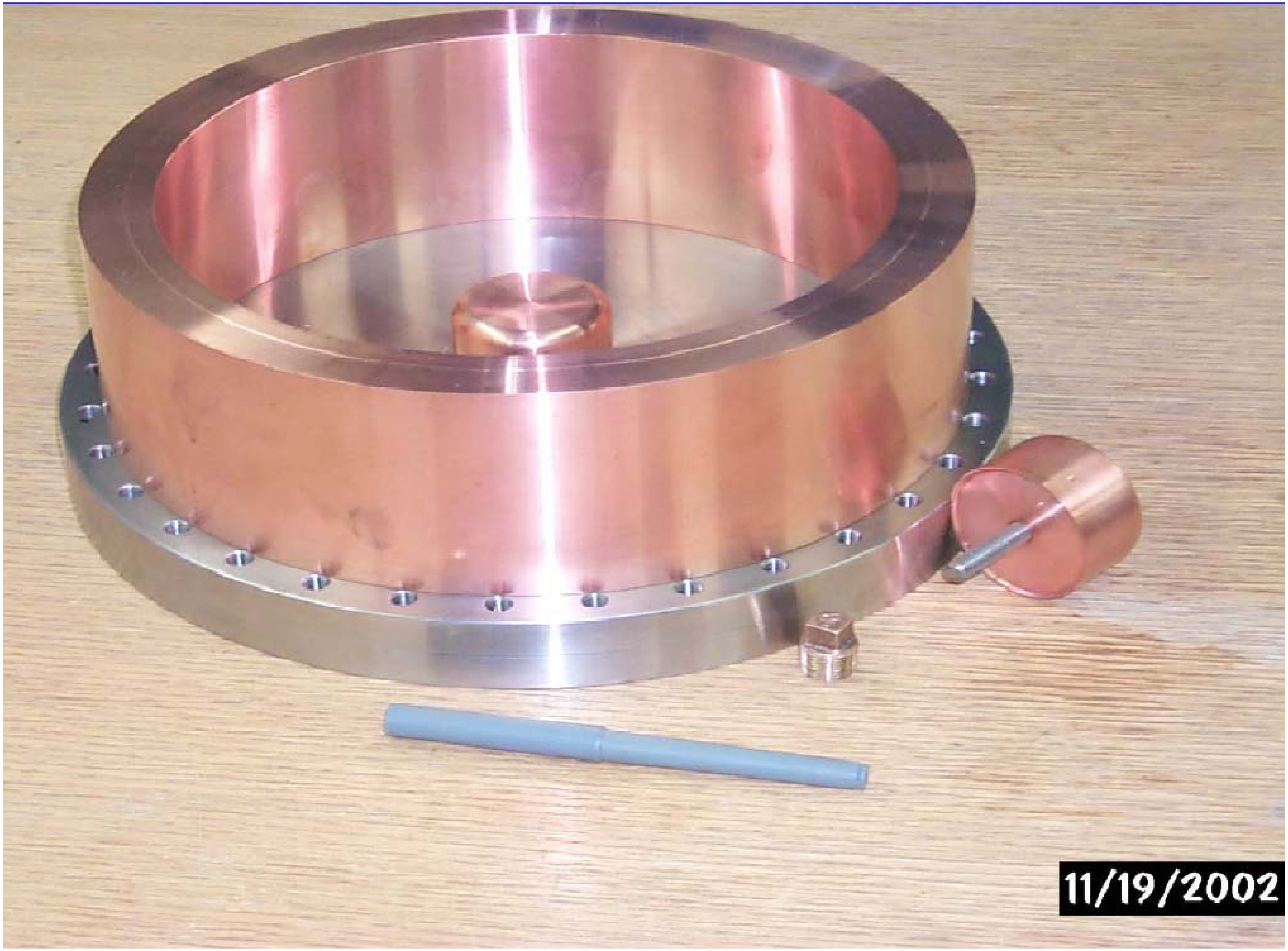
and now there is a proposal…

- *Some exotic ideas*

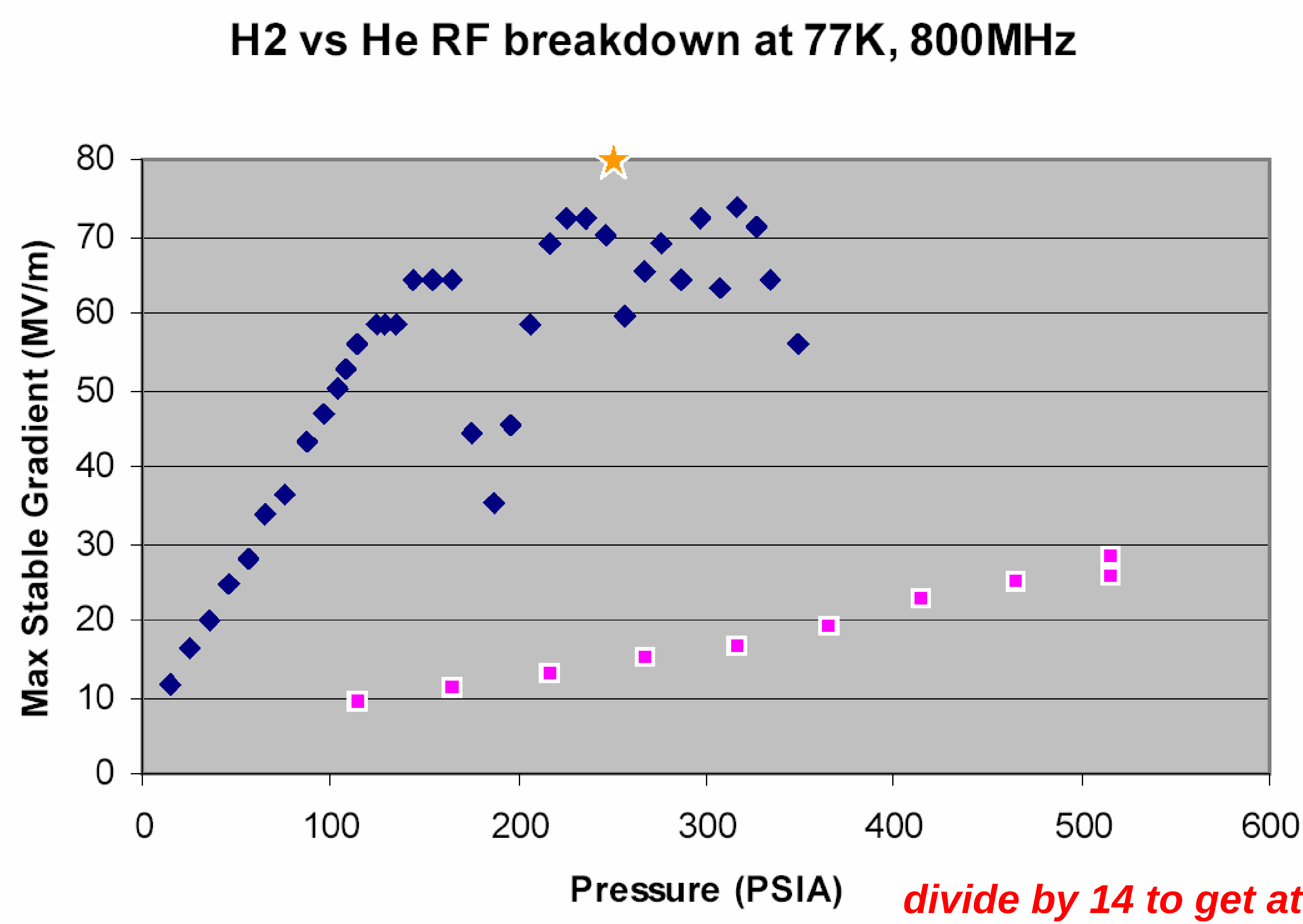
rf test cell

High pressure gaseous hydrogen (70 K)




11/19/2002

11/19/03 Lab G Results, Molybdenum Electrodes



divide by 14 to get atm !

Estimated parameters of a helical 6D cooling channel

Parameter	*Unit*	*Initial*	*Middle* ****)	*Final*
Beam momentum,	**MeV/c**	**100**	**100**	**100**
Solenoid field	**T**	**3.5**	**8**	**14**
Helix period	**m**	**1**	**0.44**	**0.22**
Transverse field at beam	**T**	**0.7**	**1.6**	**3.0**
Helix orbit radius	**cm**	**15**	**6**	**3**
Dispersion	**cm**	**37**	**15**	**7.5**
Accelerating RF field	**MV/m**	**40**	**40**	**40**
Frequency	**GHz**	**0.2**	**0.8**	**1.6**
Absorber energy loss rate	**MeV/m**	**14**	**14**	**14**
Synchrotron emittance	**cm**	**1.5**	**0.15**	**3.10^{-2}**
Relative momentum spread	**%**	**7.5**	**3**	**2**
Bunch length	**cm**	**30**	**7.5**	**1.1**
Beam width	**cm**	**3**	**0.56**	**0.15**
Transverse emittances	**cm x rad**	**1.7/1.7**	**0.2/0.2**	**$(1/3)10^{-2}$**

The cooling effect in this calculation in terms of reduction of the 6D emittance is 5×10^5. The total energy loss in absorber is about 1.12 GeV. For a channel of continuous dense hydrogen gas with 14 MeV/m of energy loss, this implies a 6D cooling channel length, $L = \frac{1.12}{.014} / \sqrt{1+\kappa^2} = 56$ m.

5 ⑨ 10^5 in 6D emittance in 56 m !

Frictional Cooling for a Muon Collider

A. Caldwell
MPI f. Physik/Columbia University

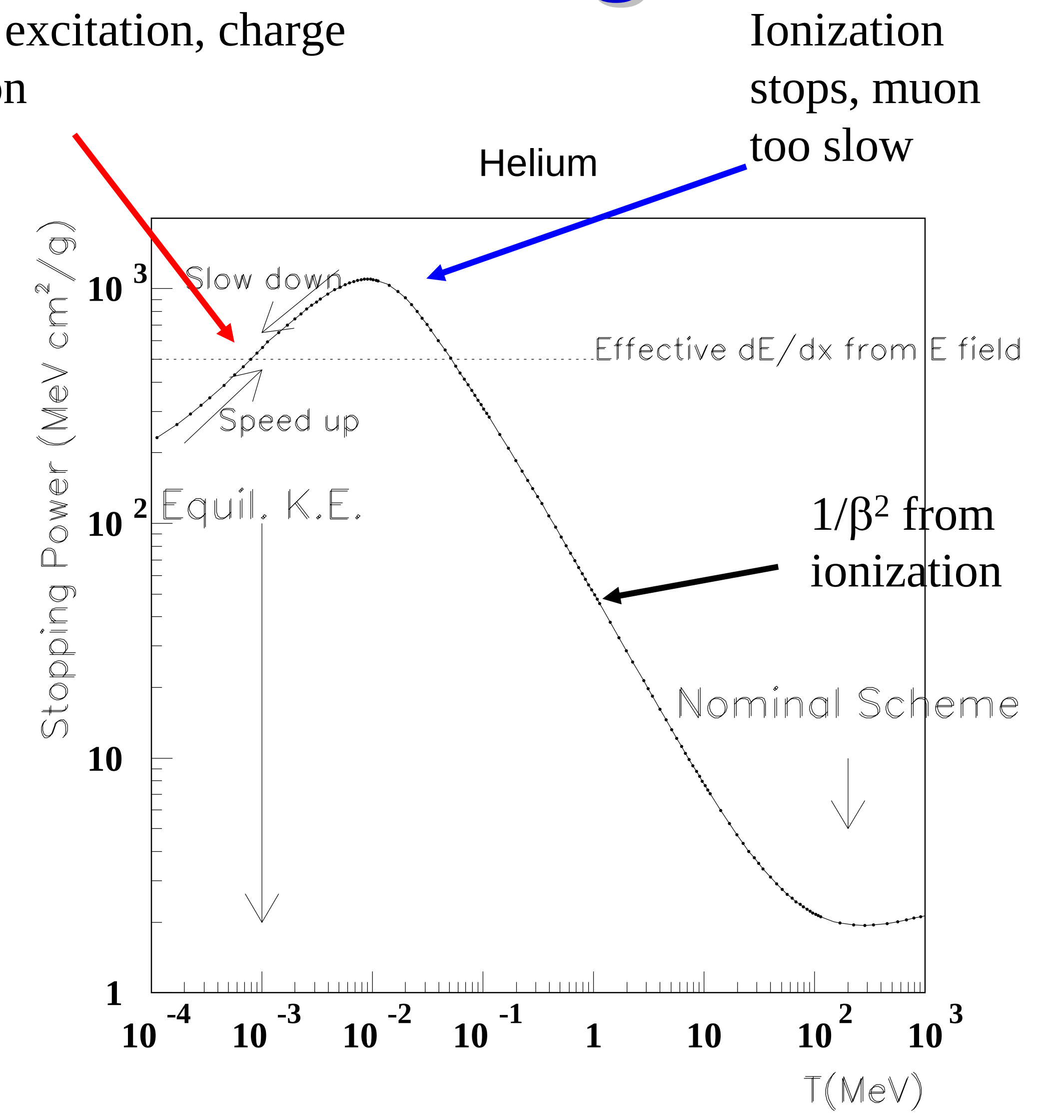
Muon Cooling is the signature challenge of a Muon Collider

Cooler beams would allow fewer muons for a given luminosity, thereby

- Reducing the experimental background
- Reducing the radiation from muon decays
- Reducing the radiation from neutrino interactions
- Allowing for smaller apertures in machine elements, and so driving the cost down

Frictional Cooling

- Bring muons to a kinetic energy (T) where dE/dx increases with T
- Constant E-field applied to muons resulting in equilibrium energy
- Big issue – how to maintain efficiency
- Similar idea first studied by Kottmann et al., PSI



Problems/comments:

- large dE/dx @ low kinetic energy

  ⇒ **low average density (gas)**
- Apply **E** ⊥ **B** to get below the dE/dx peak

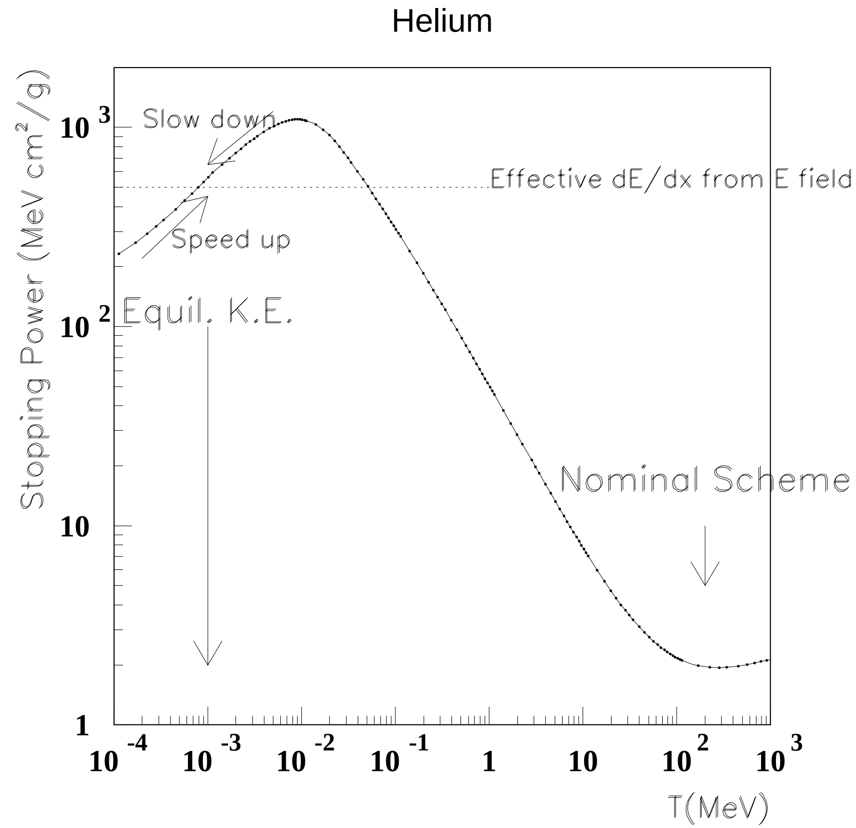
  F = q(**E** + **vxB**) – d**T**/dx
- μ^- has the problem of Atomic capture

  σ small above electron binding energy, but not known. Keep T as high as possible
- Slow muons don't go far before decaying

  d = 10 cm sqrt(T) T in eV

  so extract sideways (**E** ⊥ **B**)
- μ^+ has the problem of Muonium formation

  σ(Mμ) dominates over e-stripping in all gases except He



Conclusions for frictional cooling

- **Muon Collider complex would be a boon for physics**
- **We need to solve the muon cooling problem**
- **Different schemes should be investigated**
- **We are doing some simulation and experimental studies of frictional cooling. So far, so good, but a long way to go !**

In NewScientist of 17 April 04
you can read an article:
FROM TYRES TO NEUTRINOS

For a down-to-Earth cable manufacturer like Pirelli,
a plan to carry data on a beam of neutrinos is as wacky
as they come. How could it possibly work? p.36

Good news isn't it?

Industry is getting interested…

The (not too) bad news: They put only 150 k$/year into it…

Reference is made to an article, published in:
PHYSICAL REVIEW C
VOLUME 31, NUMBER 4
APRIL 1985

Method for observation of neutrinos and antineutrinos, J. Weber
University of Maryland, College Park, Mary/and 20742
and University of California. Irvine, California 92717
(Received 12 December l984

Theory is given for momentum transfer to an ensemble of particles by incident neutrinos or antineutrinos in such a way that subsequent measurements cannot reveal the detailed characteristics of this transfer. **It is shown that large scattering cross sections may be obtained, proportional to the square of the number of scatterers.**


Thank you