Overview of the International Design for the Neutrino Factory (IDS-NF) Accelerator systems

G. Prior
European Organization
for Nuclear Research (CERN)

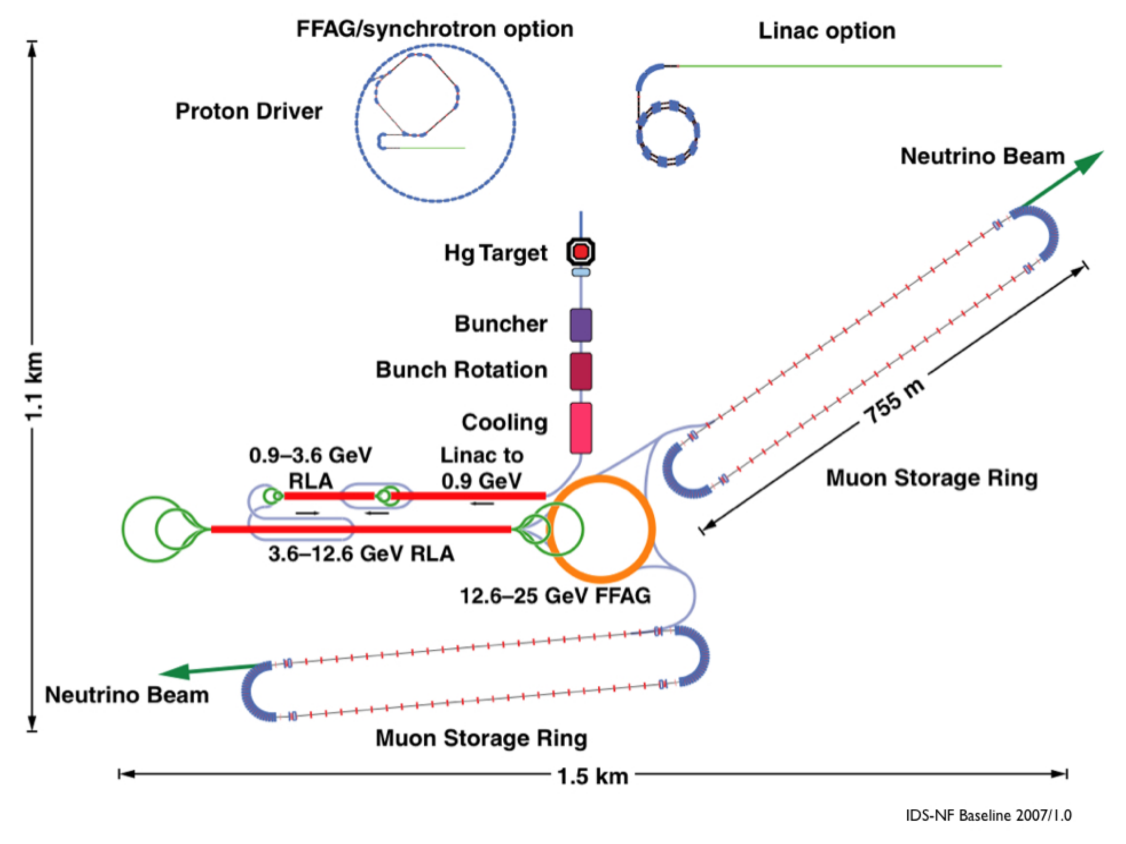
Plan

Goals of the IDS-NF

Collaborators & structure

Neutrino Factory overview

- Proton driver
- Target system
- Front-end system
- Acceleration system
- Storage rings



[Talk by M. Dracos for physics & detectors]

IDS-NF objectives

Deliver by 2012/2013 a Reference Design Report including:

- Physics performance of the Neutrino Factory
- Accelerator specification
- Detector systems
- Schedule for implementation of the Neutrino Factory
- Costing of the facility
- Technical uncertainties/risk documented and mitigation plans presented

Overlap/synergies of the IDS-NF Accelerator study with EUROnu WP3 (front-end - acceleration) & WP2 (target integration).

Collaborating institutes

Софийски университет "Св. Климент Охридски"

YORK U UNIVERSITÉ UNIVERSITY

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SINP

INFN

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CERN

University of Glasgow

Jefferson Lab

Muons, Inc.

The University Of Sheffield.

UNIVERSITY OF MARYLAND

UNIVERSITY of

Neutri

Max-Planck-Institut für Kernphysik

LNGS

ROMA TRE UNIVERSITÀ DEGLI STUDI

J.A.I.

Brunel UNIVERSITY WEST LONDON

BROOKHAVEN NATIONAL LABORATORY

Fermilab

Oulu, Finland

TIFR

UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA

KURRI Kyoto University Research Reactor Institute

Durham University

LANCASTER UNIVERSITY

NORTHWESTERN UNIVERSITY

LPSC Grenoble

OSAKA UNIVERSITY

Imperial College London

BERKELEY LAB

1872 VirginiaTech

THE UNIVERSITY OF MISSISSIPPI

ireS

The Institute of Mathematical Sciences

Uniwersytet Wrocławski

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UNIVERSITY OF OXFORD

ILLINOIS INSTITUTE OF TECHNOLOGY

UNIVERSITY OF ROCHESTER

MAX PLANCK GESELLSCHAFT

Julius-Maximilians-UNIVERSITÄT WÜRZBURG

UNIVERSITÉ DE GENÈVE

UNIVERSITY OF Southampton

MICHIGAN STATE UNIVERSITY

UNIVERSITY OF CALIFORNIA UC RIVERSIDE

ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ РОССИЙСКОЙ АКАДЕМИИ НАУК

INSTITUTE FOR NUCLEAR RESEARCH OF RUSSIAN ACADEMY OF SCIENCES

THE UNIVERSITY OF WARWICK

PRINCETON UNIVERSITY

Duke UNIVERSITY

Collaborating institutes

ASTeC

BROOKHAVEN NATIONAL LABORATORY

Brunel UNIVERSITY WEST LONDON

CERN

Durham University

Fermilab

HARISH-CHANDRA RESEARCH INSTITUTE ALLAHABAD

ILLINOIS INSTITUTE OF TECHNOLOGY

Imperial College London

IN2P3
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UNIVERSITY OF DELHI

University of Glasgow

UNIVERSITY OF OXFORD

VirginiaTech

THE UNIVERSITY OF WARWICK

YORK UNIVERSITÉ UNIVERSITY

IDS-NF Steering Group

Committee:

A. Blondel	Geneva U.
M. Zisman	LBNL
Y. Kuno	Osaka U.
K. Long	Imperial Coll. (chair)

Detectors Conveners:

A. Bross	FNAL
P. Soler	Glasgow U.
N. Mondal	Mumbai U.
A. Cervera	Valencia U.

Physics & Performance Evaluation Conveners:

A. Donini	Madrid U.
P. Huber	Virginia Tech.
S. Pascoli	Durham U.
W. Winter	Universität Würzburg
O. Yasuda	Tokyo Metropolitan U.

Accelerator Conveners:

S. Berg	BNL
Y. Mori	Kyoto U.
C. Prior	STFC
J. Pozimski	Imperial Coll.

Neutrino Factory goals

Deliver 10^{21} neutrinos/year (1 year = 10^7 s) coming from the decay of a 25 GeV muon beam, toward detectors located at 3000-5000 km and 7000-8000 km.

Muons are produced by the decay of pions coming from the interaction of a high intensity (4 MW) proton beam on target.

Bunching/rotation & cooling of the muons into a suitable beam for further acceleration.

IDS-NF baseline specifications established following the recommendation of the International Scoping Study (ISS) for a future Neutrino Factory and Super-Beam facility (2006).

Proton Driver specifications

Number of muons produced ~ to the proton driver power P:

$$P = E \cdot N_b \cdot N_p \cdot q \cdot f = E \cdot N \cdot q \cdot f$$

E = proton energy

N_b = number of bunches - N_p = number of protons/bunch

N = number of protons/pulse

f = repetition rate

q = proton charge

Need to optimize:

- the repetition rate (low rate increases charge per bunch, high rate increase RF wall power demand)
- the number of particles per bunch
- the energy (higher energy costs more)

Proton Driver other considerations

Bunch length:

- Muon capture better with short bunches.
- Multiple bunches per repetition, so better use short bunches.
- Short bunch harder at low energy.

Space charge:

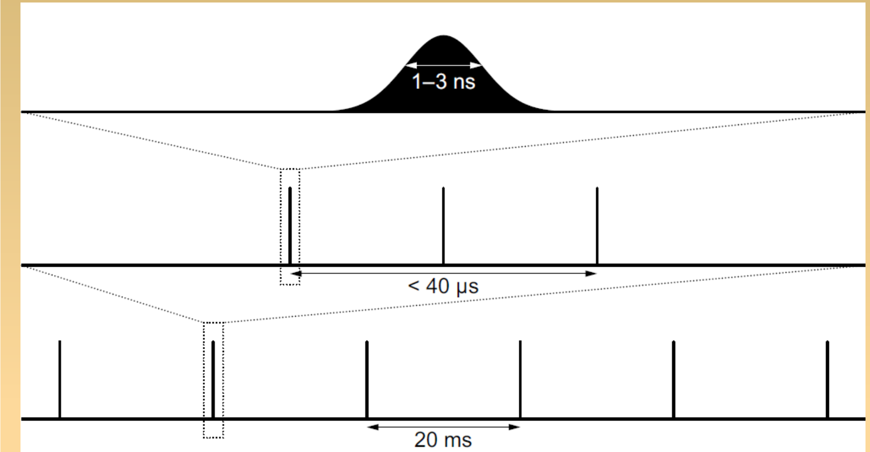
- Proton beam more stable against space-charge effect at higher energy.
- Minimum repetition rate limited by space charge effect.
- Need optimum number of bunch per repetition.

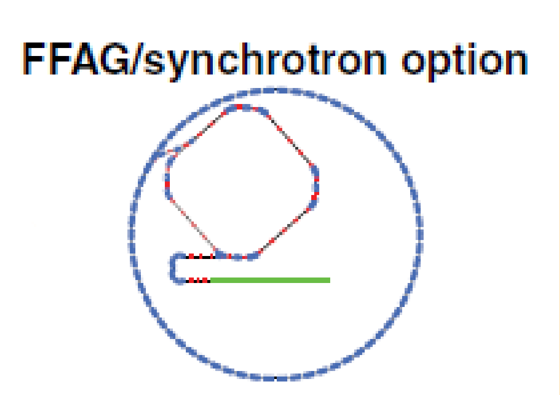
Muon production simulations:

- Decline in the production peak per power at low & high energy.

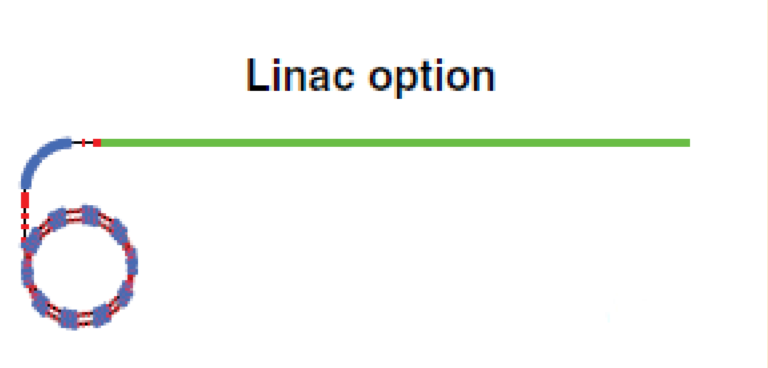
Proton Driver parameters

Proton power	4 MW
Proton kinetic energy	5-15 GeV
Pulses per second	50
Bunches per pulse	3
Minimum time between bunches	17 µs
Maximum time for all bunches	40 µs
RMS proton bunch length	1-3 ns





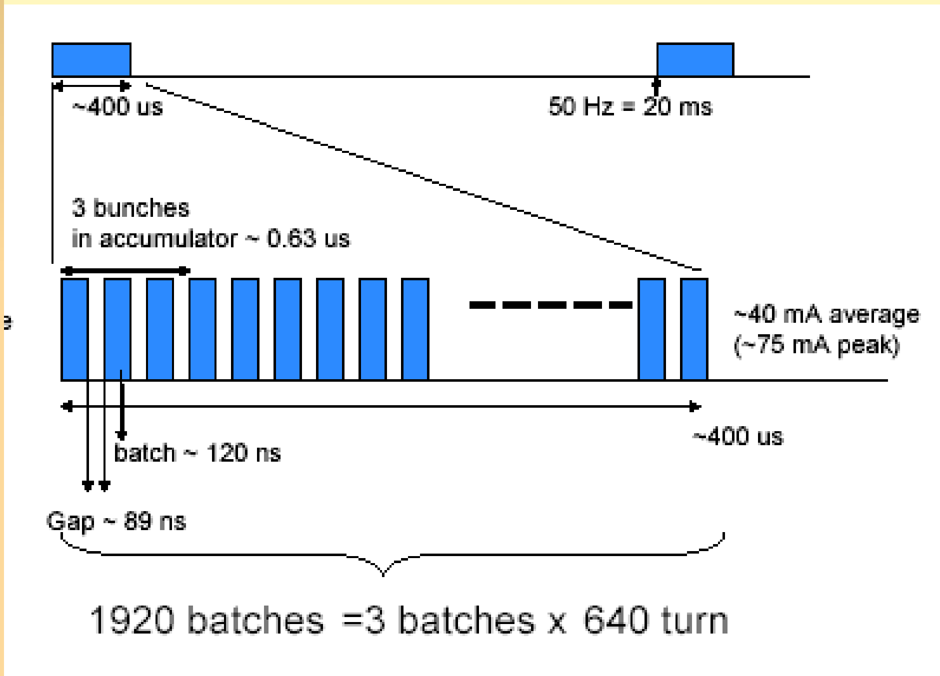
[Talk by J. Thomason]

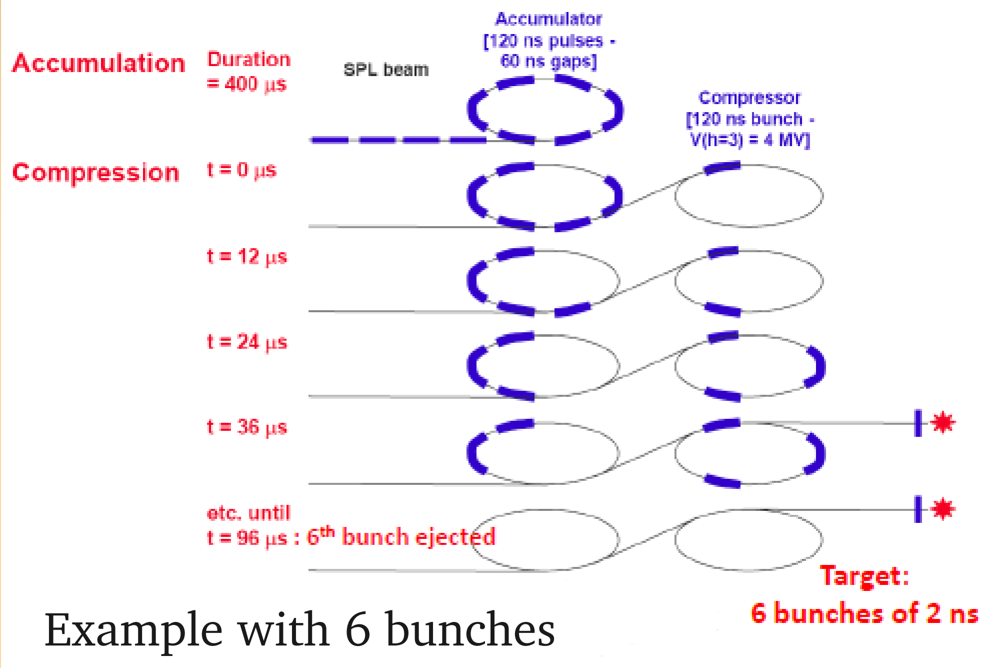


[Talk by M. Dracos]

Linac-based proton Driver

CERN Super Proton Linac (SPL) + accumulator & compressor rings:





Example with 6 bunches

640 turns in accumulator. 36 turns in compressor for bunch rotation.
Bunches spaced by 12 μs at ejection.

Linac-based proton Driver

Project X design criteria:

2 MW of beam power over the range 60-120 GeV.

Compatibility with future upgrades to 2-4 MW at 8 GeV.

Initial Configuration 1 (IC1) option:

Simultaneous with > 150 kW of beam power at 8 GeV.

Need upgrade to ~ 4 MW.

Initial Configuration 2 (IC2) option:

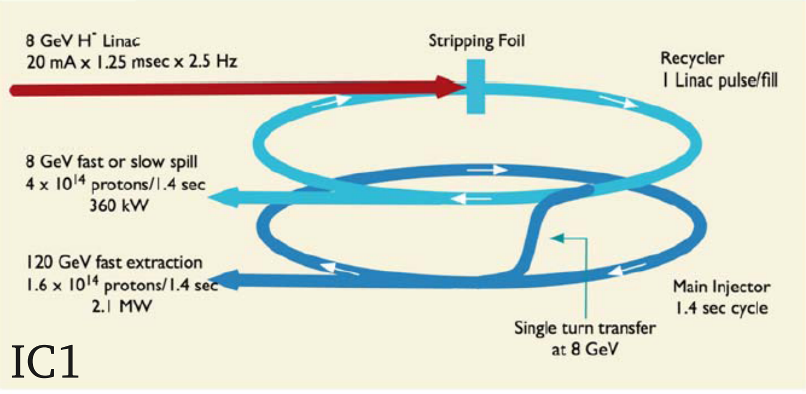
Simultaneous with 2 MW beam power at 2 GeV.

Linac as to be augmented either by

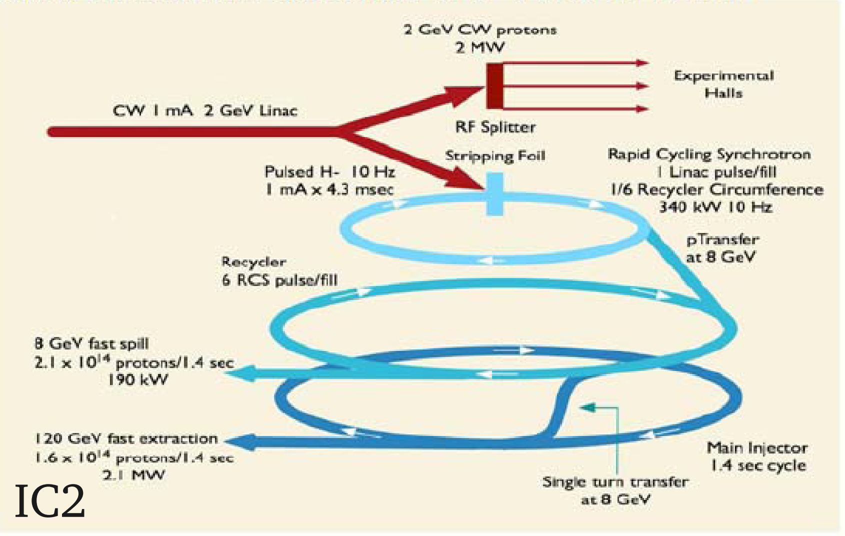
- a pulsed H- linac + RCS
- a pulsed linac from 2 to 8 GeV directly

In addition need multi-GeV:

- accumulator ring
- buncher ring



IC1

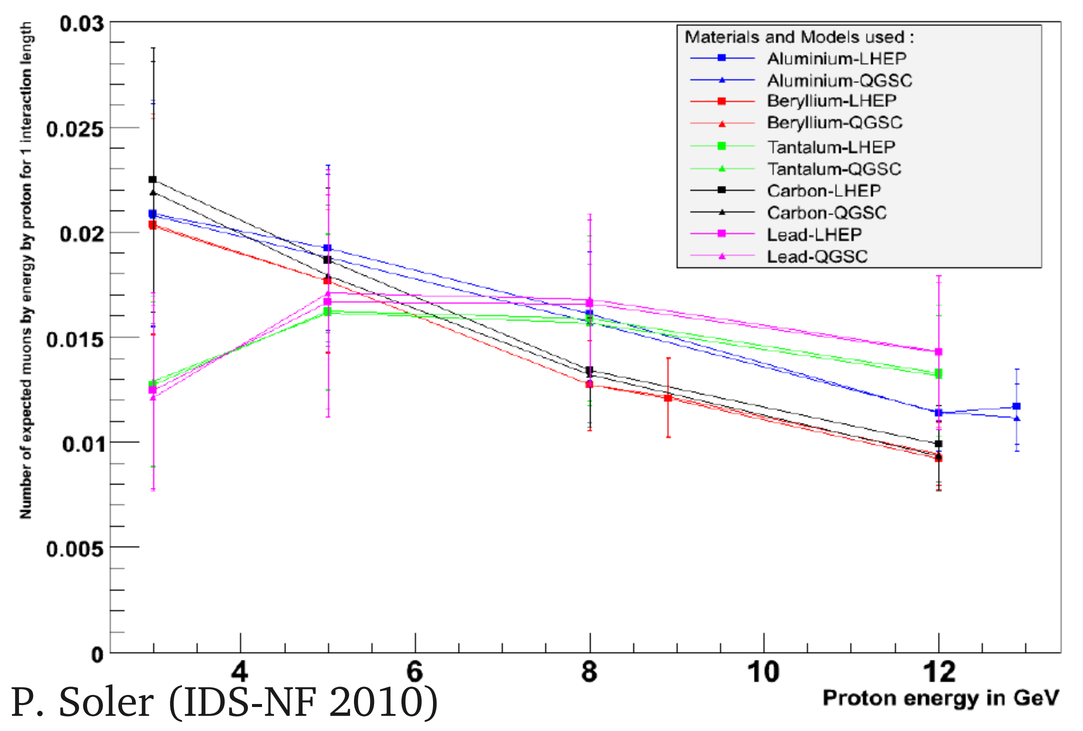


IC2

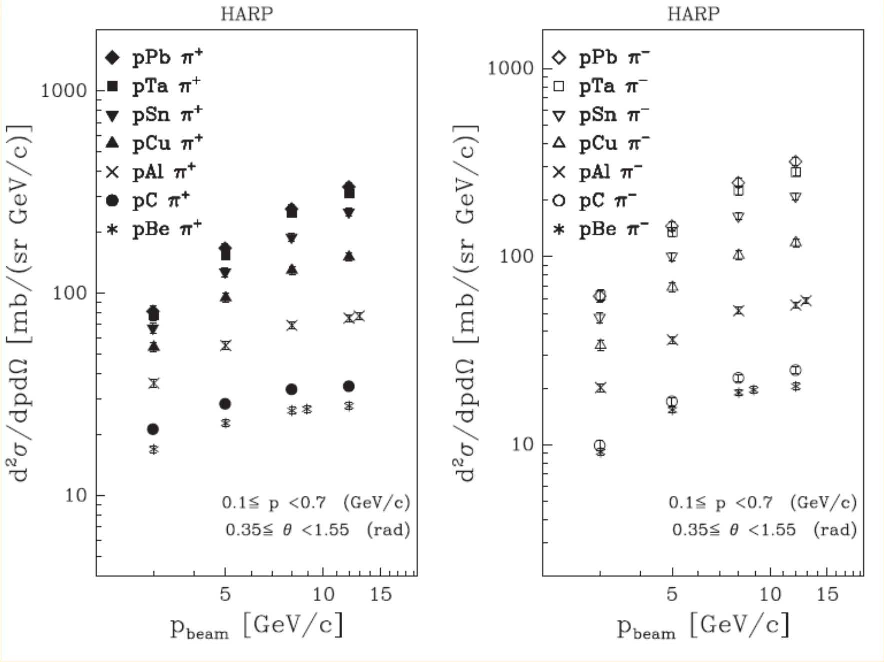
Target systems

Muon production as function of the target material:

- MC: low-Z material favoured at low energy & high-Z material less dependent on energy
- HARP data: cross-section increases linearly with energy below 10 GeV/c



P. Soler (IDS-NF 2010)



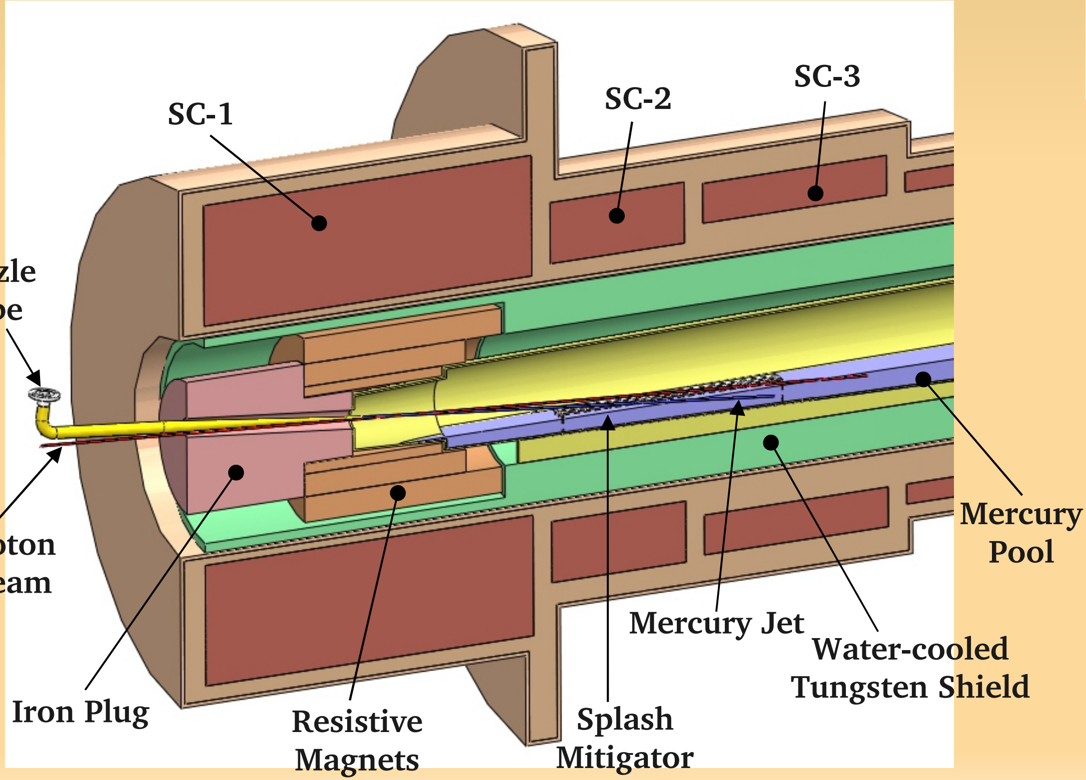
Phys. Rev. C 77, 055207 (2008)

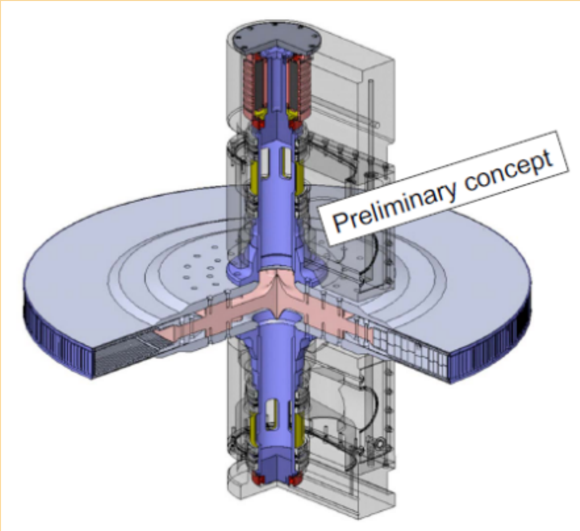
Target systems

Target damage from proton beam:

- Liquid Hg jet target is the baseline
- Solid (Tungsten bars) target under study

Jet diameter	1 cm
Jet velocity	20 m/s
Jet angle to axis	100 mrad
Jet angle to proton beam	33 mrad
Proton beam angle to axis	67 mrad

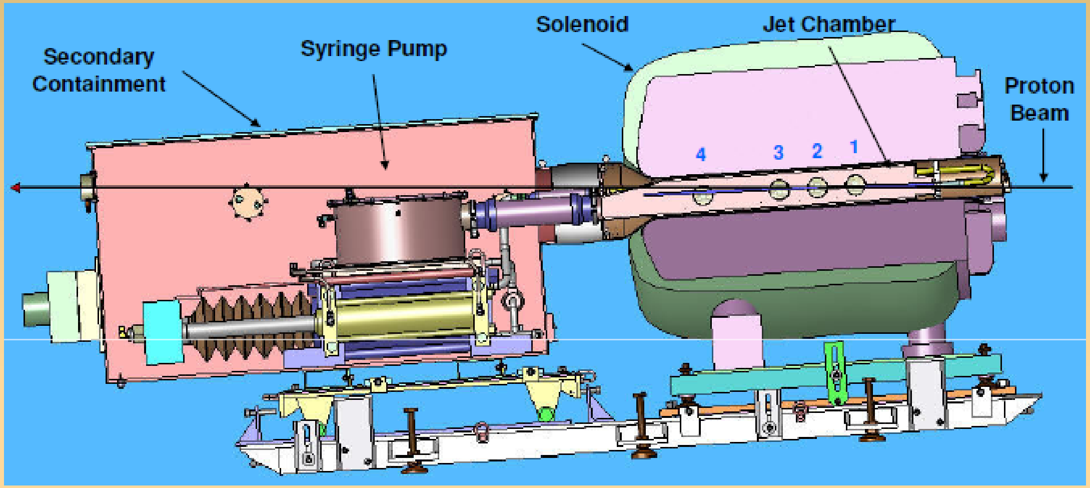




[Talk by R. Edgecock]

Liquid Hg jet target

R&D/PoP: MERcury Intense Target (MERIT) experiment at the CERN PS.



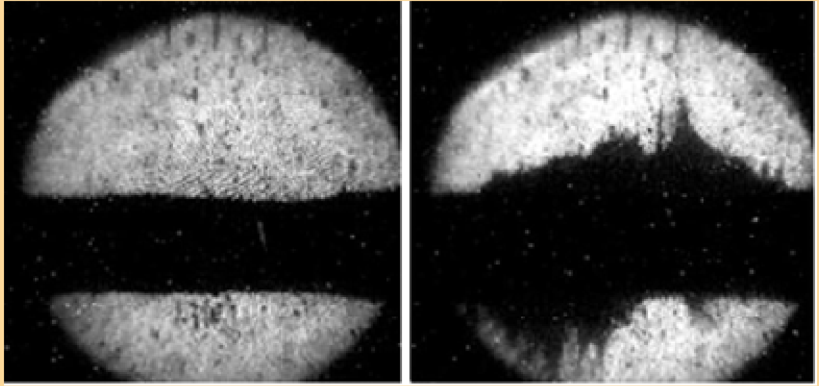
2004 proposal submitted.

2006 cryo & Hg safety review.

2007 data taking.

2008 dismantling.

Studied jet disruption from 24(14) GeV beam using different PS spill structure.



$30\text{x}10^{12}$ protons, 15 T field.

Success in validating the target concept for 4 MW, 50 Hz operation.
Need to develop a full target system than will support 4 MW.

Muon Front-End

Drift: ~100 m channel to allow for pions to decay and time-energy correlation to develop.

Bunching: Beam is sliced in short alternating-sign muons bunches, using RF with decreasing frequencies 333-234 MHz and increasing gradient 5-10 MV/m.

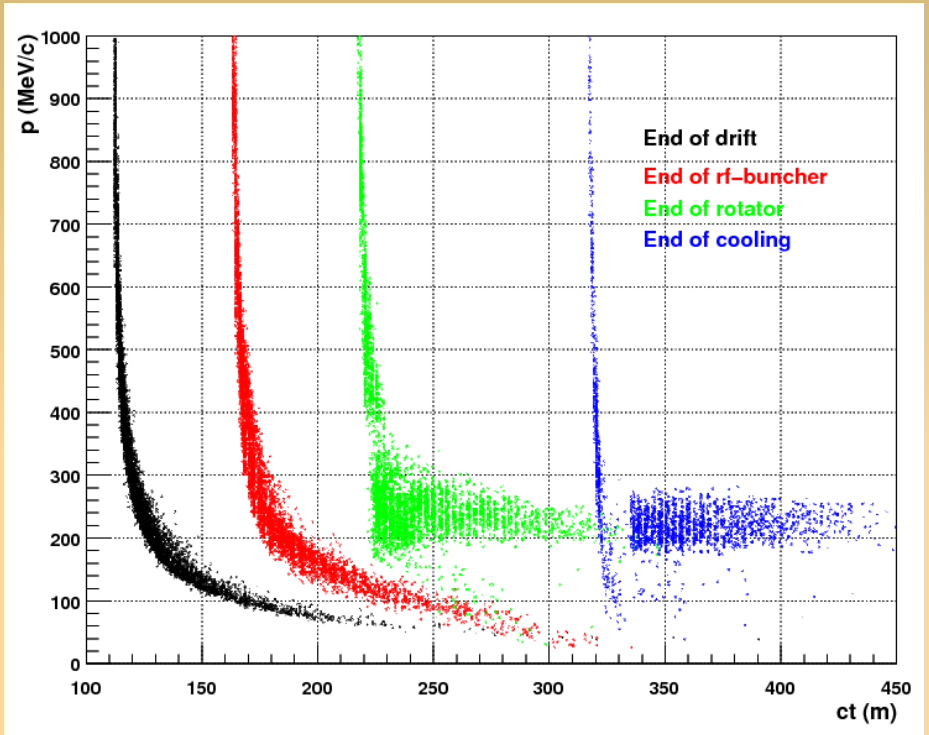
Rotation: RF with decreasing frequencies 232-201 MHz and constant 12.5 MV/m gradient reduce the particle energy spread inside the bunch train.

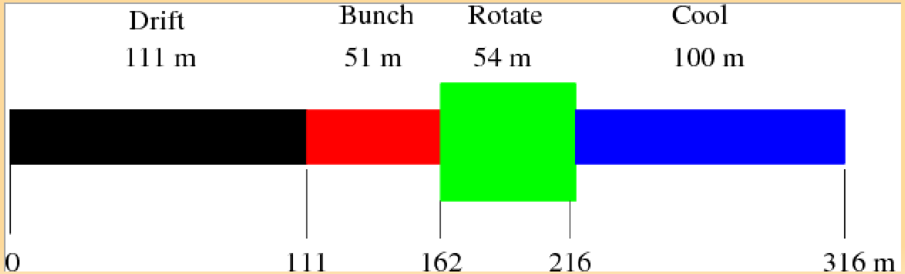
Cooling: 1 cm LiH absorbers windows allow muon momentum reduction (through ionization cooling) where 201 MHz with 15.25 MV/m RF cavities restore the longitudinal momentum only.

Delivers muons in $A_\perp = 30$ mm & $A_{/\!/} = 150$ mm.

R&D/PoP of cooling:

MICE [Talk by M. Zisman].



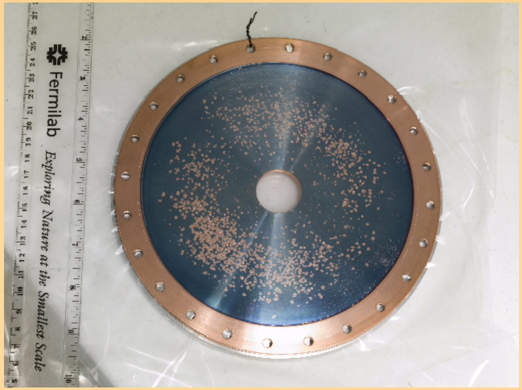


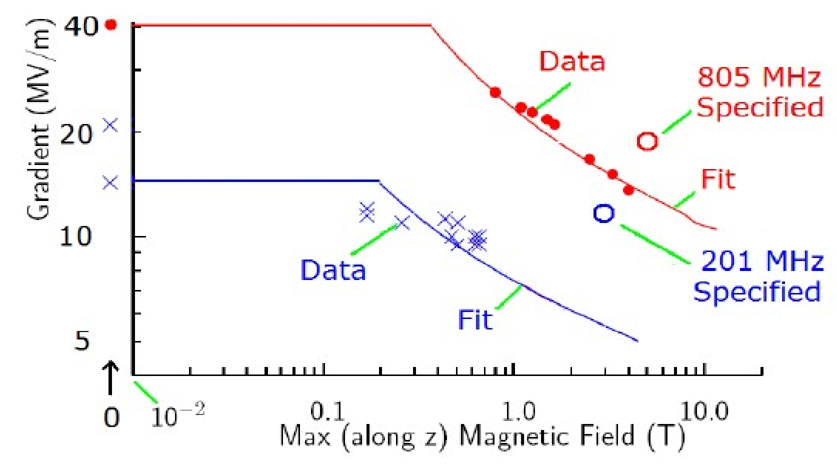
Muon front-end

Revision to baseline [Talk by C. Rogers]:

- Solenoid field tapering from 20 T to 1.5 T (was 1.75 T).
- Shorter baseline, similar performance.

Experiments have shown that the peak gradient achievable in presence of magnetic field may be limited and will not meet the baseline requirements.





Alternative to baseline as mitigation options:

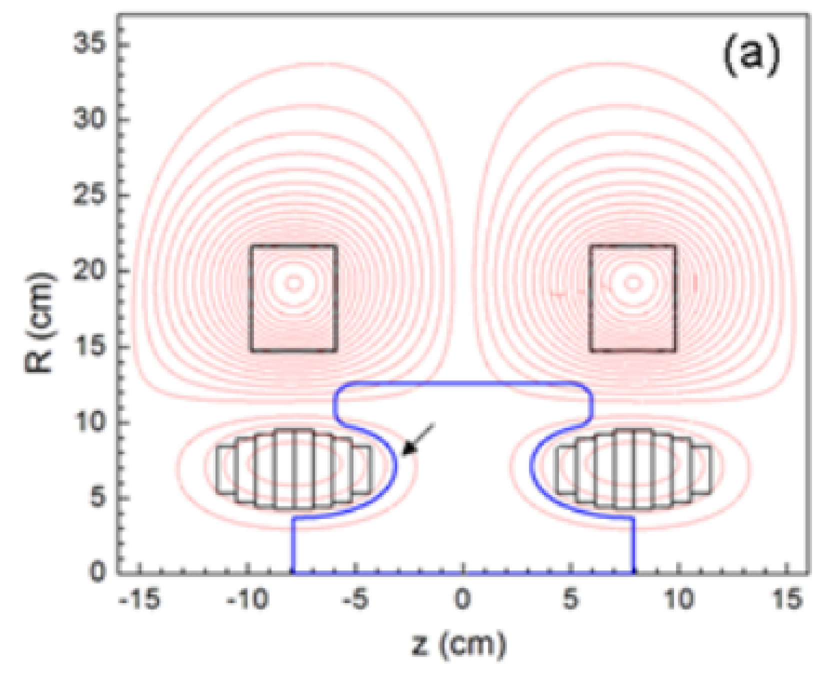
- Shielded lattice [Talk by C. Rogers]
- Magnetically insulated lattice (D. Stratakis)
- Hybrid high-pressure gas-filled cavities (M. Zisman & J. Gallardo)

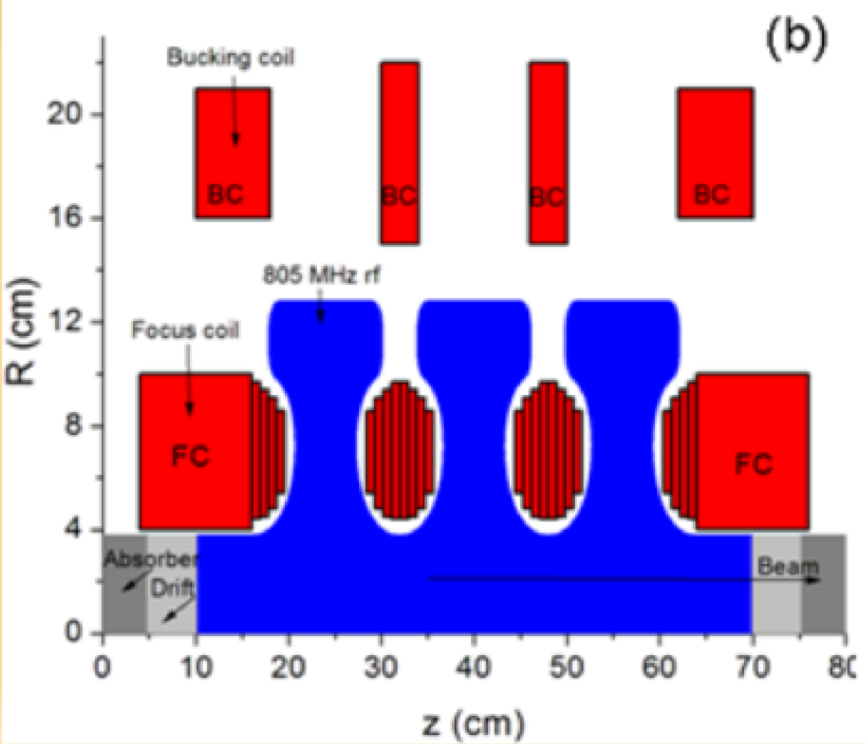
Magnetically insulated lattice

Idea:

The emitted electrons are focussed by B-field and accelerated by E-field, this results in significant energy deposition in small area leading to thermal stressing and material fatigue.

If we keep E perpendicular to B, the electrons are redirected to cavity surface without acceleration or focussing.

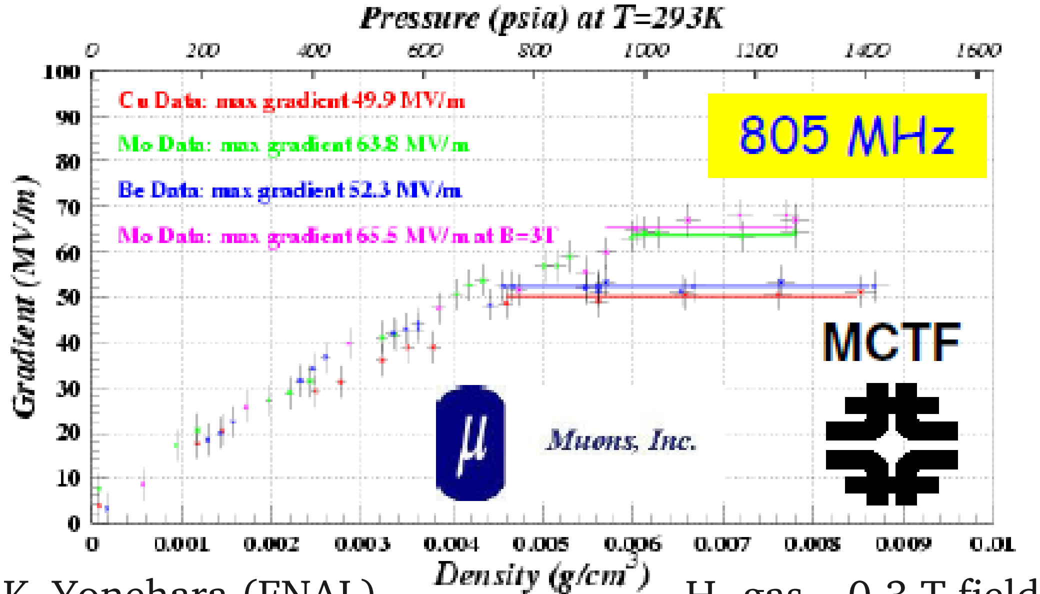




Hybrid HP gas-filled cavities

R&D:

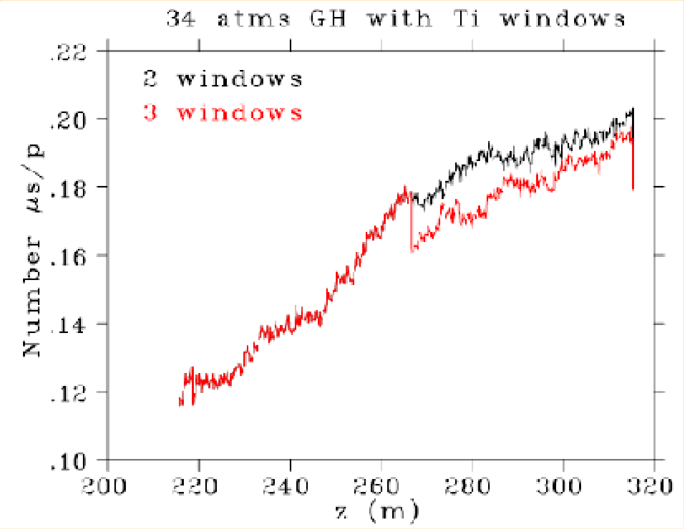
- High-pressure gas filled cavities seem to sustain magnetic field without breakdown.
- Need a demonstration with high intensity beam (foreseen at the end of the year).



K. Yonehara (FNAL)

H_2 gas – 0-3 T field

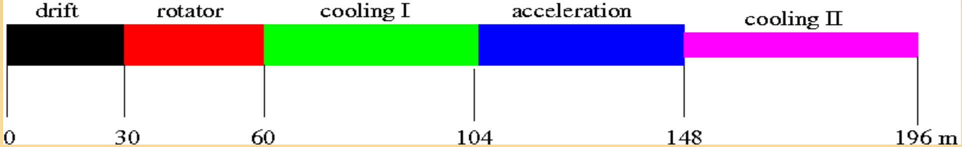
Hydrid HPRF uses LiH and H_2 gas (cooling still provided by LiH). Study in view of understanding safety, insulation and performance.

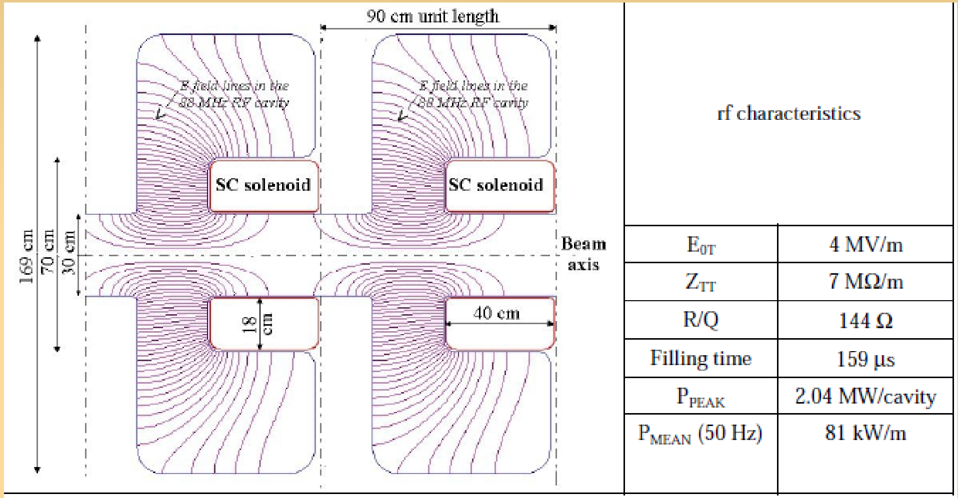


Other designs

Lower frequency (44-88 MHz) lattice:

- single muon sign, one bunch-to-bucket lattice.
- performance being re-evaluated in more recent code.





rf characteristics	
E_{0T}	4 MV/m
Z_{TT}	7 MΩ/m
R/Q	144 Ω
Filling time	159 µs
P_{PEAK}	2.04 MW/cavity
P_{MEAN} (50 Hz)	81 kW/m

Fig. 5.10: Sketch of an 88 MHz cavity with solenoid

Longitudinal cooling:

- Helical SFOFO (K. Yonehara)
- Isochronous Helical Transport Channel (C. Yoshikawa)
- Titled RFOFO (Y. Alexahin)
- Guggenheim channel (R. Fernow, B. Palmer, P. Snopok)

Acceleration & Storage rings

Linac:

- Acceleration of muons from 244 MeV to 0.9 GeV.
- Only one pass, works all energies.

Dogbone Recirculating Linear Accelerators (RLA):

- Acceleration of muons to 3.6 GeV (RLA 1) and 12.6 GeV (RLA 2)
- Passes through RF limited by switchyard

Fixed Field Alternating Gradient (FFAG) rings:

- Acceleration of muons to 25 GeV
- No switchyard allowing for 8-16 passes

Storage rings:

- Two racetracks straight angled downward to far detectors

[Talk by C. Rogers]

Conclusion

In preparation for the RDR:

- Proton driver developments according to three designs based on upgrade of existing (ISIS) or to be built (ProjectX, CERN-SPL) machines.
- Front-end study pursuing in parallel optimisation study of the baseline and few mitigating options.
- Acceleration systems performance being adressed through the end-to-end Simulations.