M6 Working Group Report:

High Intensity Proton Sources

Conveners: W. Chou (Fermilab) and J. Wei (BNL)

July 20, 2001, Snowmass

http://www-bd.fnal.gov/icfa/snowmass/

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OUTLINE

- Review of the 3-week M6 group activities
- Fermilab and BNL Proton Driver designs
- Survey of high intensity proton sources over the world
- Highlights of the proposed R&D program

- The M6 group has 42 active participants, about 2/3 from the US, 1/3 from other countries, including Canada, Japan, Switzerland, France, Germany and England.

- There are 52 presentations, which cover most of the aspects of high intensity proton sources, including the performance of existing machines, the designs of a number of new machines that have been proposed, and key R&D issues.

- A 2-page Executive Summary has been completed and submitted to the Snowmass OC. It lists a detailed and prioritized R&D program.

- A 30-page Working Group Report will be completed in early August.

- All of these will be posted on the web. (Many of them already are.) *http://www-bd.fnal.gov/icfa/snowmass/*

Snowmass 2001

M6

Working Group on High-Intensity Proton Sources

Working Group Convenors:
W. Chou (Fermilab), J. Wei (BNL)

ICFA Beam Dynamics Home Page
ICFA High Intensity Hadron Beams Working Group

Proton Drivers around the World

Fermilab Proton Driver
European Proton Drivers
Brookhaven Proton Driver
Japan JKJ Project

Other High Intensity Proton Sources

ORNL SNS
LANL LANSCE
RAL ISIS
BNL AGS
CEA CONCERT

members	agenda	talks	joint sessions	reports

CHARGE; Several present and future high energy physics facilities are based on high intensity secondary particle beams produced by high intensity proton beams. The group is to perform a survey of the beam parameters of existing and planned multi GeV high intensity proton sources and compare with the requirements of high energy physics users of secondary beams. The group should then identify areas of accelerator R&D needed to achieve the required performance. This should include simulations, engineering and possibly beam experiments. The level of effort and time scale should also be considered.

E.M./W.C., July 16, 2001

The US HEP program needs an intense proton source (the Proton Driver) by the end of this decade.

- The physics cases of the Proton Driver are strong. (E1, E5)

- The US HEP community needs to maintain accelerator competence in high intensity proton machines.

  - Japan is building the JHF.
  - CERN is working on the SPL.
  - The US needs to take the Proton Driver seriously.

- This is a versatile machine and can serve multiple purposes:

  - A stand-alone facility (super ν beam, μ, k, n, pbar) (E1, E5)
  - The first stage of a neutrino factory (M1)
  - A high brightness source for a VLHC (M4)

- We know how to build it.

  There are two Proton Driver design studies, one at Fermilab, another at the BNL. The design reports have been published.

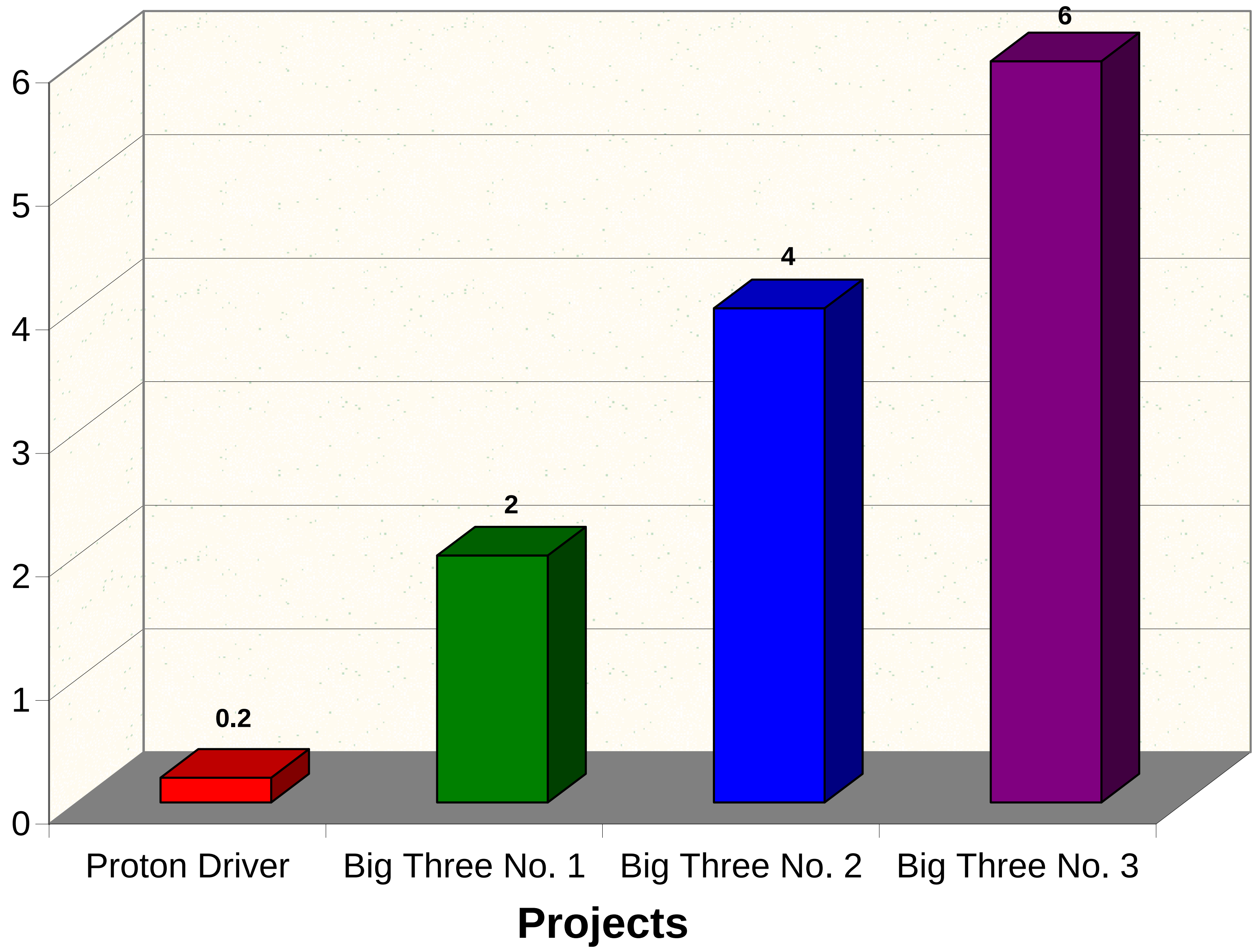
- The price is affordable.

  It can be supported by the DOE base line HEP program budget.

- This is a promising intermediate size project.

  If we start pushing it now, we can have it by the end of this decade.

- READY AND WAITING.


6
5
4
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Proton Driver
Big Three No. 1
Big Three No. 2
Big Three No. 3
Projects

Executive Summary

The US high-energy physics program needs an intense proton source (a 1-4 MW Proton Driver) by the end of this decade. This machine will serve multiple purposes: (i) a stand-alone facility that will provide neutrino superbeams and other high intensity secondary beams such as kaons, muons, neutrons, and anti-protons (cf. E1 and E5 group reports); (ii) the first stage of a neutrino factory (cf. M1 group report); (iii) a high brightness source for a VLHC (cf. M4 group report).

Based on present accelerator technology and project construction experience, it is both feasible and cost-effective to construct a 1-4 MW Proton Driver. There are two PD design studies, one at FNAL and the other at the BNL. Both are designed for 1 MW proton beams at a cost of about US$200M (excluding contingency and overhead) and upgradeable to 4 MW. An international collaboration between FNAL, BNL and KEK on high intensity proton facilities addresses a number of key design issues. The sc cavity, cryogenics, and RF controls developed for the SNS can be directly adopted to save R&D efforts, cost, and schedule. PD studies are also actively pursued at Europe and Japan.

There are no showstoppers towards the construction of such a high intensity facility. Key research and development items are listed below ({} indicates present status). Category A indicates items that are not only needed for future machines but also useful for the improvement of existing machine performance; category B indicates items crucial for future machines and/or currently underway.

1) H^- source: Development goals - current 60–70 mA {35 mA}, duty cycle 6–12% {6%}, emittance 0.2 π mm-mrad rms normalized, lifetime > 2 months {20 days}. (A)
2) LEBT chopper: To achieve rise time < 10 ns {50 ns}. (B)
3) Study of 4-rod RFQ at 400 MHz, 100 mA, 99% efficiency, HOM suppressed. (B)
4) MEBT chopper: To achieve rise time < 2 ns {10 ns}. (B)
5) Chopped beam dump: To perform material study & engineering design for dumped beam power > 10 kW. (A)
6) Funneling: To perform (i) one-leg experiment at the RAL by 2006 with goal one-leg current 57 mA; (ii) deflector cavity design for CONCERT. (all B)
7) Linac RF control: To develop (i) high performance HV modulator for long pulsed (>1ms) and CW operation; (ii) high efficiency RF sources (IOT, multi-beam klystron). (all A)
8) Linac sc RF control: Goal - to achieve control of RF phase error < 0.5° and amplitude error <0.5% {presently 1°, 1% for warm linac}. (i) To investigate the choice of RF source (number of cavity per RF source, use of high-power source); (A) (ii) to perform redundancy study for high reliability; (B) (iii) to develop high performance RF control (feedback and feedforward) during normal operation, tuning phases and off-normal operation (missing cavity), including piezo-electric fast feedforward. (A)
9) Space charge: (i) Comparison of simulation code ORBIT with machine data at FNAL Booster and BNL Booster; (ii) to perform 3D ring code bench marking including machine errors, impedance, and space charge (ORNL, BNL, SciDAC, PPPL). (all A)
10) Linac diagnostics: To develop (i) non-invasive (laser wire, ionization, fluorescent-based) beam profile measurement for H^-;(ii) on-line measurement of beam energy and energy spread using time-of-flight method; (iii) halo monitor especially in sc environment; (iv) longitudinal bunch shape monitor. (all A)
11) SC RF linac: (i) High gradients for intermediate beta (0.5 – 0.8) cavity; (A) (ii) Spoke cavity for low beta (0.17 – 0.34). (B)

12) Transport lines: To develop (i) high efficiency collimation systems; (A) (ii) profile monitor and halo measurement; (A) (iii) energy stabilization by HEBT RF cavity using feedforward to compensate phase-jitter. (B)
13) Halo: (i) To continue LEDA experiment on linac halo and comparison with simulation; (ii) to start halo measurement in rings and comparison with simulation. (all B)
14) Ring lattice: To study higher order dependence of transition energy on momentum spread and tune spread, including space charge effects. (B)
15) Injection and extraction: (i) Development of improved foil (lifetime, efficiency, support); (A) (ii) experiment on the dependence of H^0 excited states lifetime on magnetic field and beam energy; (B) (iii) efficiency of slow extraction systems. (A)
16) Electron cloud: (i) Measurements and simulations of the electron cloud generation (comparison of the measurements at CERN and SLAC on the interaction of few eV electrons with accelerator surfaces, investigation of angular dependence of SEY, machine and beam parameter dependence); (A) (ii) determination of electron density in the beam by measuring the tune shift along the bunch train; (A) (iii) theory for bunched beam instability that reliably predicts instability thresholds and growth rates; (A) (iv) investigation of surface treatment and conditioning; (A) (v) study of fast, wide-band, active damping system at the frequency range of 50–800 MHz. (B)
17) Ring beam loss, collimation, protection: (i) Code benchmarking & validation (STRUCT, K2, ORBIT); (A) (ii) engineering design of collimator and beam dump; (A) (iii) experimental study of the efficiency of beam-in-gap cleaning; (A) (iv) bent crystal collimator experiment in the RHIC; (B) (v) collimation with resonance extraction. (B)
18) Ring diagnostics: (i) Whole area of diagnosing beam parameters during multi-turn injection; (ii) circulating beam profile monitor over large dynamic range with turn-by-turn speed; (iii) fast, accurate non-invasive tune measurement. (all A)
19) Ring RF: To develop (i) low frequency (~5 MHz), high gradient (~1 MV/m) burst mode RF systems; (B) (ii) high gradient (50-100 kV/m), low frequency (several MHz) RF system with 50-60% duty cycle; (B) (iii) high-voltage (>100 kV) barrier bucket system; (B) (iv) transient beam loading compensation systems (e.g. for low-Q MA cavity). (A)
20) Ring magnets: (i) To develop stranded conductor coil; (ii) to study voltage-to-ground electrical insulation; (iii) to study dipole/quadrupole tracking error correction. (all B)
21) Ring power supplies: To develop (i) dual-harmonic resonant power supplies; (ii) cost effective programmable power supplies. (all B)
22) Kicker: (i) Development of stacked MOSFET modulator for DARHT and AHF to achieve rise/fall time <10-20 ns; (B) (ii) impedance reduction of lumped ferrite kicker for SNS. (A)
23) Instability & impedance: (i) To establish approaches for improved estimates of thresholds of fast instabilities, both transverse and longitudinal (including space charge and electron cloud effects); (ii) to place currently-used models such as the broadband resonator and distributed impedance on a firmer theoretical basis; (iii) impedance measurement based on coherent tune shifts *vs*. beam intensity, and instability growth rate *vs*. chromaticity, including that for flat vacuum chambers; (iv) to develop new technology in feedback implementation. (all B)
24) FFAG: (i) 3-D modeling of magnetic fields and optimization of magnet profiles; (ii) wide-band RF systems; (iii) transient phase shift in high frequency RF structures; (iv) application of sc magnets. (all B)
25) Inductive inserts: (i) Experiments at the FNAL Booster & JHF3; (A) (ii) programmable inductive inserts; (B) (iii) development of inductive inserts which have large inductive impedance and very small resistive impedance; (B) (iv) theoretical analysis. (B)
26) Induction synchrotron: (i) Study of beam stability; (ii) development of high impedance, low loss magnetic cores. (all B)

M6 Working Group TALKS

OVERVIEW

Tom Wangler, "High-Power Proton Linacs"

Robert Macek, "High Intensity Proton Accumulators

F. Mills, "High Intensity Proton Synchrotrons"

MACHINES - EXISTING

Bob Shafer, "LANSCE Overview"

D. Raparia, "BNL Linac"

Thomas Roser, "BNL AGS and AGS Booster Performance"

R. Webber, "FNAL Booster Performance and Challenges"

Roberto Cappi, "High Intensity Issues in the CERN PS and PSB"

MACHINES - UNDER CONSTRUCTION

J. Wei, "Design and Optimization of the SNS"

S. Nath, "SNS Linac"

D. Raparia, "SNS Transport Line"

J. Galambos, "SNS Beam Loss, Activation and Collimation"

S. Machida, "JHF Project and Lattice"

MACHINES - PROPOSED

W. Chou, "The Fermilab Proton Driver"

T. Roser, "One MW AGS Proton Driver"

H. Haseroth, "CERN Proton Driver: SPL"

Roberto Cappi, "CERN Proton Driver Accumulator and Compressor"

C. Prior, "ESS and RAL Proton Driver"

J-M. Lagniel, "The CONCERT Project"

A. Thiessen, "The Advanced Hydrotest Facility (AHF) Overview"

P. Schwandt, "LANL AHF Lattice"

Tom Wangler, "Proton Linac for Nuclear Waste Transmutation"

S. Machida, "Progress on FFAG Accelerators"

S. Martin, "The FFAG is a Challenge"

K. Takayama, "Induction Synchrotron"

J-M. Lagniel, "Challenges and R&D for New Facilities"

S. Martin, "SC Linac Optimization"

S. Martin, "Topics to Study for Making ESS Less Expensive"

Rol Johnson, "Linac Afterburner in the Booster Tunnel"

ACCELERATOR PHYSICS AND EXPERIMENTS

Christopher R. Prior, "Injection, Extraction and Lattice Design"

Christopher R. Prior, "Lattice, Injection and Space Charge"

S. Machida, "Space Charge in Rings"

J. A. Holmes, "Resonant Beam Response in the PSR Accumulator Ring"

J. A. Holmes, "Transverse Impedance Model for Particle Tracking Calculations"

I. Hofmann, "Coulomb Effects in High Intensity Drivers"

I. Hofmann, "Resonances in High Intensity Linacs (and Rings) "

R. Ryne, "Simulation for High Intensity Linac and Ring"

H. Qin, "Beam Instabilities"

Francesco Ruggiero, "Collective Effects and Electron Cloud Effects at CERN SPS and LHC"

M. Furman, "Electron Cloud and e-p Instability"

T-S. Wang, "A chat about transverse e-p instability"

Y. Shimosaki, "Halo Formation and Equilibrium"

P. Colestock, "Halo Experiment at LANL"

N. Mokhov, "Beam Loss and Shielding"

Shane Koscielniak, "Beam Loading and Compensation"

Rick Baartman, "End Effects of Beam Transport Elements"

ACCELERATOR SYSTEMS

Ka-Ngo Leung, "High Intensity Negative Ion Sources"

J. Griffin, "RF System and Inductive Insert"

F. Ostiguy, "Proton Driver Magnets"

P. Walstrom, "Extraction Kickers and Modulators for the AHF"

A. Drozhdin, "Beam Collimation in the Low and High Energy Accelerators"

Bob Shafer, "Diagnostics of High Intensity Hadron Accelerators"

R. Webber, "Scope of the Proton Driver Beam Diagnostics"

M6 WORKING GROUP ACTIVITY REPORTS

W. Chou, "Report at the July 12 mid-term Plenary Session"

W. Chou and J. Wei, "Report at the July 20 Final Plenary Session"

rev. August 6, 2001.

About the Proton Driver

- What is a Proton Driver?

  Proton Driver = High beam power + Short bunch length

- Nominal parameters:

  Beam power = 1 - 4 MW

  Bunch length = 1 - 3 ns (rms)

Table 1. Beam Parameters of Existing and Proposed Proton Sources

Machine	Flux (10^{13}/pulse)	Rep Rate (Hz)	Flux† (10^{20}/year)	Energy (GeV)	Power (MW)
Existing:					
RAL ISIS	2.5	50	125	0.8	0.16
BNL AGS	7	0.5	3.5	24	0.13
LANL PSR	2.5	20	50	0.8	0.064
Fermilab MiniBooNE (*)	0.5	7.5	3.8	8	0.05
Fermilab NuMI	3	0.5	1.5	120	0.3
CERN CNGS	4.8	0.17	0.8	400	0.5
Under construction:					
ORNL SNS	20	60	1200	1	2
JHF 50 GeV	32	0.3	10	50	0.75
JHF 3 GeV	8	25	200	3	1
Proton Driver proposals:					
Fermilab Phase I	3	15	45	16	1.2
Fermilab Phase II	10	15	150	16	4
BNL Phase I	10	2.5	25	24	1
BNL Phase II	20	5	100	24	4
CERN SPL	23	50	1100	2.2	4
RAL 15 GeV (**)	6.6	25	165	15	4
RAL 5 GeV (**)	10	50	500	5	4
Other proposals:					
Europe ESS (**)	46.8	50	2340	1.334	5
Europe CONCERT	234	50	12000	1.334	25
LANL AAA	-	CW	62500	1	100
LANL AHF	3	0.04	0.03	50	0.003

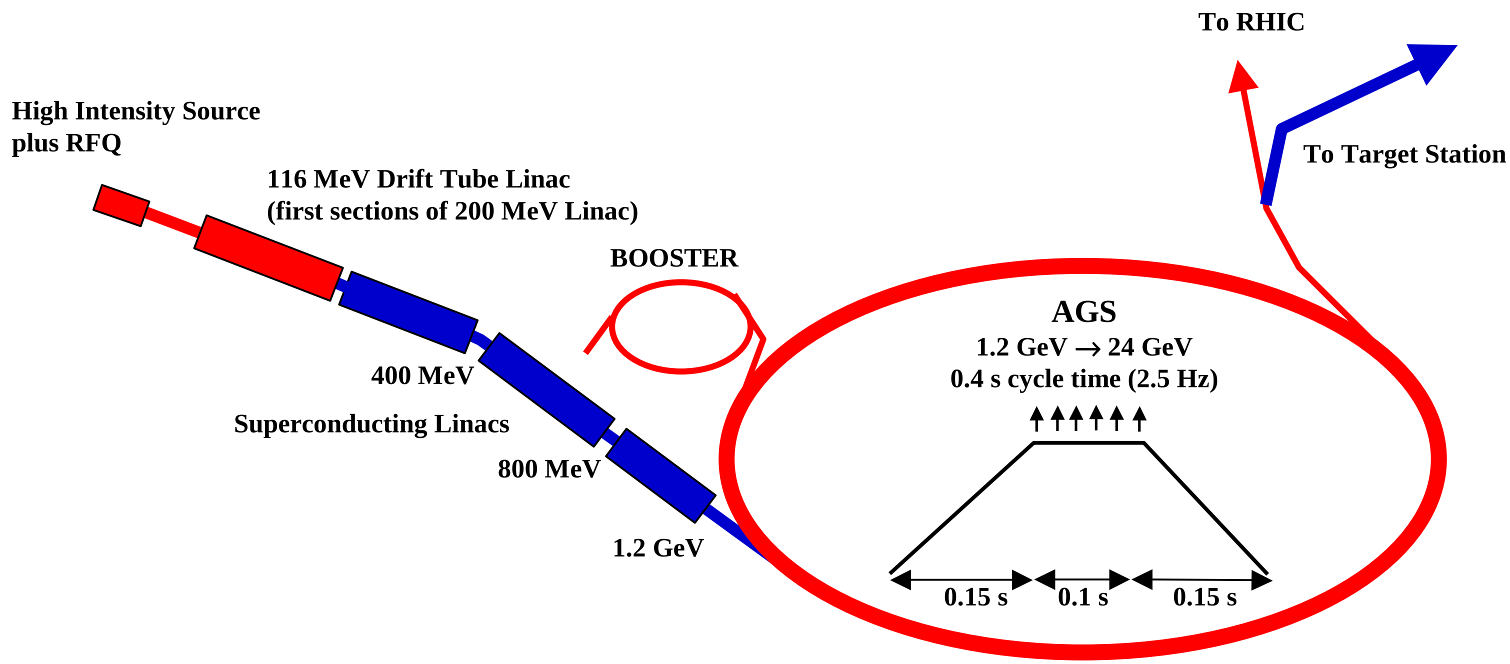
† 1 year = 1 x 10^7 seconds.
(*) Including planned improvements.
(**) Based on 2-ring design.

Fermilab Proton Driver Site Plan

Fermilab Proton Driver Parameters of Present, Phase I and Phase II

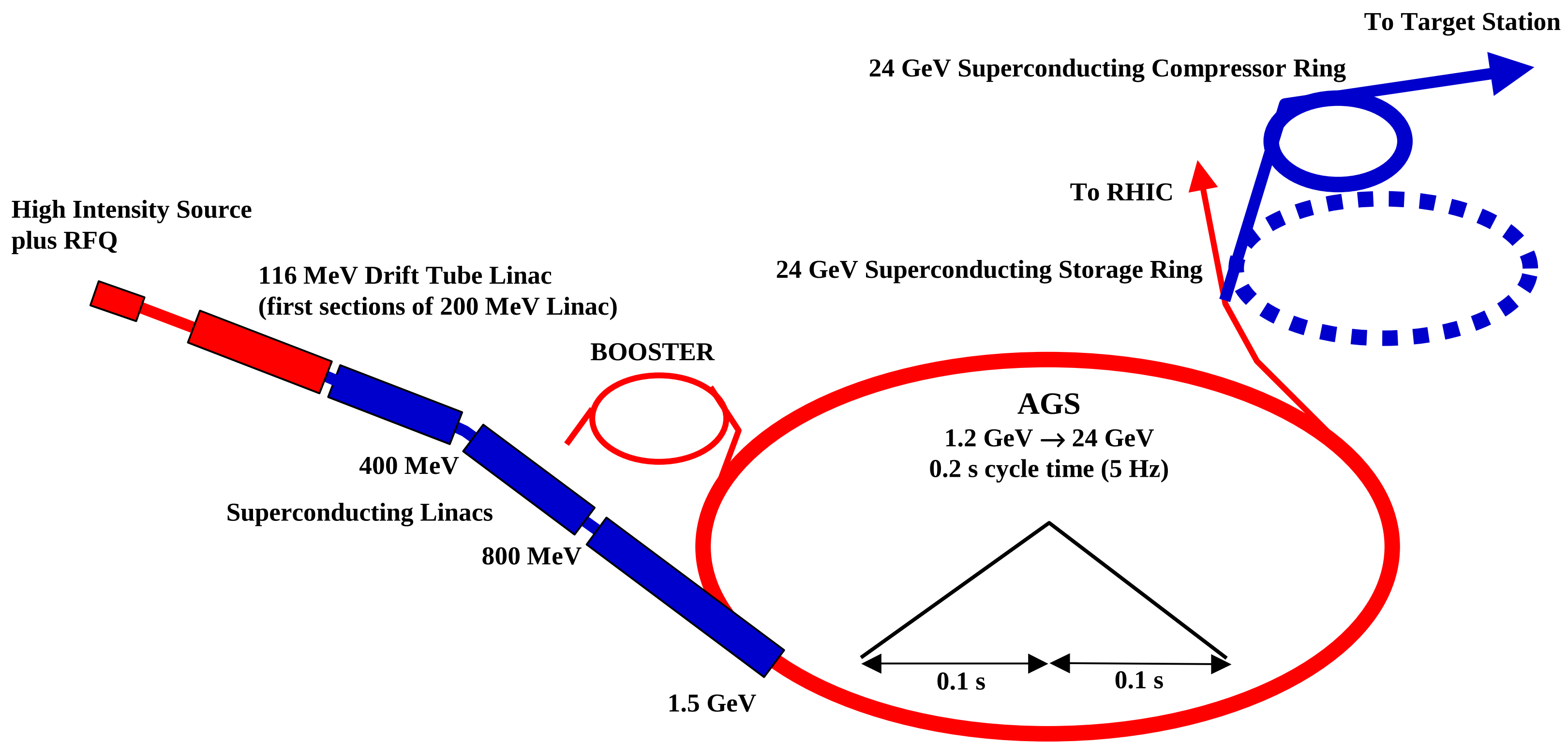
Parameters	Present	Phase I (MI, ν-Fact)	Phase II (μ-Coll)
Linac (operating at 15 Hz)			
Kinetic energy (MeV)	400	400	1000
Peak current (mA)	40	60	80
Pulse length (μs)	25	90	200
H^- per pulse	6.3×10^{12}	3.4×10^{13}	1×10^{14}
Average beam current (μA)	15	81	240
Beam power (kW)	6	32	240
Pre-Booster (operating at 15 Hz)			
Extraction kinetic energy (GeV)			3
Protons per bunch			$2,5 \times 10^{13}$
Number of bunches			4
Total number of protons			1×10^{14}
Normalized transverse emittance (mm-mrad)			200 π
Longitudinal emittance (eV-s)			2
RF frequency (MHz)			7.5
Average beam current (μA)			240
Target beam power (MW)			720
Booster (operating at 15 Hz)			
Extraction kinetic energy (GeV)	8	16	16
Protons per bunch	6×10^{10}	1.7×10^{12}	2.5×10^{13}
Number of bunches	84	18	4
Total number of protons	5×10^{12}	3×10^{13}	1×10^{14}
Normalized transverse emittance (mm-mrad)	15 π	60 π	200 π
Longitudinal emittance (eV-s)	0.1	0.4	2
RF frequency (MHz)	53	7.5	7.5
Extracted bunch length σ_t (ns)	0.2	1	1
Average beam current (μA)	12	72	240
Target beam power (MW)	0.1	1.2	4

AGS proton driver layout



BROOKHAVEN
NATIONAL LABORATORY

4 MW AGS proton driver layout



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Towards 4 MW

	Upgrade I	Upgrade II	Upgrade III
Linac intensity/pulse	1.2×10^{14}	2.4×10^{14}	2.4×10^{14}
Linac rep. rate	2.5 Hz	2.5 Hz	5.0 Hz
Linac extraction energy	1.2 GeV	1.5 GeV	1.5 GeV
$\beta^2\gamma^3$	9.6	14.9	14.9
Beam power	54 kW	144 kW	288 kW
AGS intensity/pulse	1.0×10^{14}	2.0×10^{14}	2.0×10^{14}
AGS rep. rate	2.5 Hz	2.5 Hz	5.0 Hz*
Rf peak power	3 MW	6 MW	8 MW
Rf gap volts/turn	1 MV	1 MV	1.5 MV
AGS extraction energy	24 GeV	24 GeV	24 GeV
Beam power	1 MW	2 MW	4 MW
Bunch area	5 eVs	10 eVs	10 eVs
Compressor ring	no	yes	yes

* Symmetric cycle (0.1 s up, 0.1 s down) without flattop.

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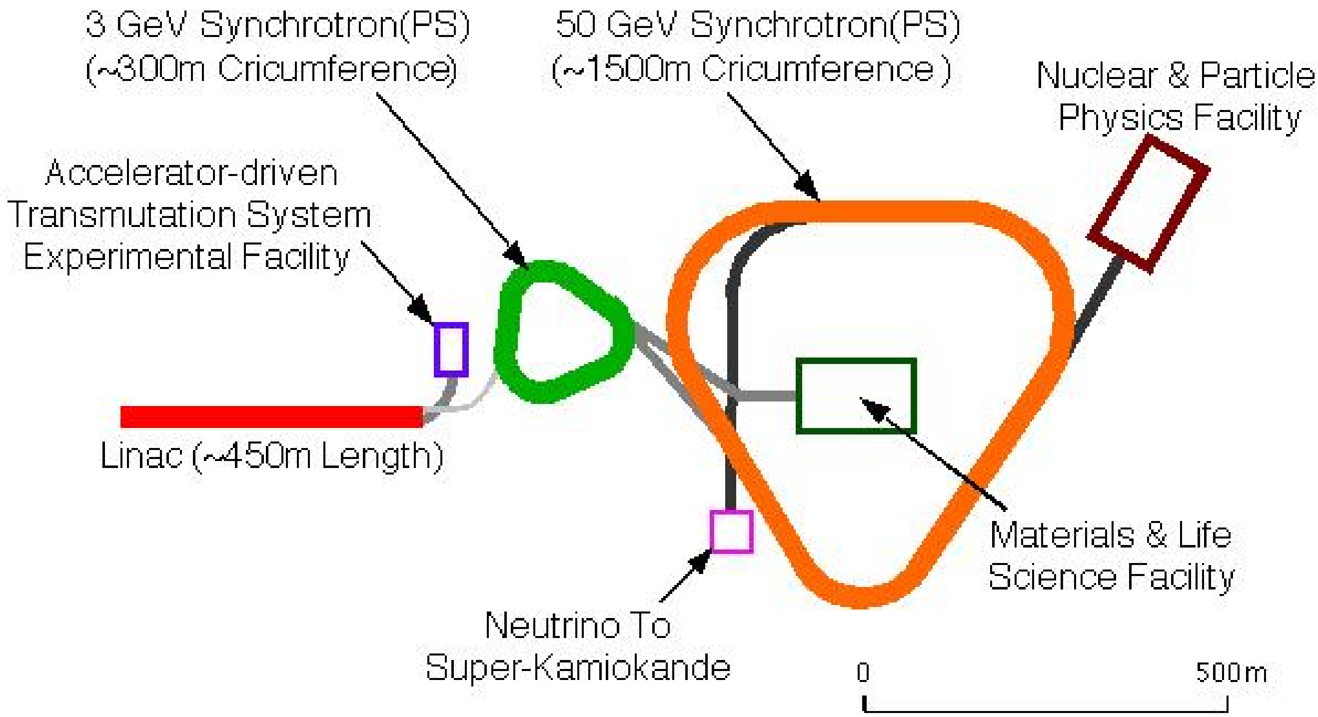
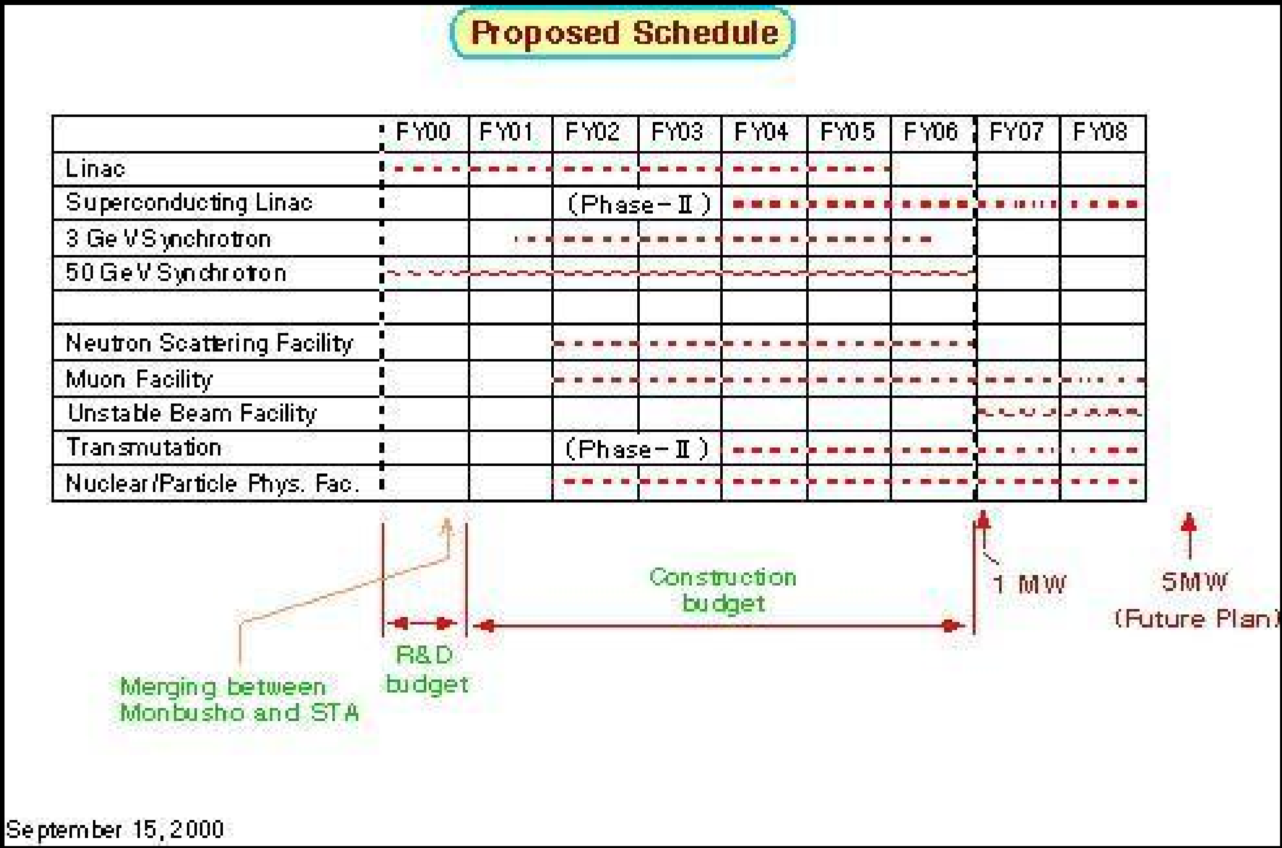


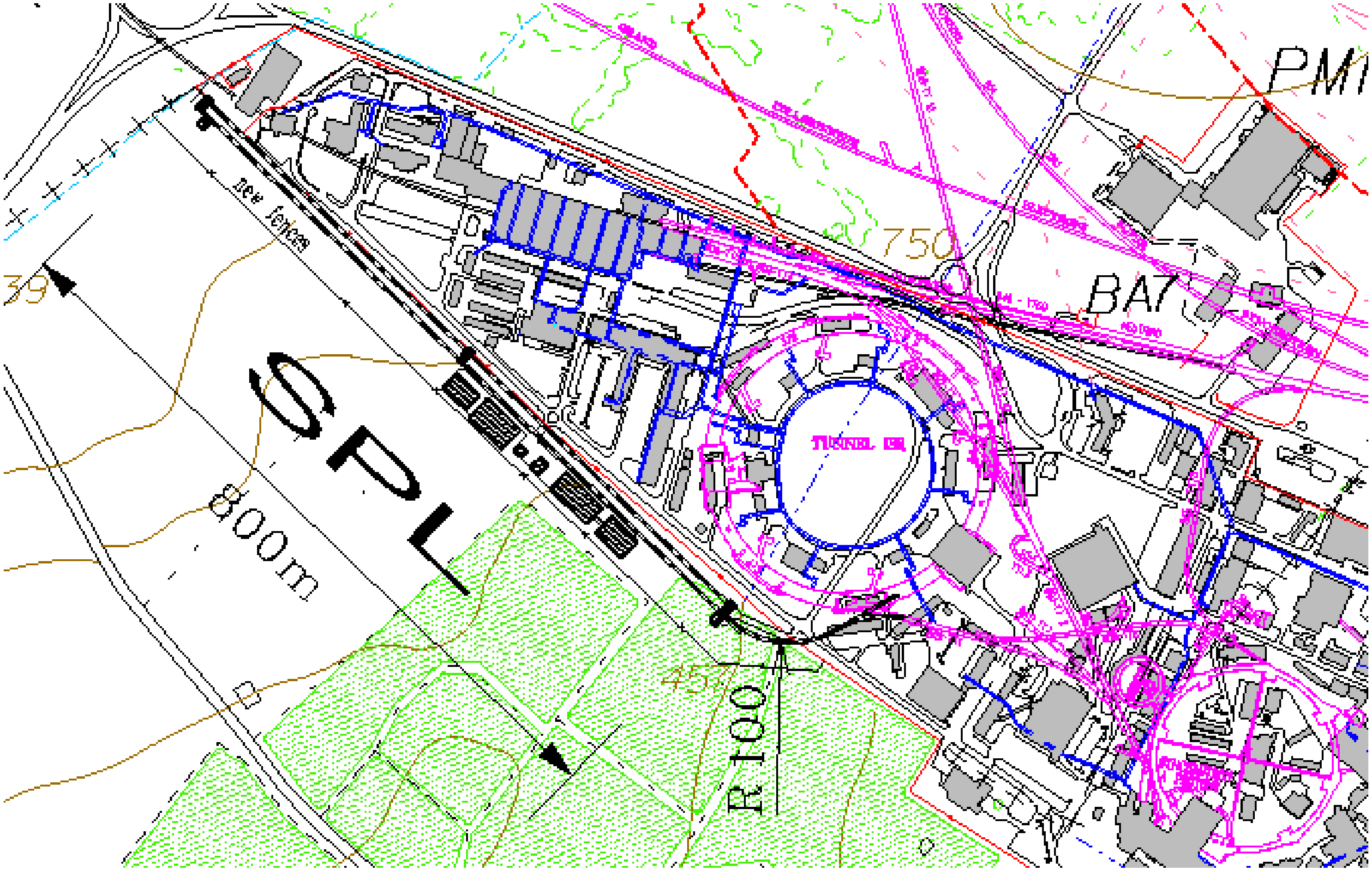
High Intensity Proton Accelerator Project

Schedule

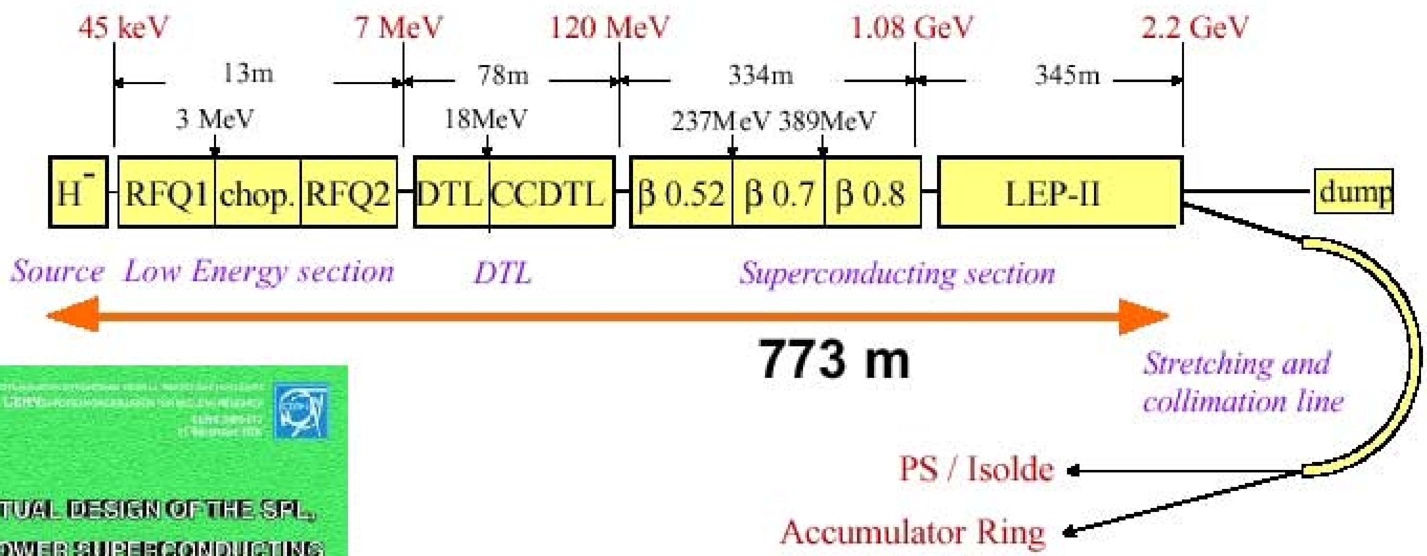


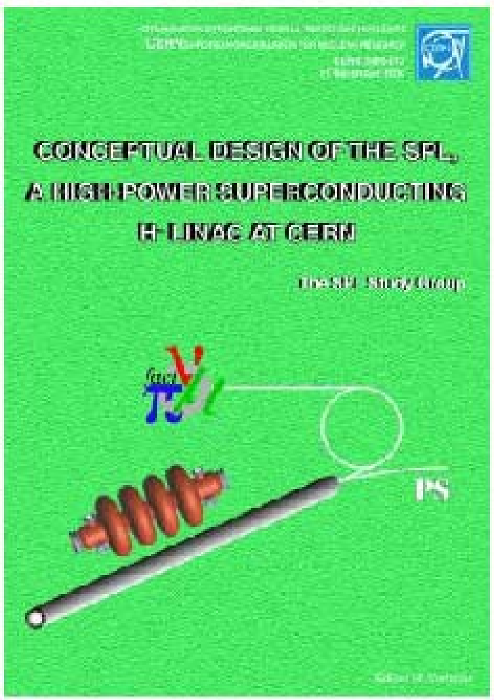
Proposed Schedule
FY00 FY01 FY02 FY03 FY04 FY05 FY06 FY07 FY08
Linac
Superconducting Linac
(Phase−II)
3 GeV Synchrotron
50 GeV Synchrotron
Neutron Scattering Facility
Muon Facility
Unstable Beam Facility
Transmutation
(Phase−II)
Nuclear/Particle Phys. Fac.
Construction budget
1 MW
5MW (Future Plan)
R&D budget
Merging between Monbusho and STA
September 15, 2000

Layout on the CERN site



Basic lay-out of the SPL





CERN 2000-012

Basic Parameters:

Energy	2.2 GeV
Mean current	11 mA
Repetition rate	75 Hz
Beam Power	4 MW

Superconducting cavities

The β=0.7 4-cell prototype

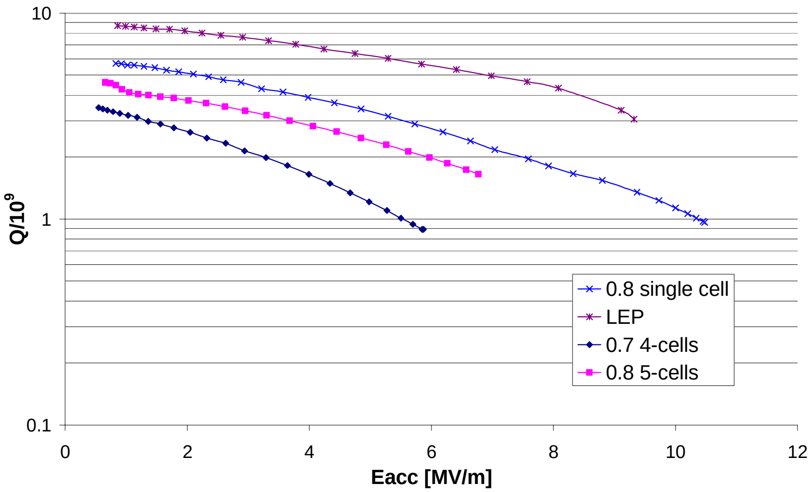
☆ CERN technique of Nb/Cu sputtering for β=0.7, β=0.8 cavities (352 MHz):

⇨ excellent thermal and mechanical stability

⇨ (very important for pulsed systems)

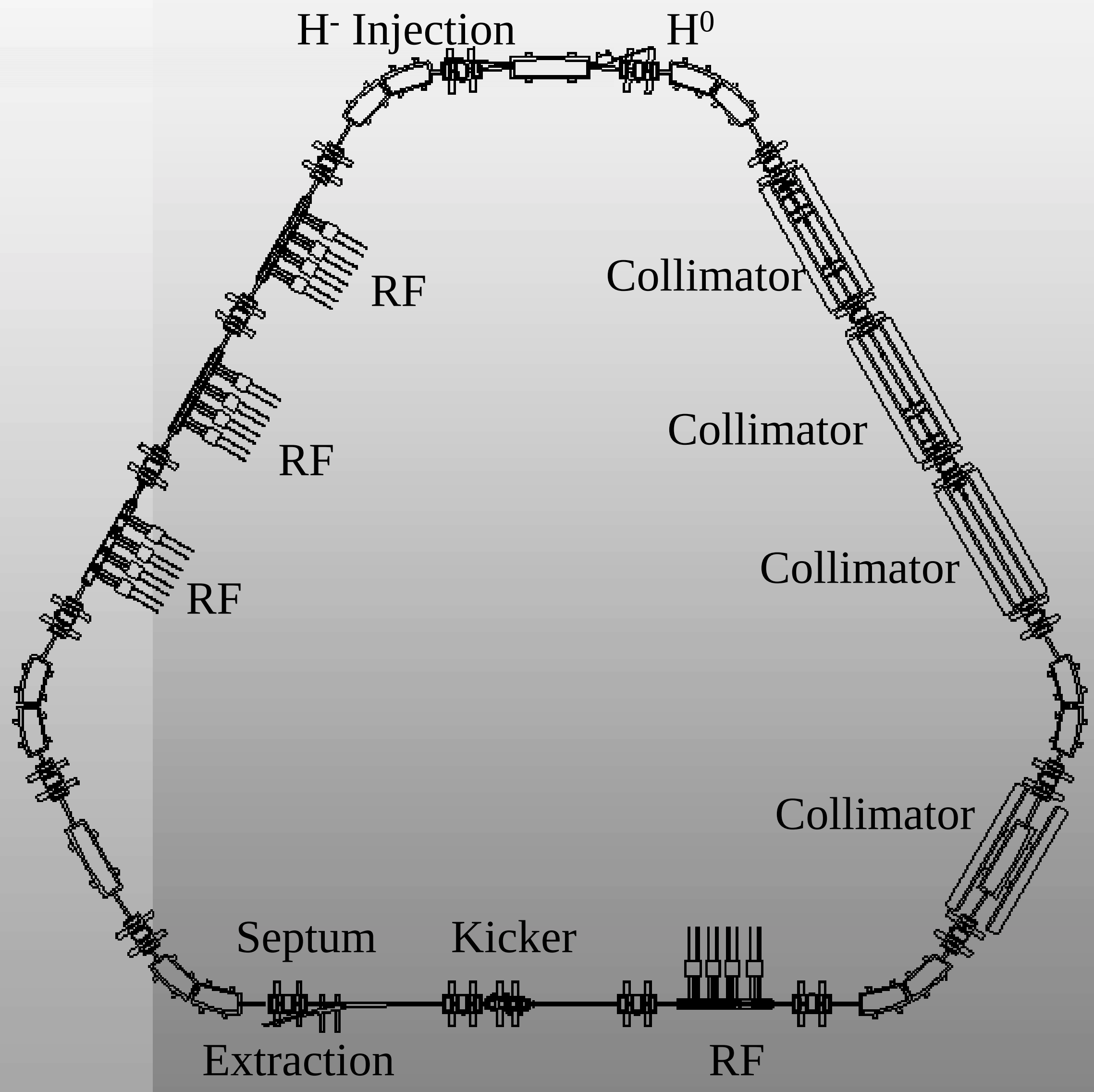
⇨ lower material cost, large apertures, released

⇨ tolerances, 4.5 °K operation with Q = 10^9

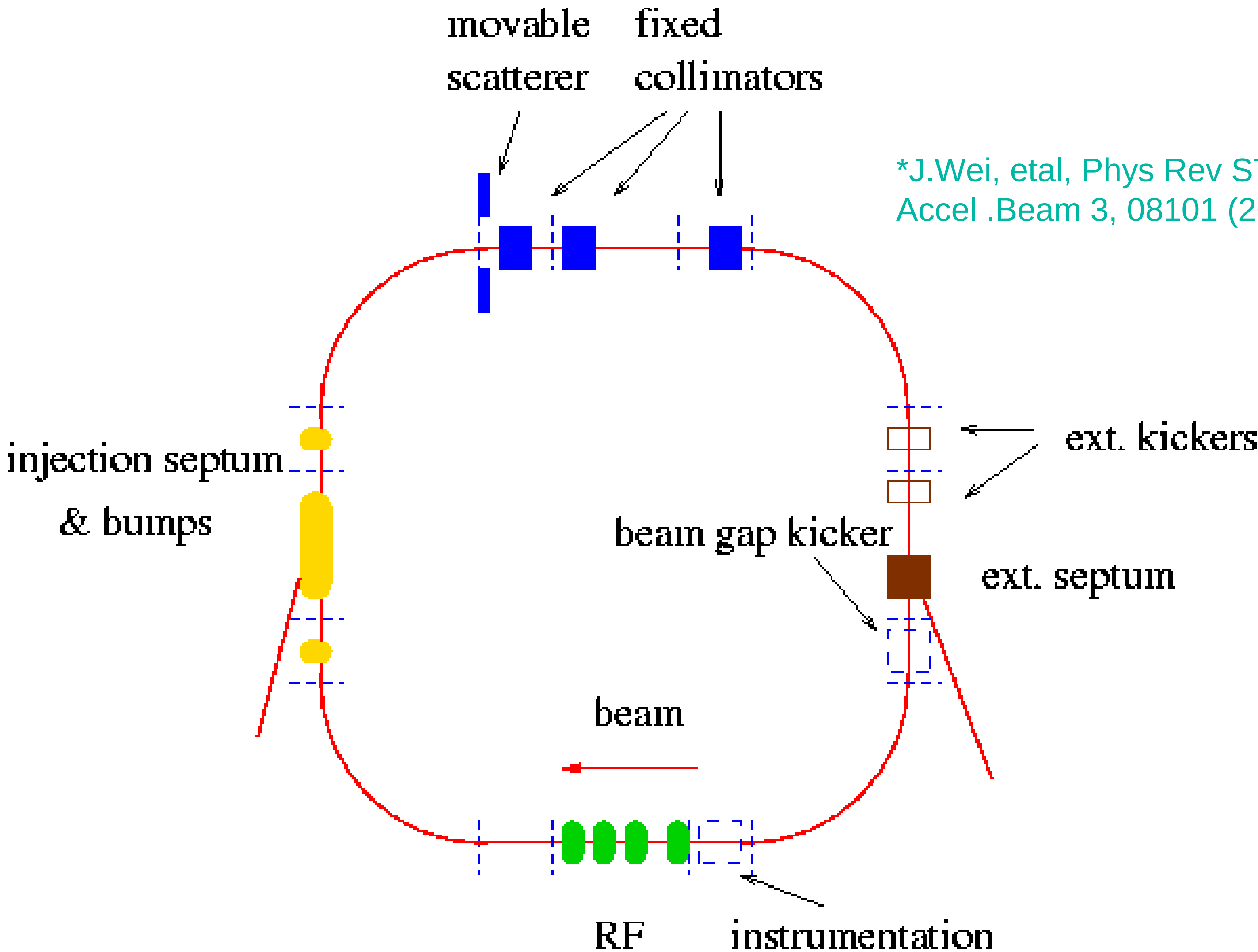


☆ Bulk Nb or mixed technique for β=0.52 (one 100 kW tetrode per cavity)

RCS Lattice 180MeV-3GeV



SNS Ring Layout*
(courtesy Jie Wei)



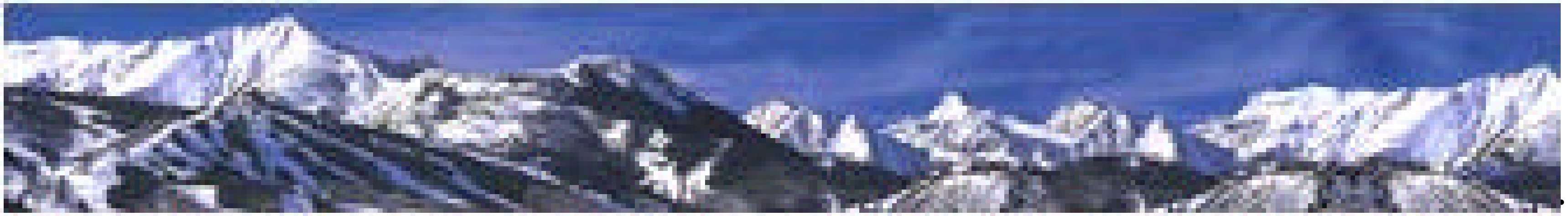
*J.Wei, etal, Phys Rev ST-Accel .Beam 3, 08101 (2000)

LANSCE
Los Alamos Neutron Science Center

R & D Issues for
High Intensity Proton Sources

M6 Working Group

Snowmass, July 20, 2001



Present status

- **Proposed PD projects: technically feasible? cost effective?**

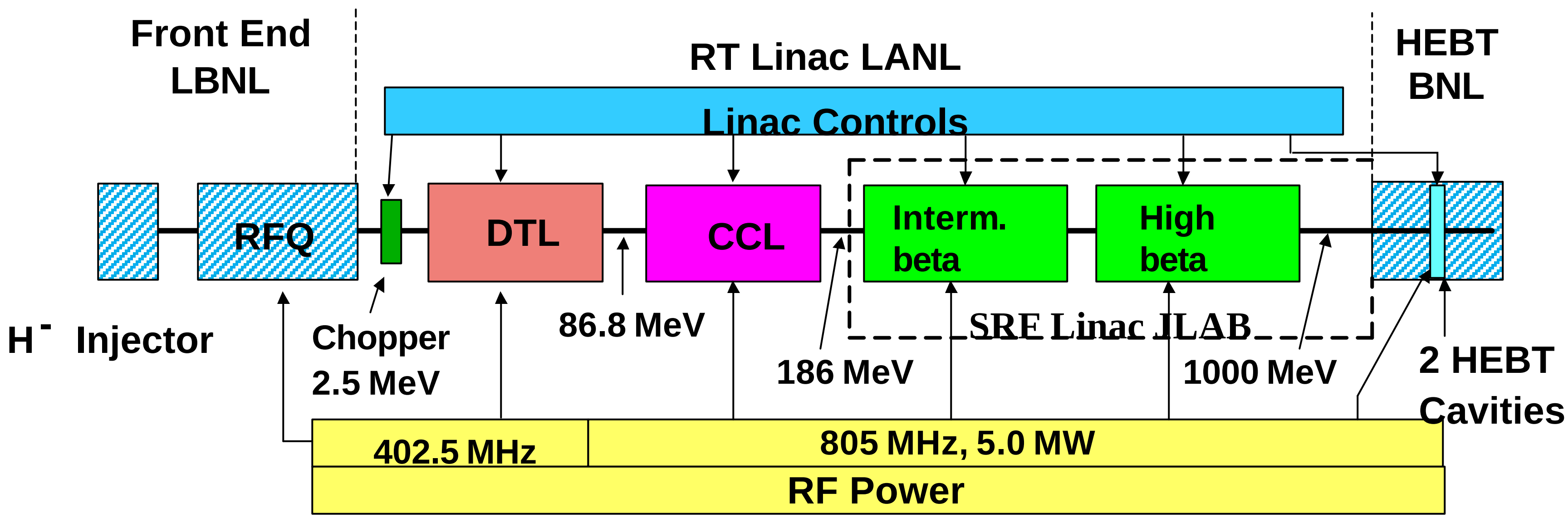
- Present construction projects serve as best R&D and prototypes for high intensity proton sources
  - Spallation Neutron Source: up to 2 MW

    developed super-conducting RF linac for intense proton beams
  - JAERI/KEK: 1 MW multi-purpose

    Rapid-cycling synchrotrons for intense beams
- No show stoppers towards a multi-MW source, based on present accelerator technology
- Reliable cost estimates based on line-item construction projects

Example: SNS technology (transfer?)

- SNS technologies for direct adoption
  - (engineering) Superconducting RF cavity, couplers, RF control
  - (simulation) Codes development including space charge, impedance, painting, collimation, fringe fields, (electron-cloud)
  - (experiment) Collimation study at Protvino, space charge comparison with PSR



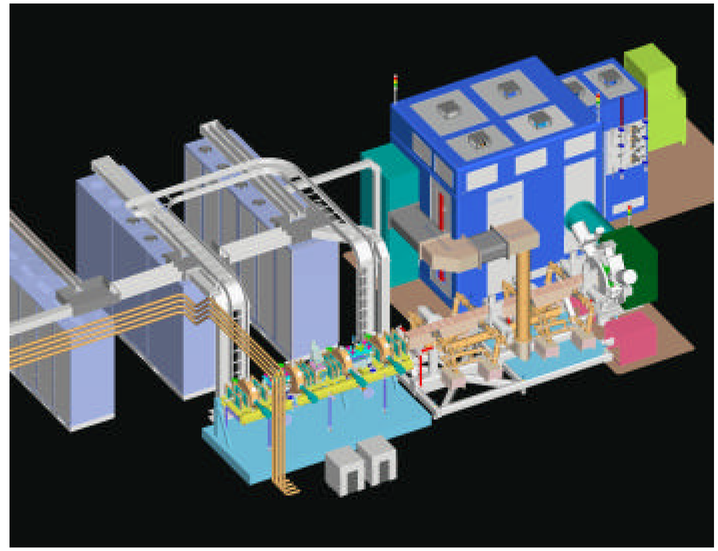
M6 Group R&D items

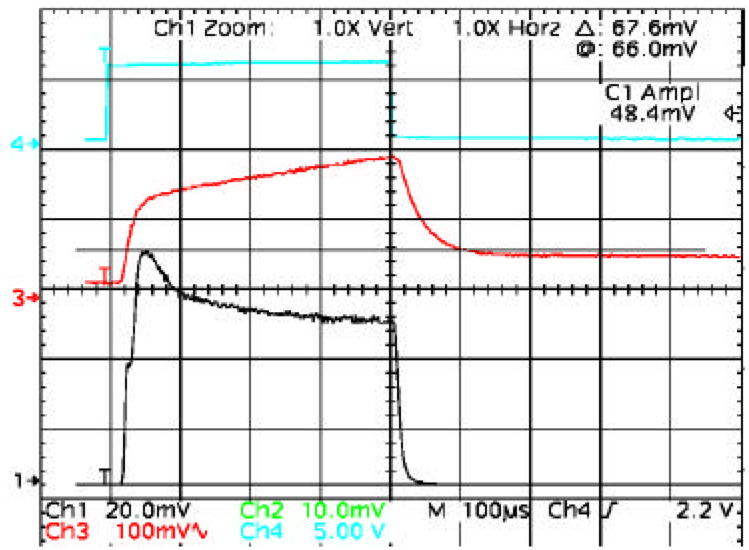
- Engineering
  - Ion source lifetime
  - Superconducting RF linac gradient, RF control
  - Ring RF gradient, magnet, coil, modulators, kicker impedance, collimation
  - New development: FFAG, Inductive insert, induction synchrotron
- Simulation
  - Codes development & benchmarking
  - Electron cloud effects
- Experiments
  - Halo experiments
  - Diagnostics

H$^-$ ion source; lifetime

- Goal
  - 60-70 mA current; 6-12% duty
  - 0.2πmm mr rms norm. emittance
  - 60 day lifetime
- Achieved
  - 35-50 mA current; 6% duty
  - Up to 20 day lifetime
- Main focus on ion source lifetime and machine availability
  - Antenna coating
  - Cesium enhancement & sparking
  - Electron dumping

(Courtesy LBNL / R. Keller)

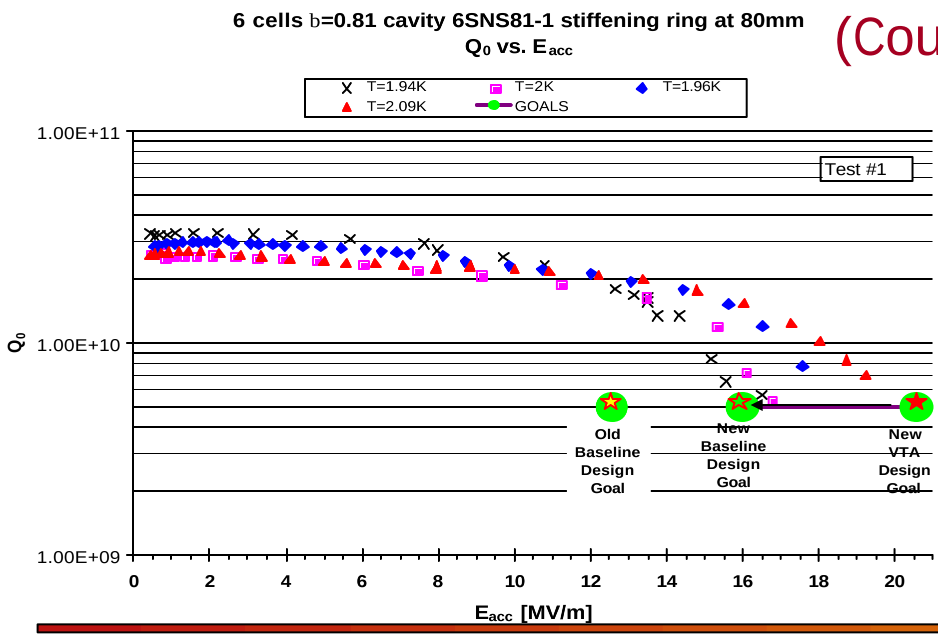


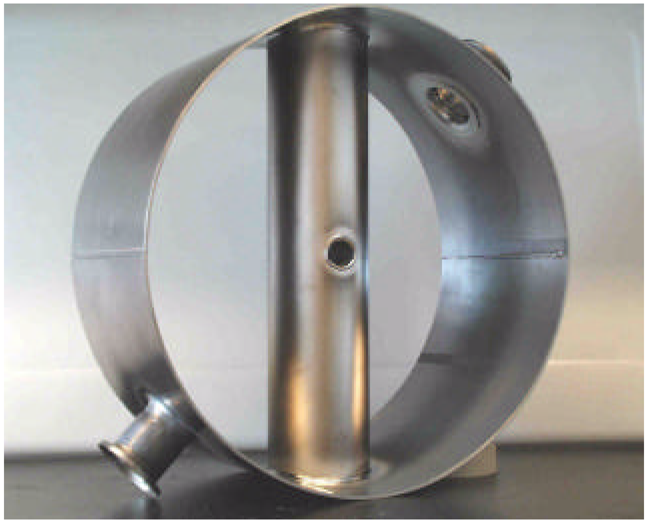


Superconducting RF linac cavities

- Steady increase in accelerating gradient
  - Achieved (E_{acc}) 16 MV/m; electro polishing, Nb sheet scan
  - Nb/Cu sputtered cavity at CERN; 4.5° operation
- Extending SC technology towards lower β (0.17-0.34)
  - Power saving, larger aperture for lower loss

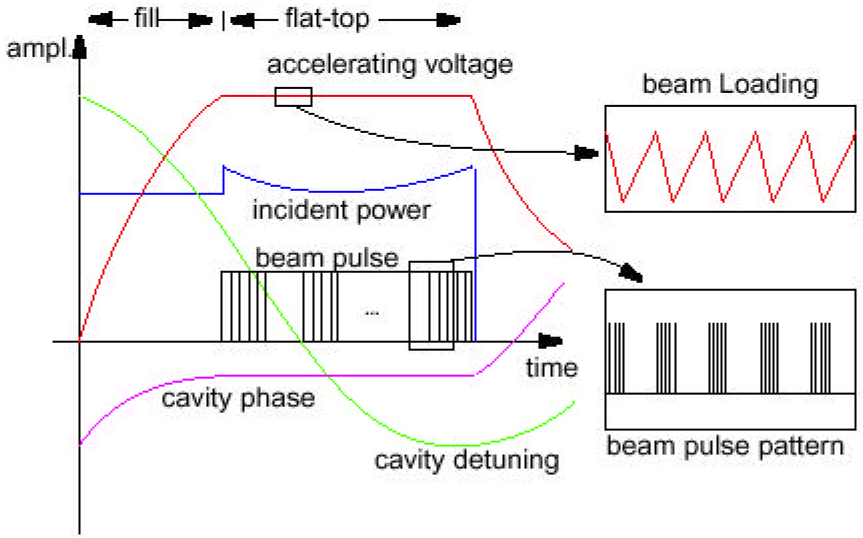
(Courtesy Jlab/C. Rode, ANL, T. Wangler)

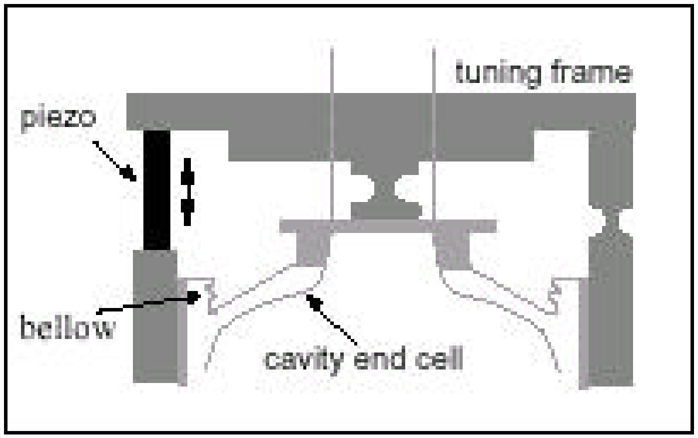


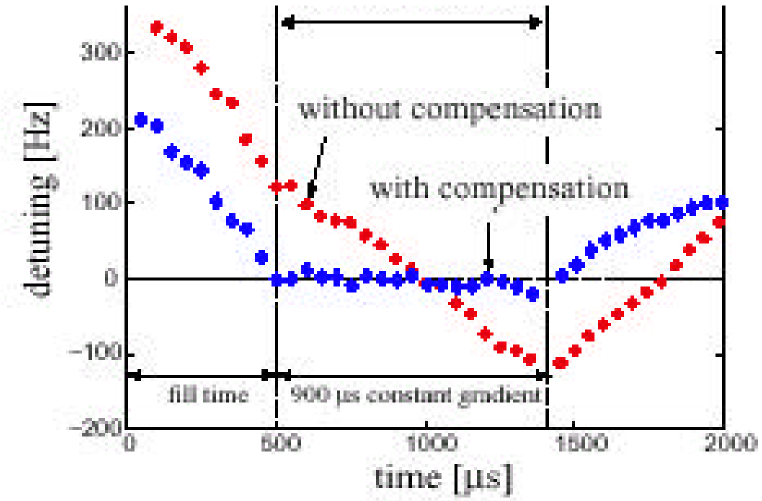


Linac RF control for pulsed operation

- New challenges from pulsed superconducting RF linac
  - Lorentz detuning, $\sim E_{acc}^2$
  - Microphonics
- Development of piezo-translator for measurement/feedforward compensation (RF power saving)
  (Courtesy M. Liepe, S. Simrock)

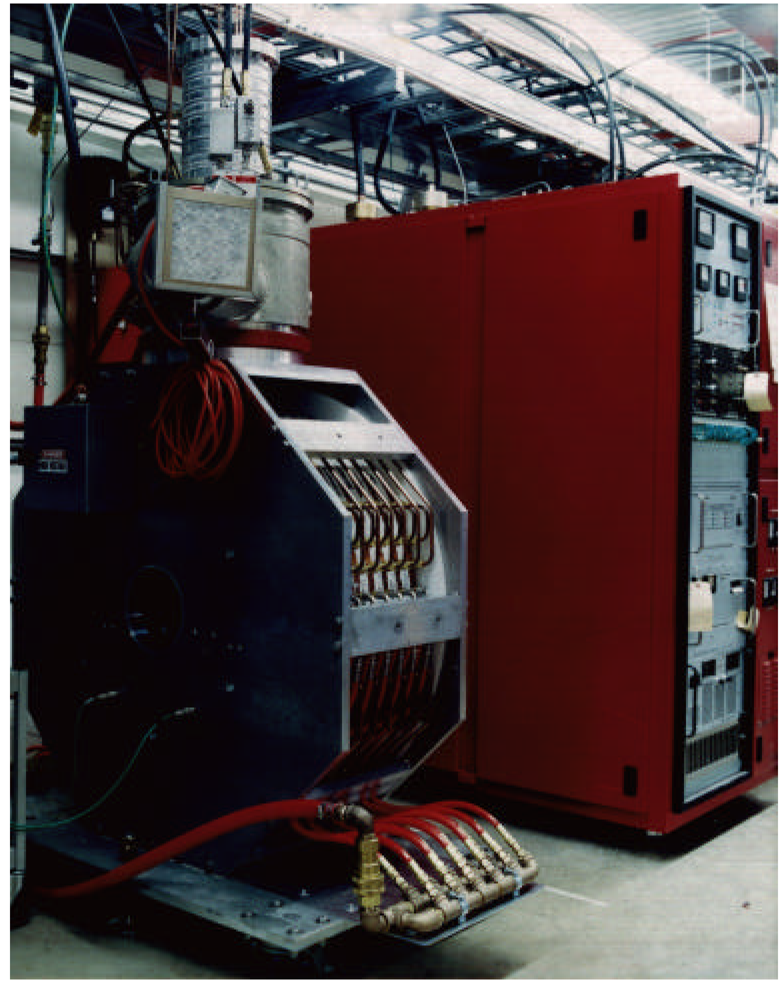






Ring RF development

- Development of Magnetic Alloy (MA) loaded cavity of high gradient
  - Goal: 50-100 kV/m at low frequency (few MHz) with 50-60% duty cycle (conventional ferrite loaded: 10 kV/m)
  - Need to investigate power load/cooling, beam loading
- Development of burst mode RF of high gradient (~1 MV/m) at low frequency (~5 MHz)

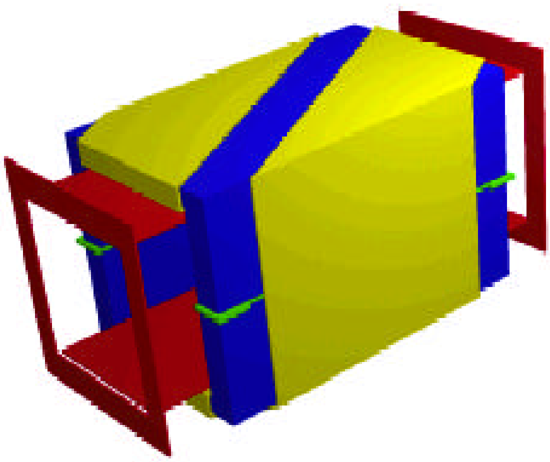


(Courtesy D. Wildman, W. Chou)

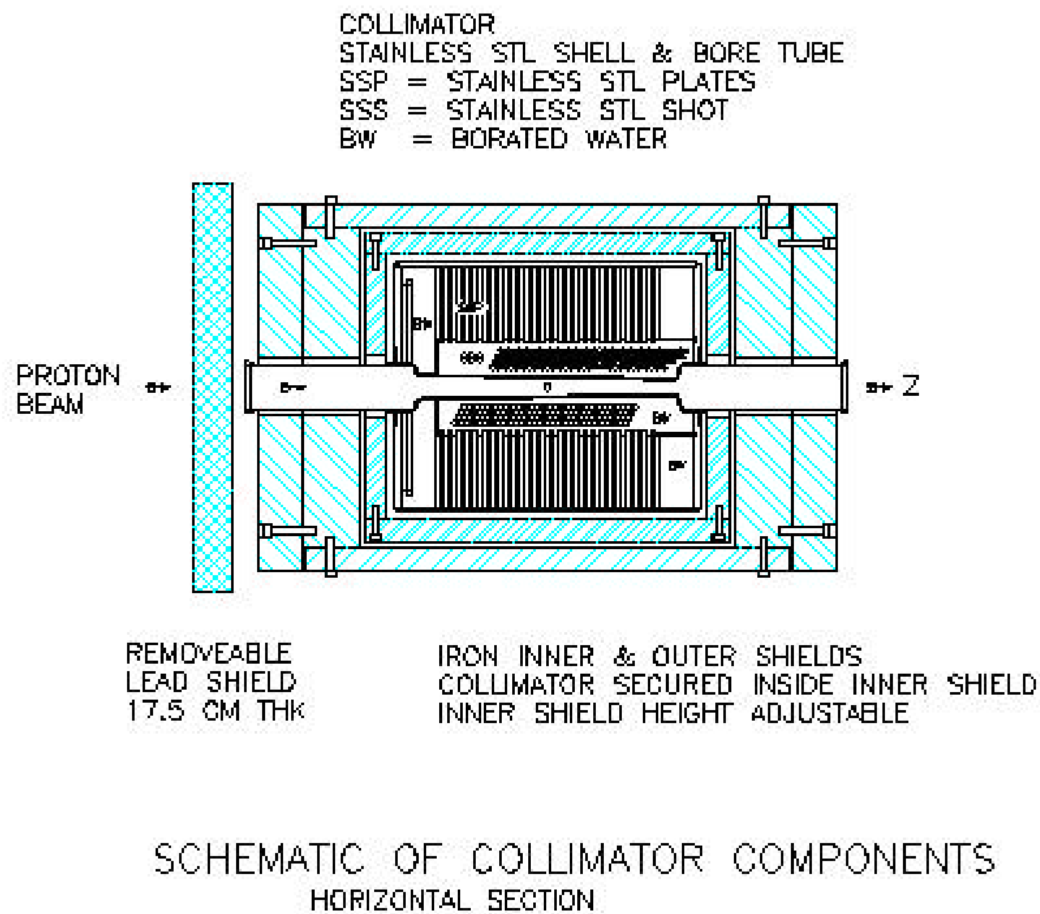
Extraction kicker & modulator

- Development of solid-state (stacked Mosfet) modulators
  - Fast rise / fall time (10-20 ns)
  - Possible reliability improvement
- Impedance reduction of lumped ferrite kickers

(Courtesy AHF/A. Thiessen, Y.Y. Lee)



Collimation and cleaning



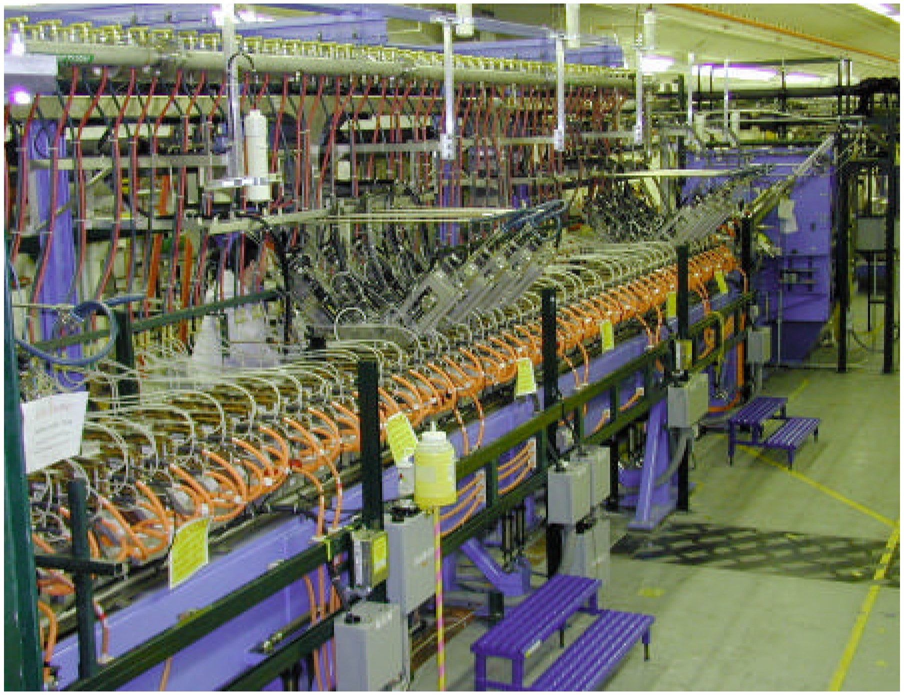
- Development of high-efficiency 2-stage collimation
- Development of self-shielding collimator
- Development of beam-in-gap cleaning

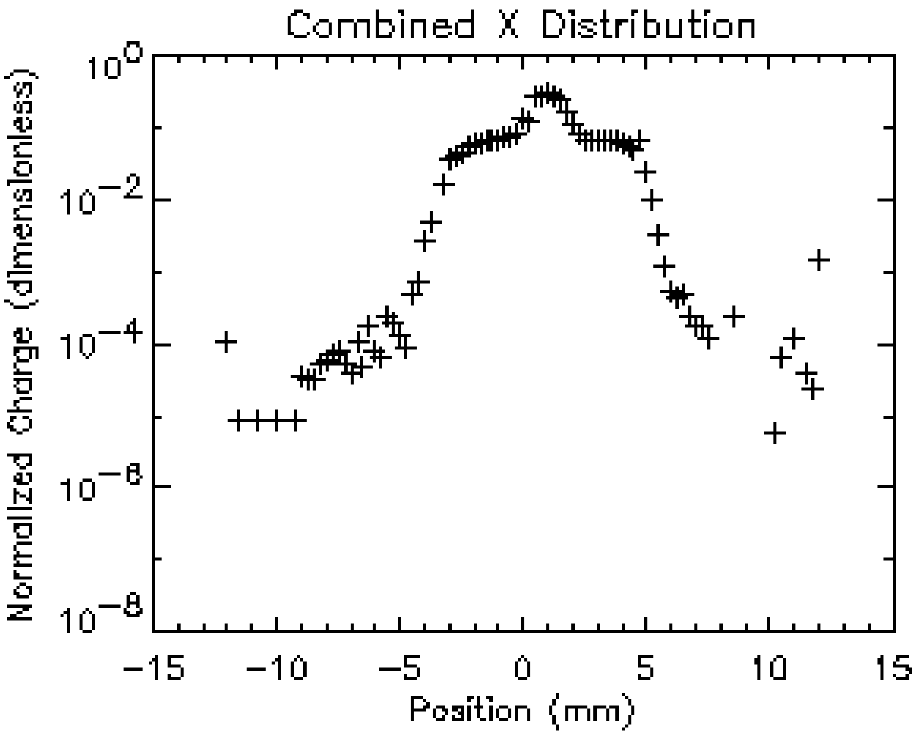
(Courtesy H. Ludewig)

Space charge and halo study

- LEDA halo experiment and unresolved issues
  - Higher-than-predicted emittance / halo growth; profile structure
- Parametric resonance, space charge coupling resonance

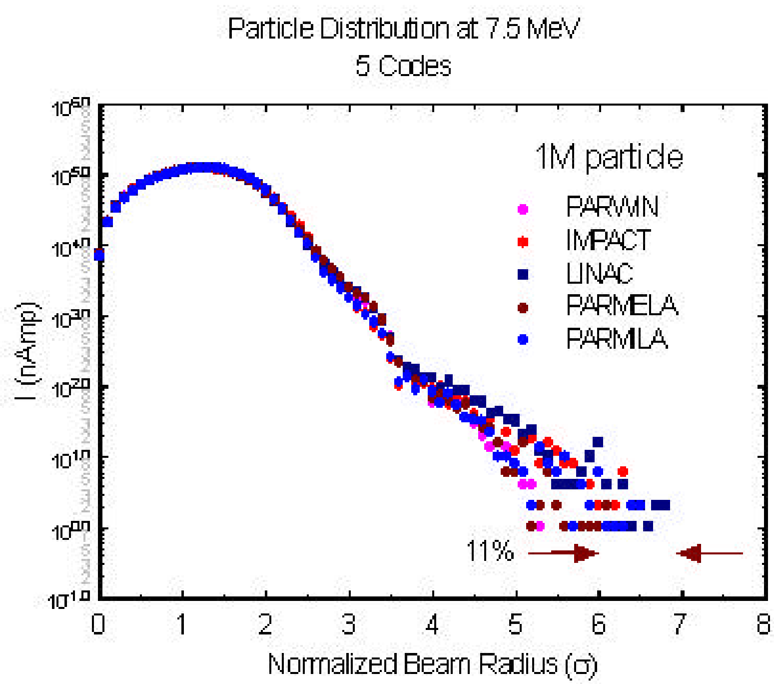
(Courtesy T. Wangler, P. Colestock)



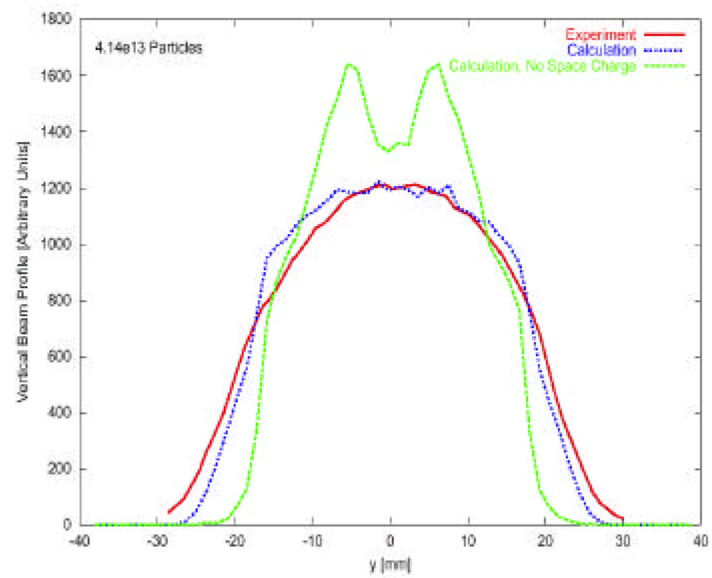


Machine study/codes benchmarking

- Machine study: halo experiments for both linac and ring; space charge effects; collimation; electron cloud
- Codes comparison: linac codes and ring codes

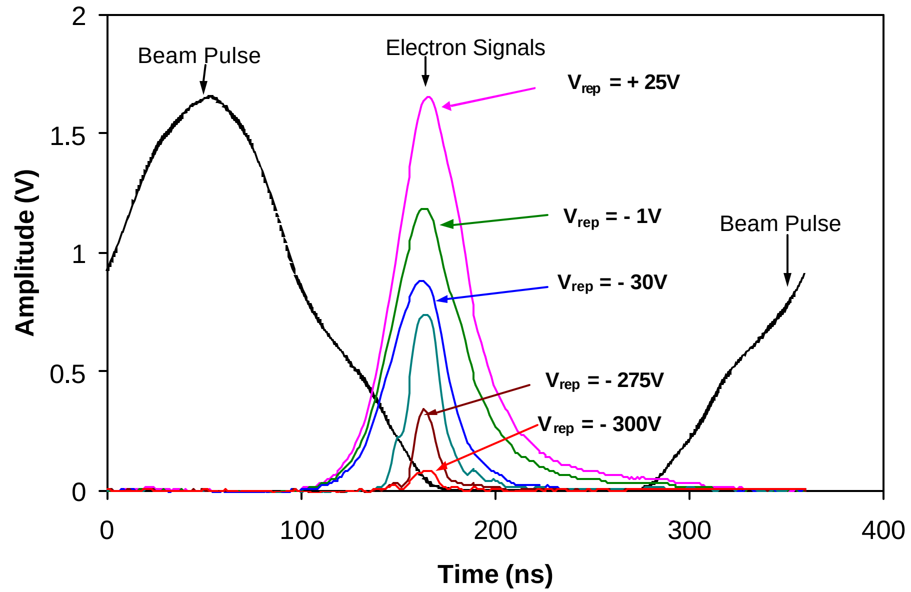


(Courtesy LANL/S. Nath, J. Holmes)



Electron cloud effects

- Intensity limiting mechanism at PSR and SPS
- Extensive effort is needed
  - Theory: to reliably predict instability threshold and growth rate for bunched beam
  - Measurement/simulation: on electron accumulation and secondary yield details
- Cures
  - Investigate surface treatment & conditioning
  - Development of wide-band, fast, active damping system at frequency 50-800 MHz

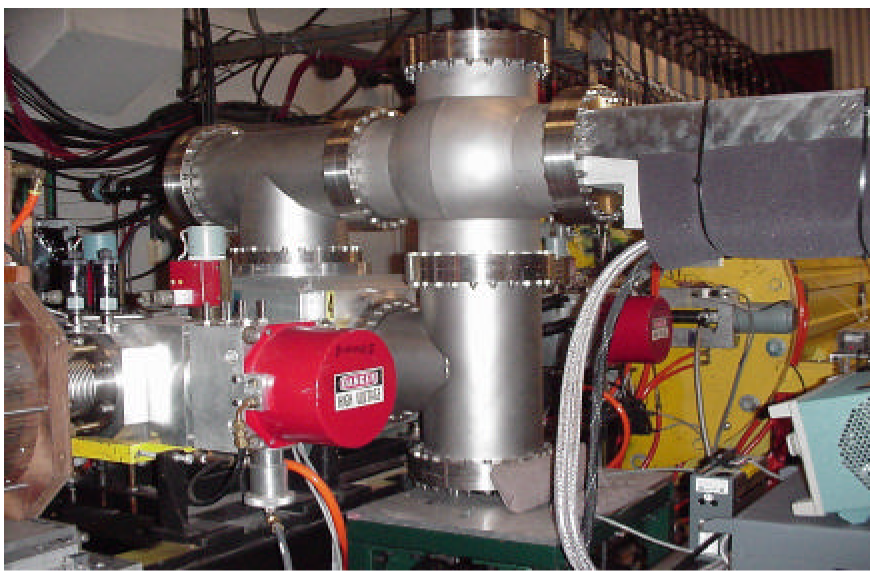


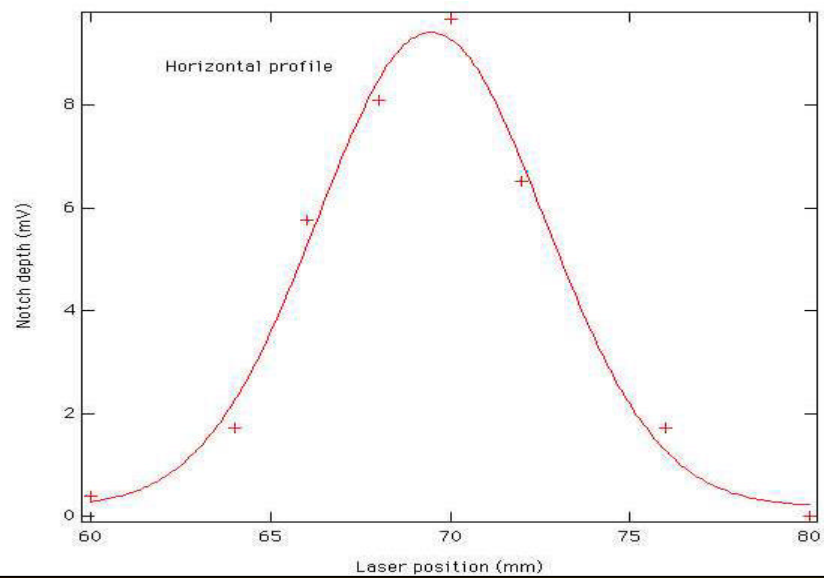
(Courtesy R. Macek)

Diagnostics

- Whole area of diagnosing beam parameter during multi-turn injection; profile measurement over wide range, turn-by-turn
- Development of laser-based profile measurement for H^- beam
  - Avoid wire heating at low energy
  - Superconducting environment cleanness requirements

(Courtesy BNL/P. Cameron)

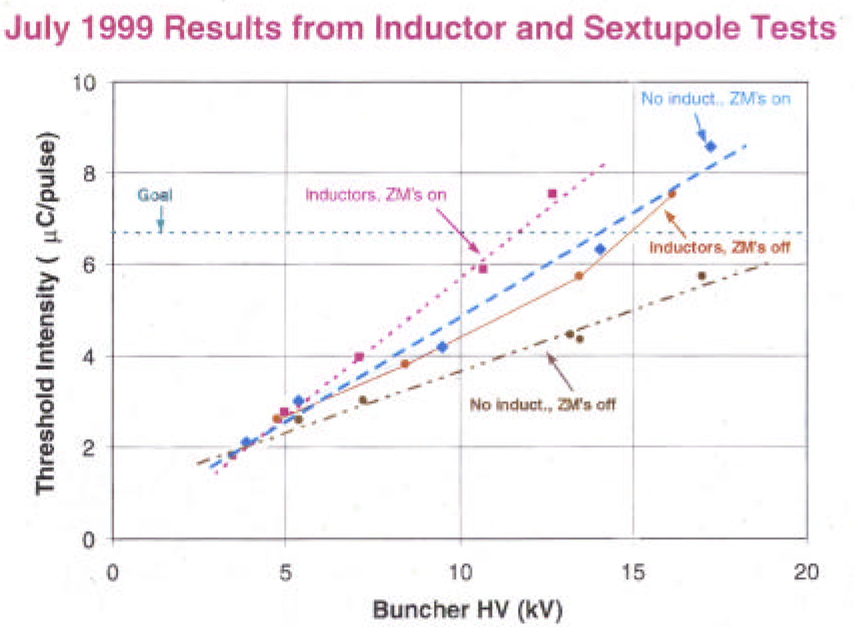


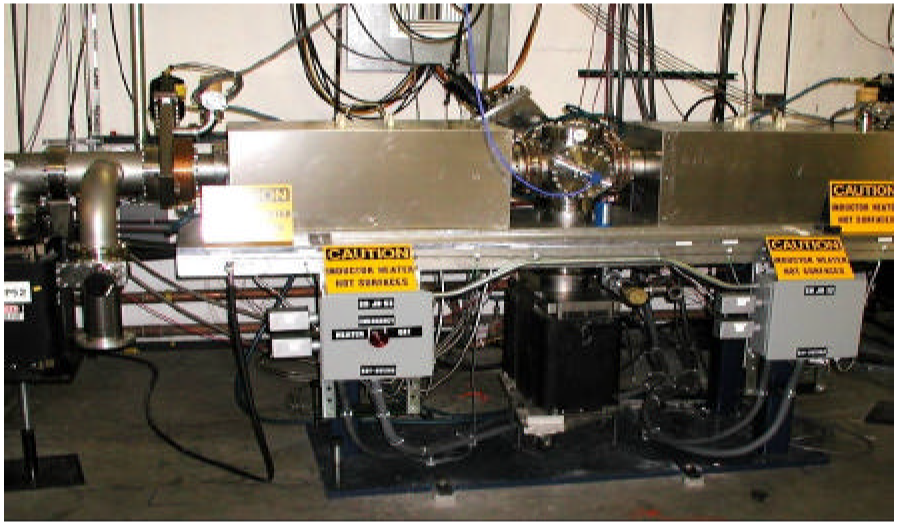


New developments

- <u>Inductive insert</u>
  - Passive compensation of space charge effects
  - Improves instability threshold at PSR
- <u>FFAG</u> (Y. Mori)
  - Proof-of-Principle model demonstrated at KEK (50-500 keV)
  - 150 MeV FFAG planned
- <u>Induction synchrotron</u> (K. Takayama, J. Kishiro)
  - Barrier cavity acceleration
  - Development of low loss cores

(Courtesy W. Chou, R. Macek)





Summary

- Presently proposed Proton Drivers (FNAL, BNL) are feasible and cost effective
- Based on current technology, there are no showstoppers
- Present construction projects serve as best R&D and prototypes for high intensity proton sources