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- Substantial progress in this area. Too early yet for conclusions.

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- Roughly two schools of thought:

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- Several proposals for simplified cooling demonstrations and facilities where such experiments could be carried out:

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SUMMARY – WG5

FEATURES

- Slanted towards experiments underway or proposed - hardware components – test facilities proposed
- Much work in this year since Lyon – much more to do
- Highlights only – beg pardon (credits too – see Web please)

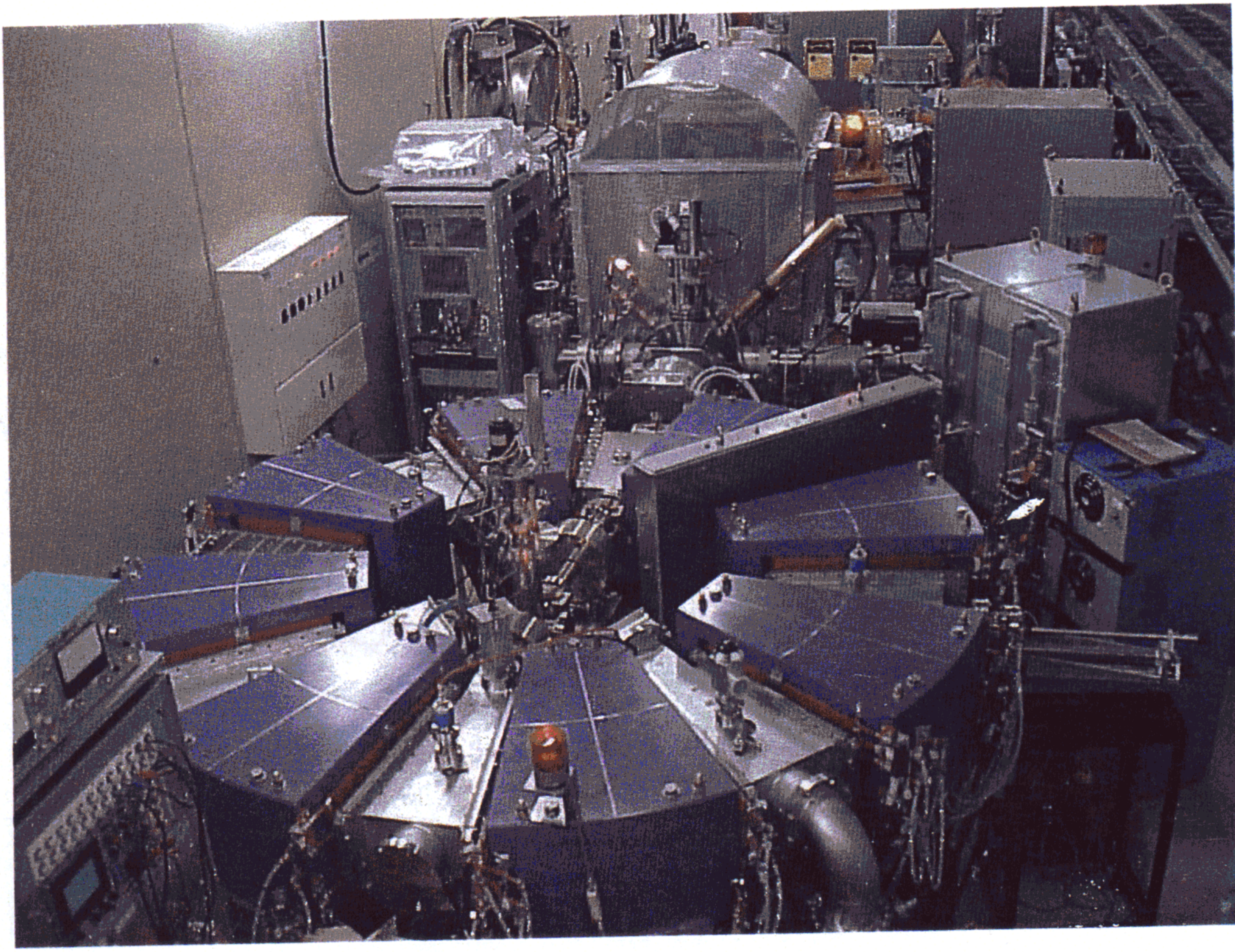
WORLD R/D SURVEY (Y.M., H.H. M.Z.)

- Most presented in plenary session – will not repeat in detail (note that combined transparencies mention almost everything that is going on so are good reference)

  1. of note: Feasibility Study #1 (centered at FNAL w. essential help from MC and folks from CERN, DoE and NSF Labs) did great service in combining all elements for a NuFac and thereby exposing problems – more to come

- WG session showed
  2. not much, if any, duplication yet – no worry there
  3. program still thin in simulation of cooling and in common terms of reference for stating results
  4. items missing so far:
     - muon test beam(s) for NuFac development work
     - beam instrumentation development program (Workshop needed)
     - cooling experimental demo. – no consensus yet (see later)
     - only a little on RF source development

FFAG POP model



5. **interesting play on the FFAG idea – big apertures good - working model being tested now in Japan – other applications being discussed.

PRODUCTION AND SCATTERING EXPERIMENTS

- E-910 BNL et al, H.K. 17 GeV ?

  - *thin target* data analyzed to date indicate that at high π energies MARS does pretty well on production. In 100 – 200 MeV range there may be *more* pions than MARS predicts ~ 10%? 30% ? Some thick target data yet to be analyzed.

- HARP, M.C., approved for running at CERN will have data over all target materials, thicknesses and energies relevant to NuFac now discussed. Preparations far along. Will have results in '01.

- ** R.E. Muon scattering run at TRIUMF by RAL & collaborators. Will begin running in weeks

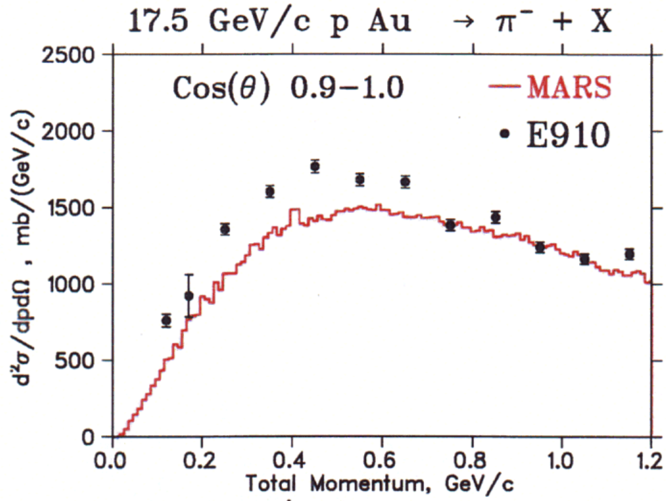
TARGETRY EXPERIMENT/FACILITY

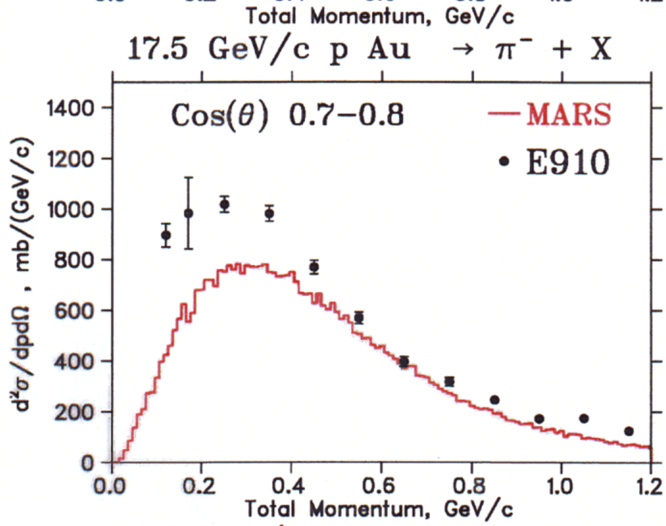
- **K.M. E951 Approved at BNL- production, collection, phase rotation, liquid jet target, low freq. cavity in high radiation, etc.

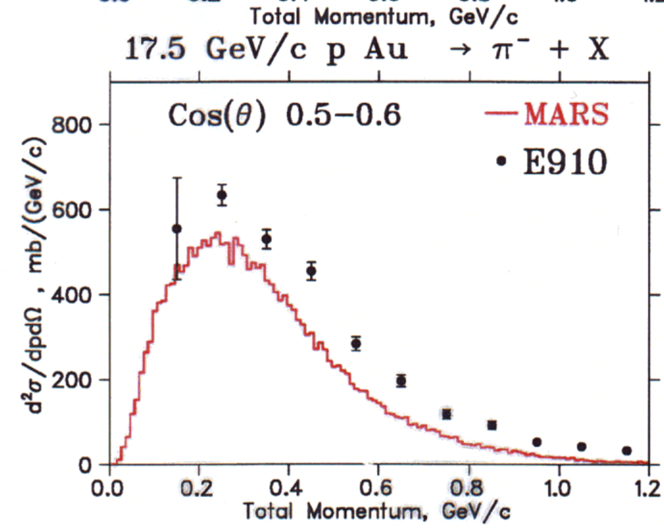
COOLING FRONT ENDS - *four arrangements discussed* (WG4)

- Importance underlined by results of Feasibility Study #1

- **R.P. w. two phase rotations, combines RF and Induction linac. Model for Feasibility Study #2?


17.5 GeV/c p Au → π⁻ + X
Cos(θ) 0.9–1.0
MARS
E910
d²σ/dpdΩ , mb/(GeV/c)
0
500
1000
1500
2000
2500
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Total Momentum, GeV/c


17.5 GeV/c p Au → π⁻ + X
Cos(θ) 0.7–0.8
MARS
E910
d²σ/dpdΩ , mb/(GeV/c)
0
200
400
600
800
1000
1200
1400
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Total Momentum, GeV/c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200
400
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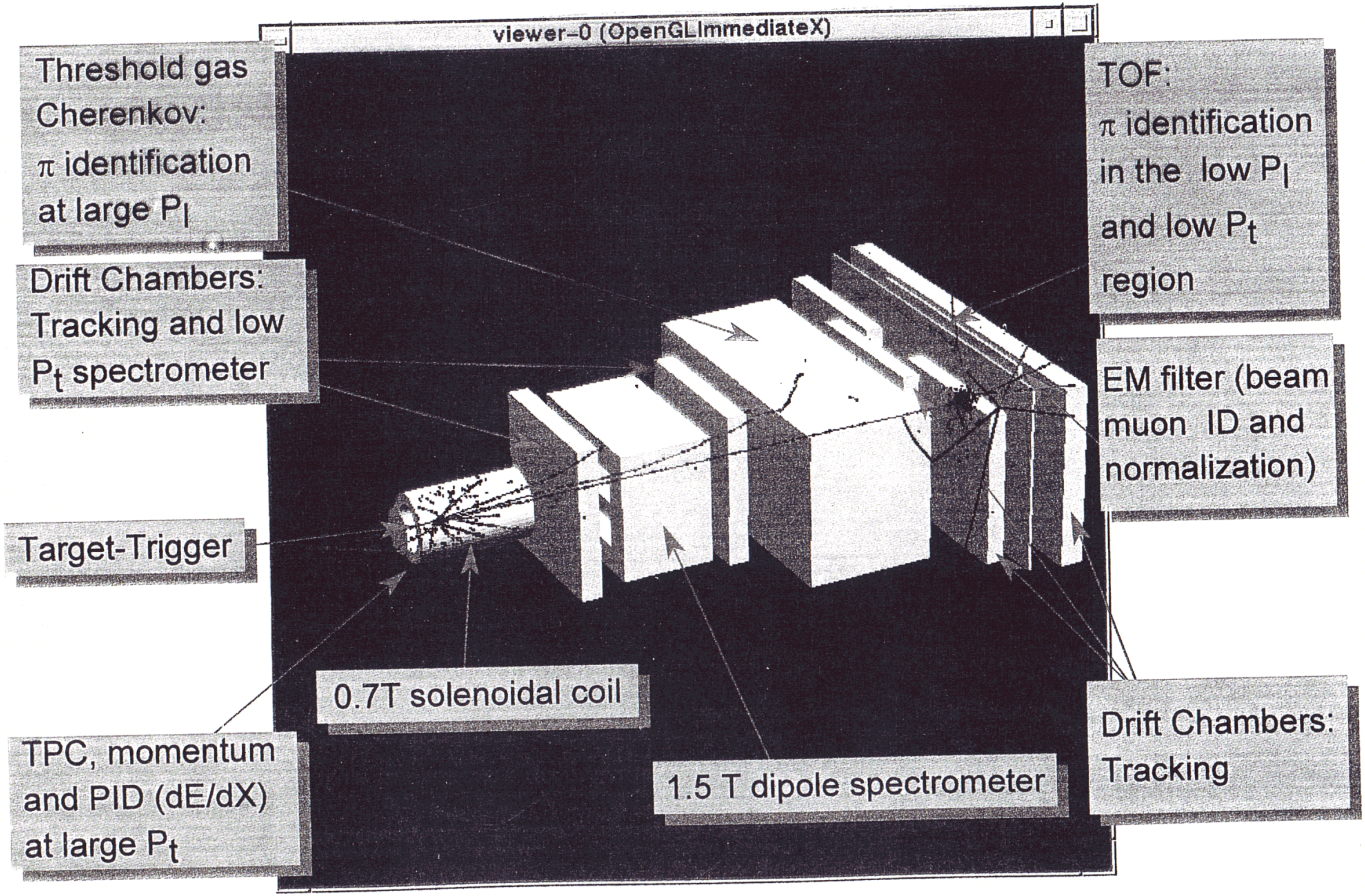
0.2
0.4
0.6
0.8
1.0
1.2
Total Momentum, GeV/c

The detector: *Acceptance, PID, Redundancy*



Location

- Experiment has been approved at TRIUMF
- 2/3 running periods in M11/M9B beam lines
- Approved in M11 from 22nd June till 17th July

Parameter	M11	M9B
Beam type	Pion	Muon
Momentum range (MeV/c)	80 - 415	20 - 100
Intensity (Hz)	2×10^5	1.4×10^6
Pion/muon	50!	0.01
Momentum resolution	1%	3.4%

- **Main disadvantage:** $\pi/\mu \Longrightarrow$ TOF
- **Main advantage:** Momentum range

But

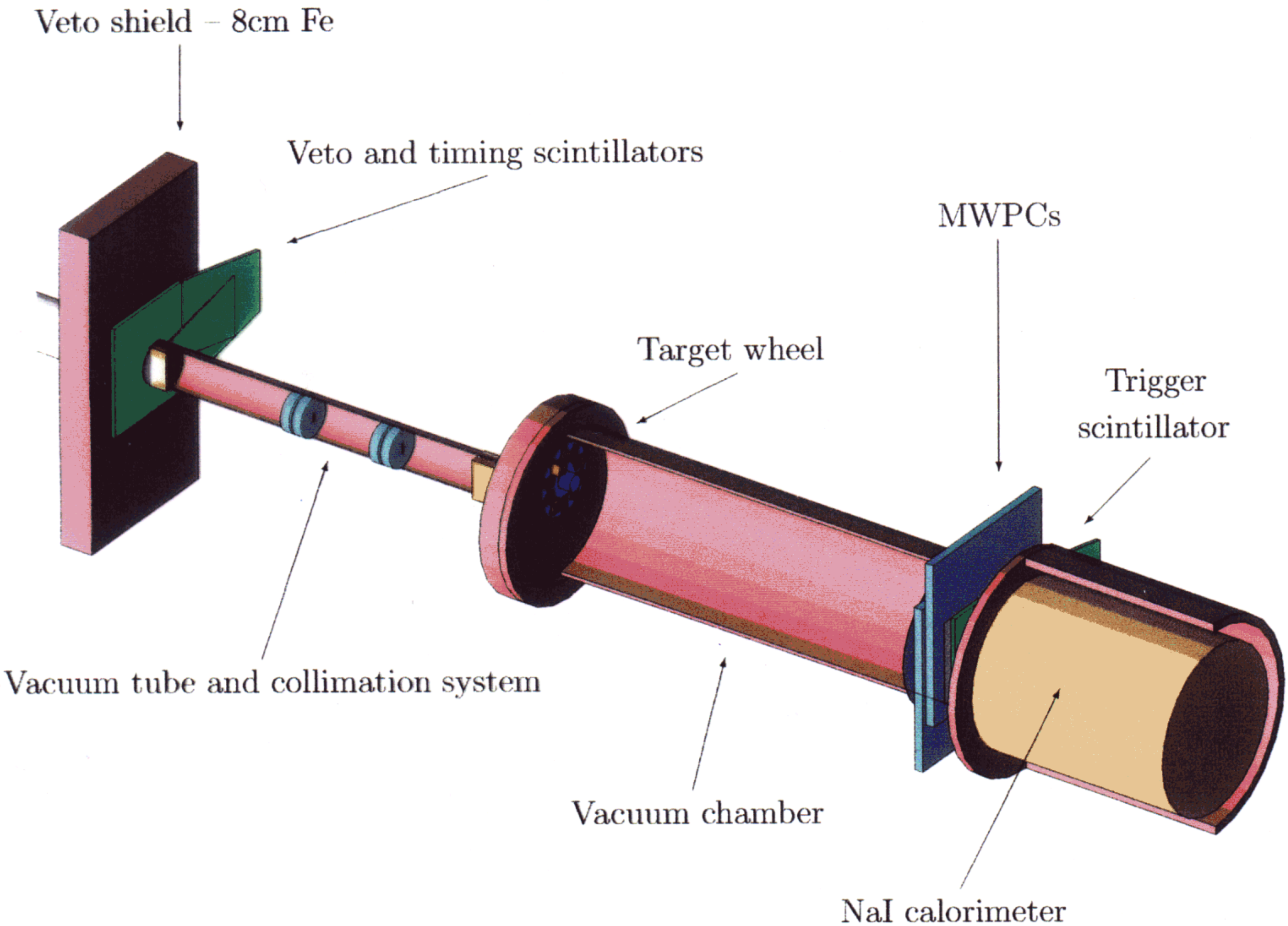
TOF

Scattering angle

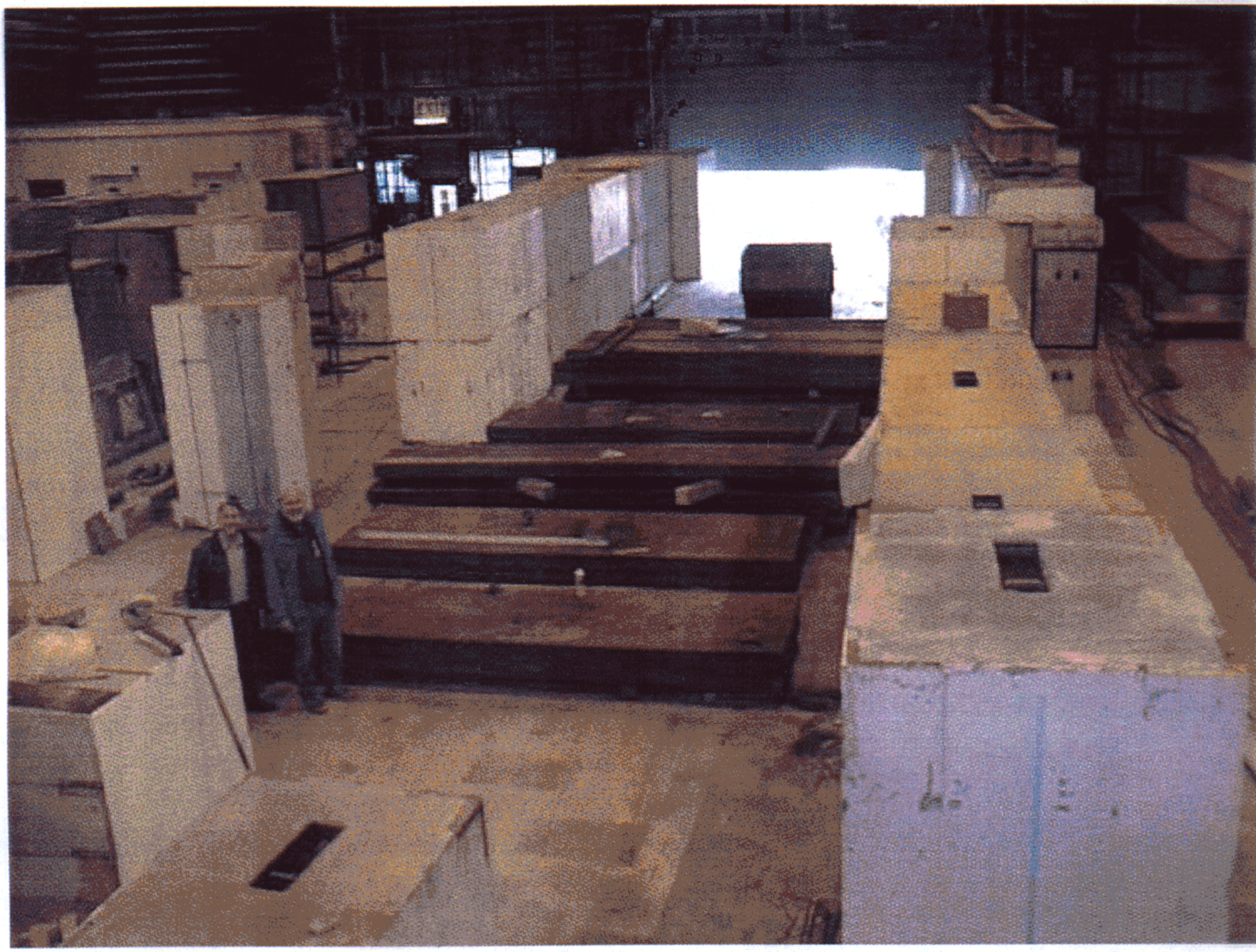
Penetration

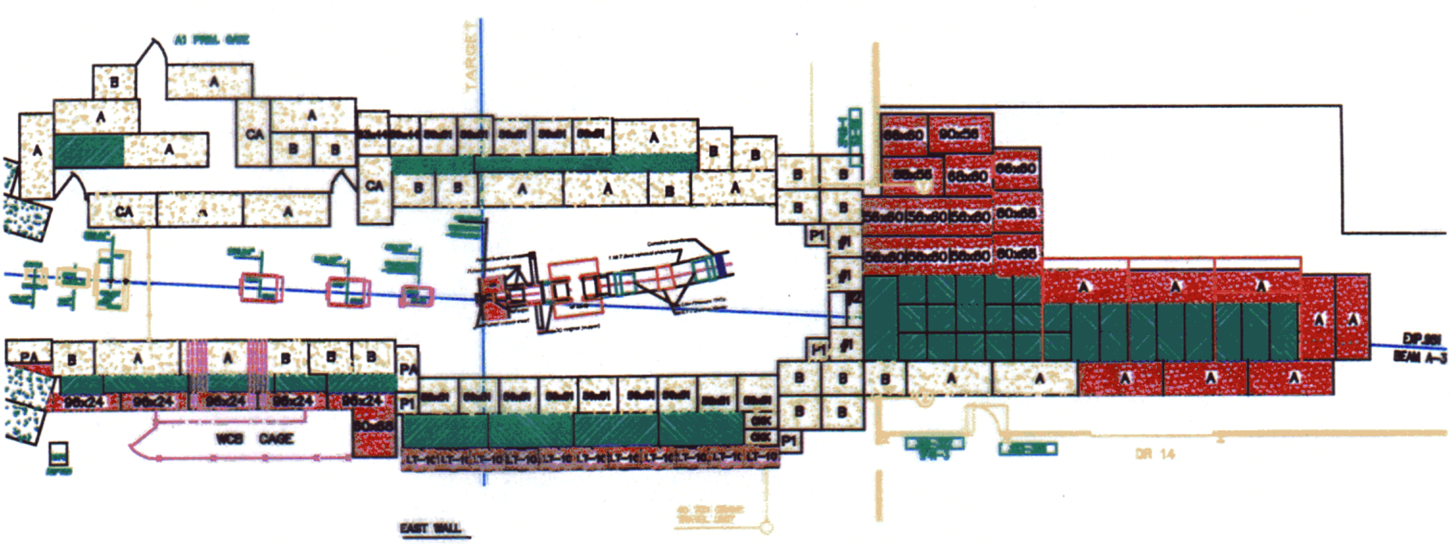
The Experiment

- **Constraints:**
  - Minimum material $\Longrightarrow$ tracking not possible
  - Beam origin well-defined $\Longrightarrow$ collimation system
  - Good background rejection $\Longrightarrow$ tof system



Construction in the A3 Beamline





E951 Schedule

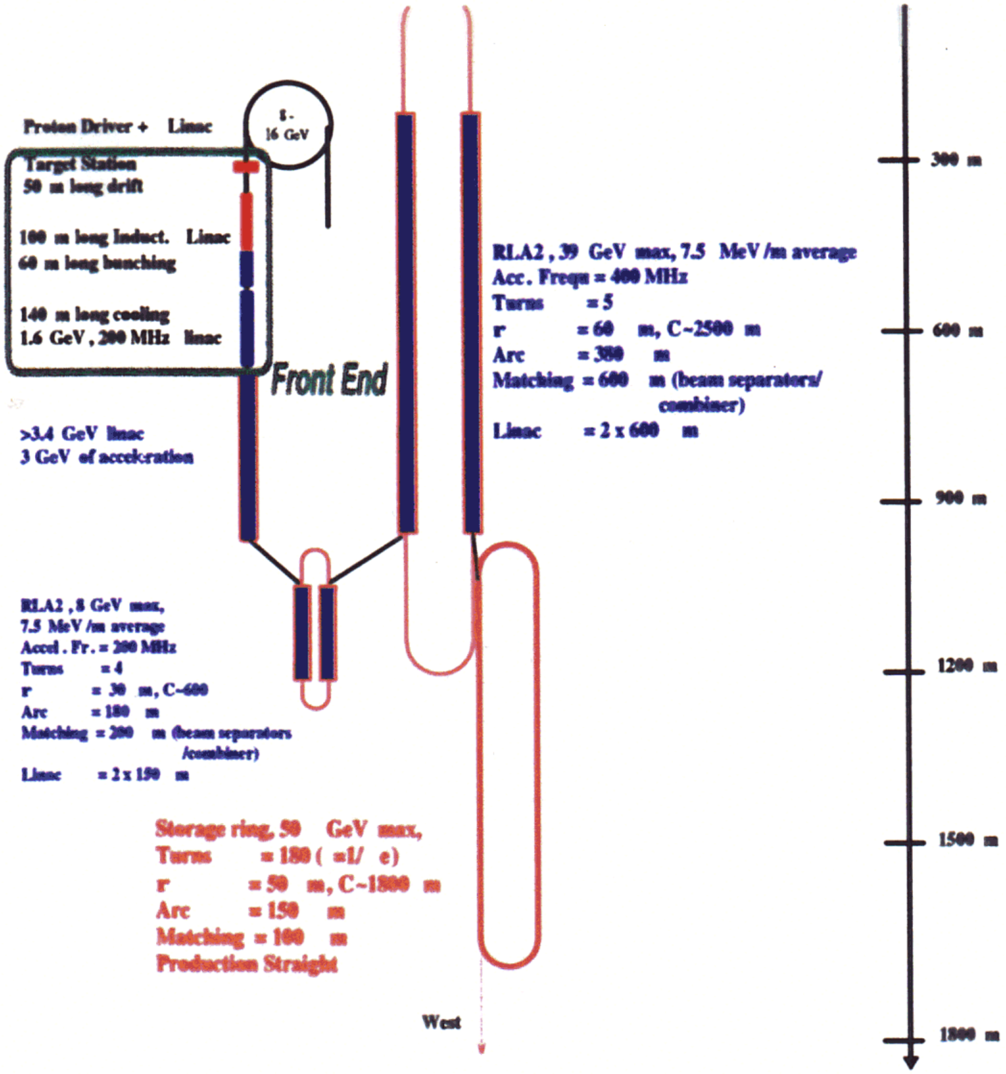
- FY99:
  Prepare A3 area at the AGS (Step 1);
  Begin work on liquid jets, magnet and rf systems (Steps 2, 4-6).

- FY00:
  Complete A3 line (Step 1);
  Continue work on jet, magnet and rf systems (Steps 2, 4-6);
  Begin work on AGS extraction upgrade (Step 3).

- FY01:
  First test of targets in A3 (Step 1);
  Liquid jet test in 20-T magnet at NHMFL (Step 2);
  Continue work on extraction, magnet, and rf systems (Steps 3-6).

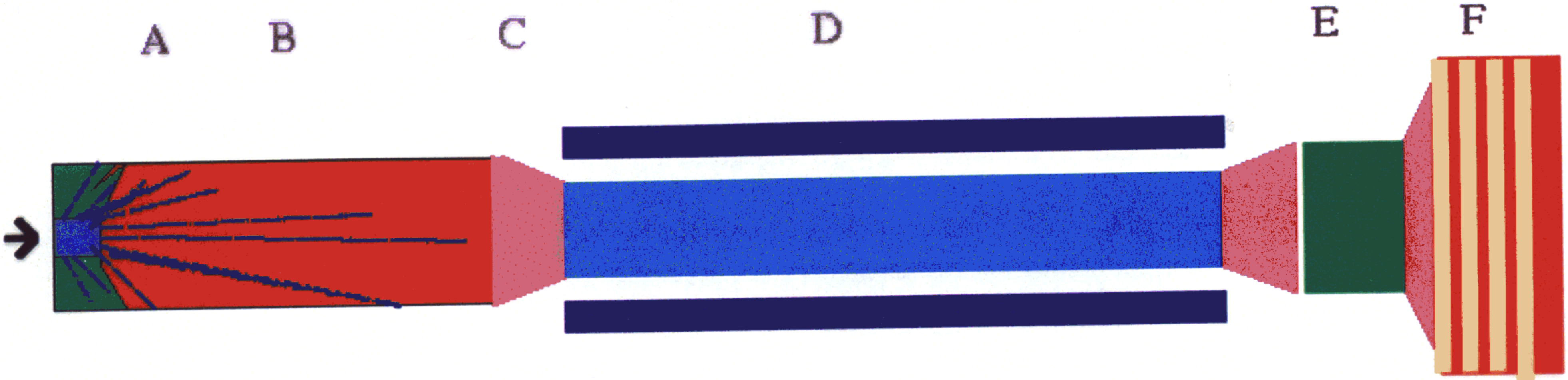
- FY02:
  Complete extraction upgrade, magnet, and rf systems (Steps 3-6);
  Test targets with 10^{14} *ppp* (Step 3);
  Begin work on pion yield diagnostics (Step 7);
  Option to study mercury dump in vertically pitched beam (Step 3.5).

- FY03:
  Beams tests of target + 20-T pulsed magnet + rf cavity (Steps 4.6);
  Complete pion detectors; test yield with low intensity SEB (Step 7).



Basic Calculation: with 1/3 of μ's decay in the straight, 2×10^7 sec/year, and 2×10^{13} POT per pulse at 15Hz

$\Rightarrow$ **need** $2 \times 10^{12} \mu$ per pulse to be delievered to the acceleration ($0.1\mu/p$), to acheive the 10^{20} ν's per year objective.



(Lengths of Sections are Not to Scale)

Schematic Overview: π –> μ production, capture, and bunching

A. Proton Beam (16 GeV, 4 bunches)

Target Station (Carbon target)

B. Drift: π –> μ decay region (L = 47 m, B = 1.25 T)

C. Matching Section (L = 1 m)

D. Induction Linac (L = 100 m, B = 3 T, -0.5 < V' < 1.5 MV/m)

Matching Section (L = 1m)

E. Minicooling (Liquid Hydrogen, L = 2.45 m, B = 5 T)

Matching Section (L = 1m)

F. Buncher (L = 16.432 m, B = 5 T, includes 3x2m RF accelerating cells)

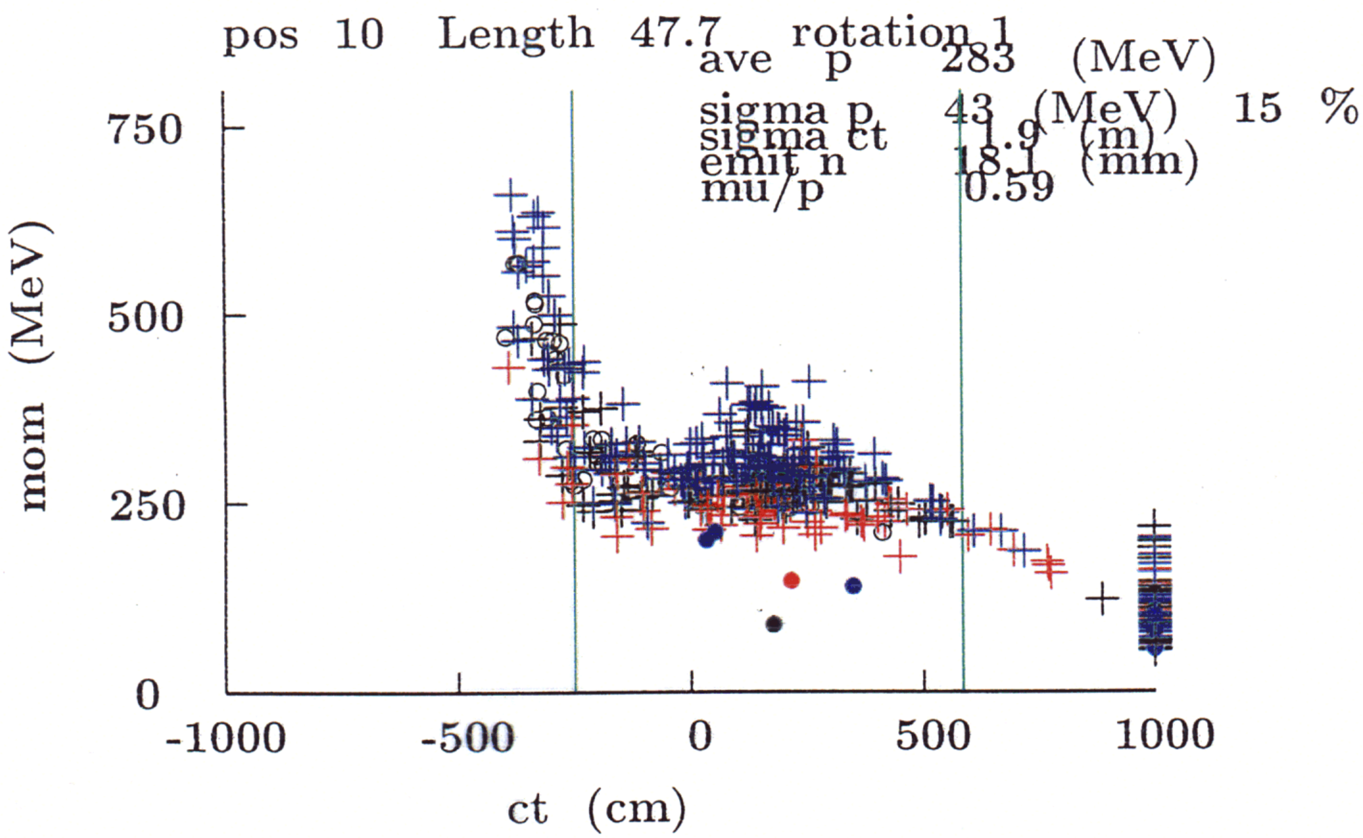
Phase Rotation 1

length m	frequency MHz	Gradient MeV/m
12	40	5
30	30	5
5	45	6

cf CERN 2 MeV/m

Non Distorting

Designed to match 20 MHz Cooling

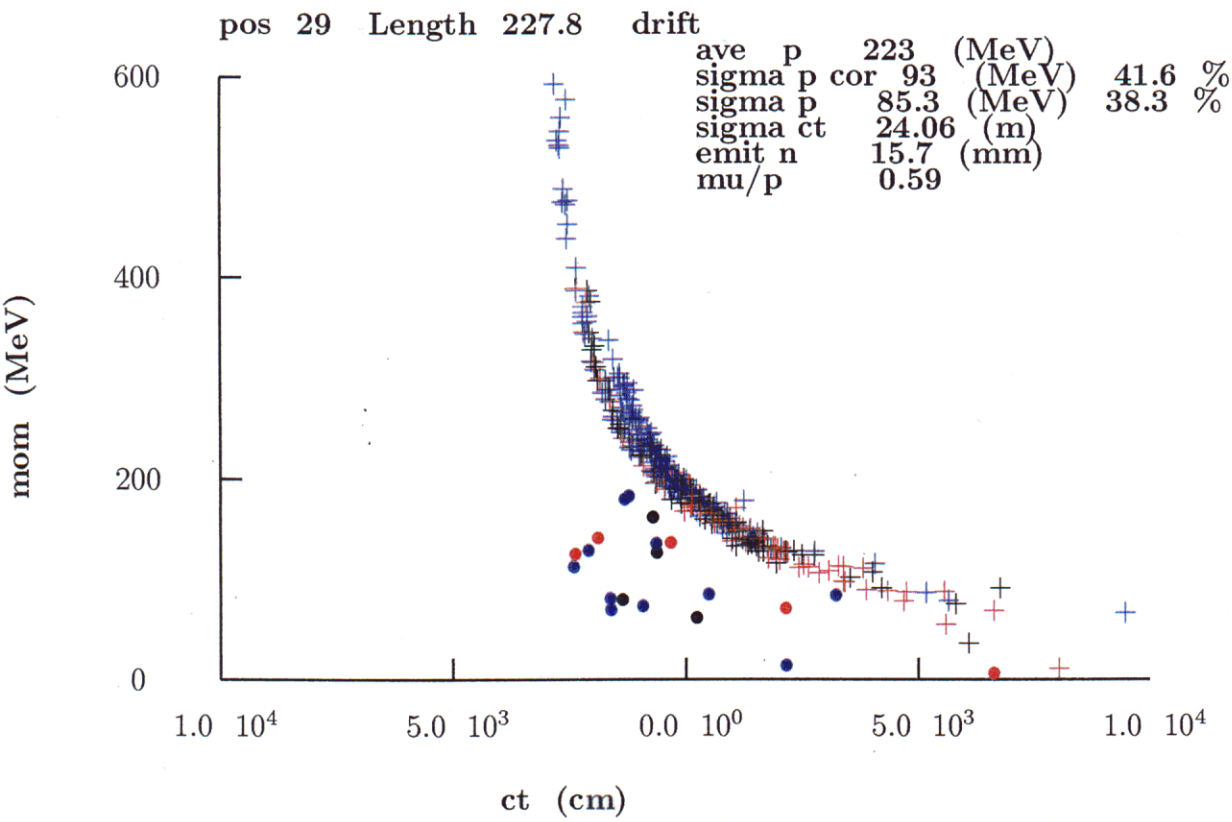


Phase Rotation 2

length	frequency	Gradient
m	MHz	MeV/m
140	2.2	+/- 0.57

cf Study I
used +/- 1.0

Distorting



after Drift (150m)

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

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

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Final remarks

1. Can FFAG's match the various constraints on:
    - acceptances
    - isochronicity
    - chromaticity ?

2. How many muons can be stored?

3. If answers to 1. and 2. are satisfactory, then the various manipulations needed in the front end of a ν-factory may be implemented with their technology and diagnostics in a rather economic way.

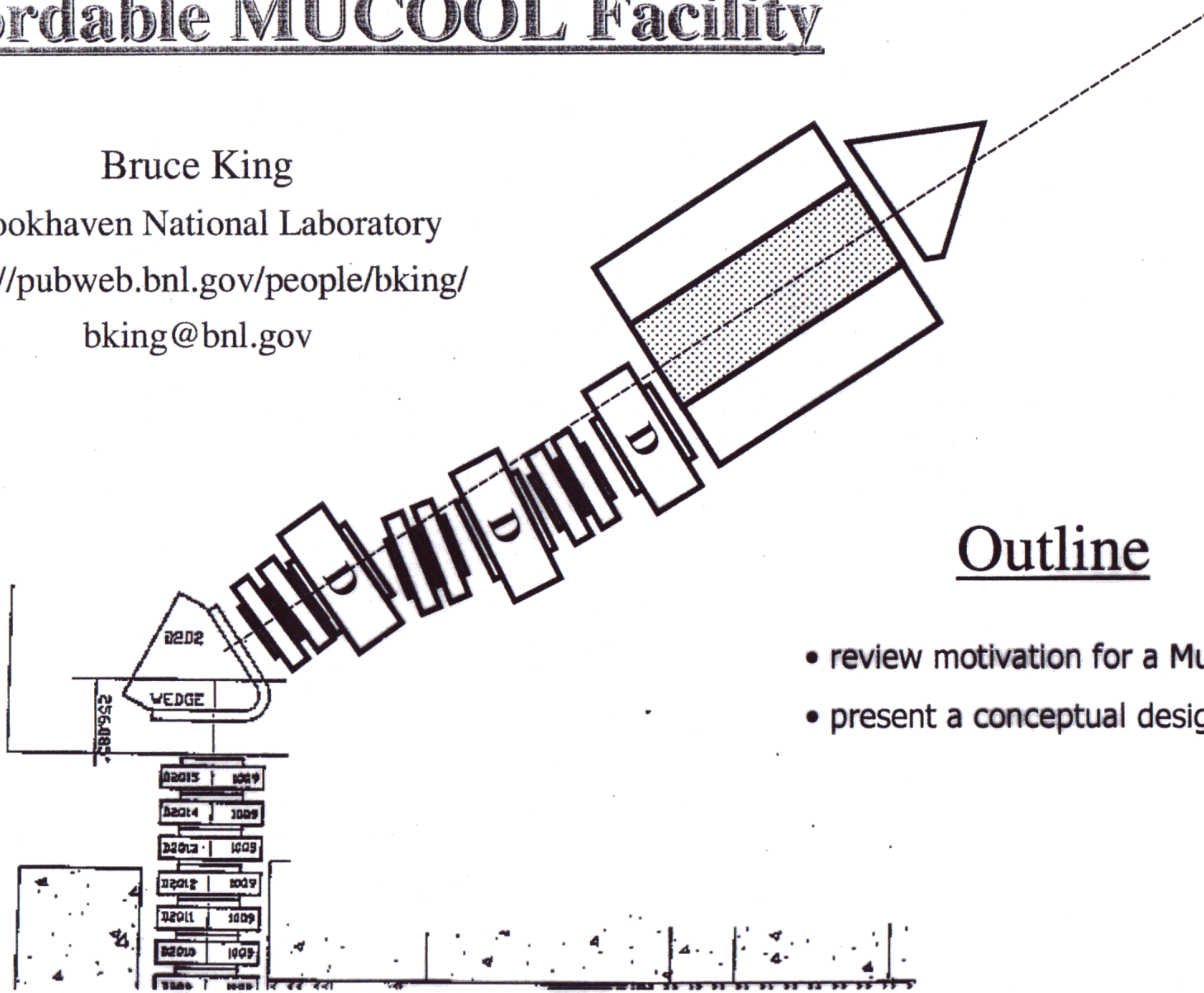
A Possible Option for a Flexible and Affordable MUCOOL Facility

Bruce King

Brookhaven National Laboratory

http://pubweb.bnl.gov/people/bking/

bking@bnl.gov

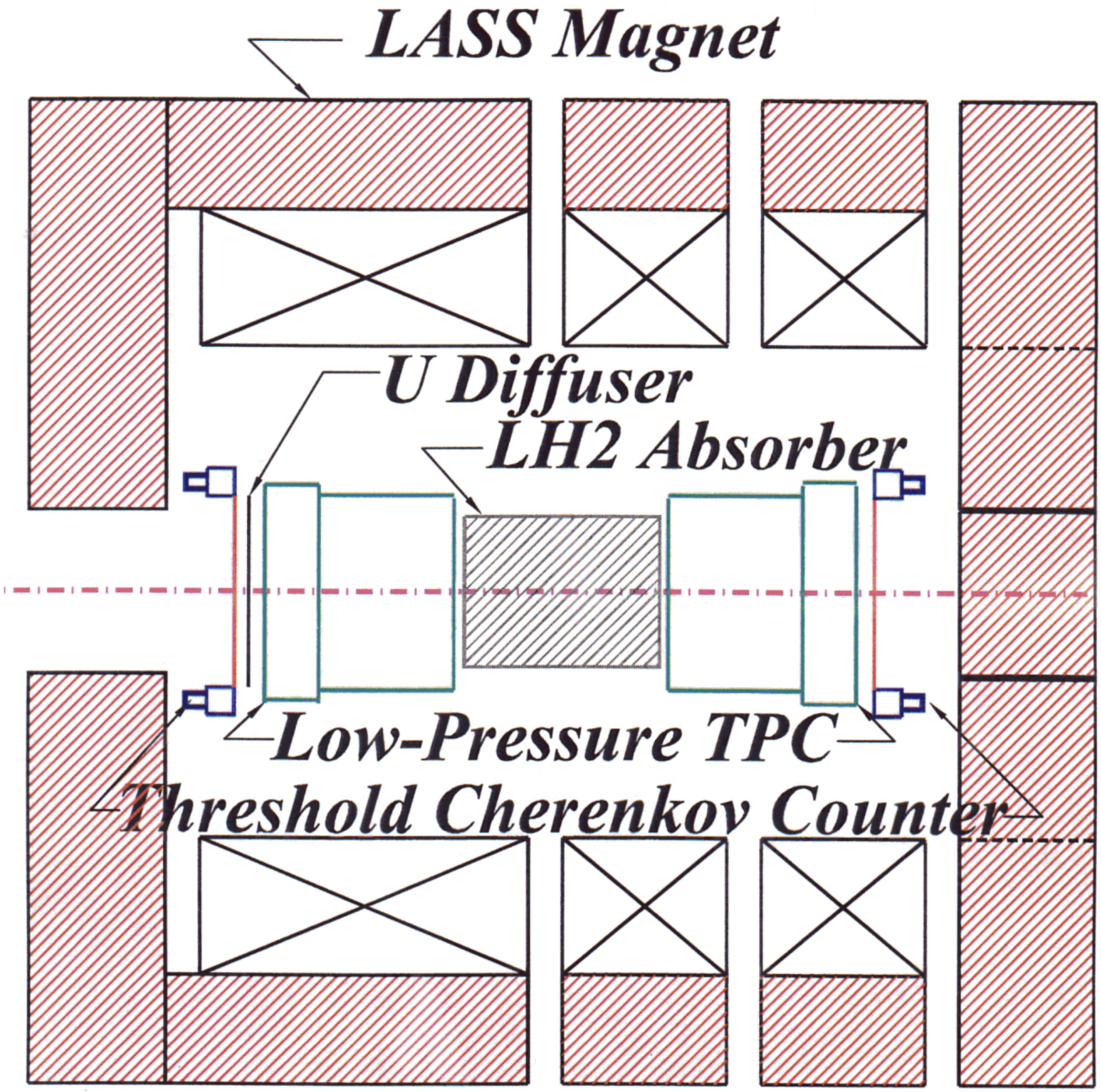


Outline

- review motivation for a MuCOOL facility
- present a conceptual design scenario

Acknowledgments: thanks to Al Pendzick, Charlie Pearson and Steve Peggs for engineering guidance.

An Initial Ionization Cooling Demonstration



K.T. McDonald

Princeton University

May, 2000

http://puhep1.princeton.edu/mumu/cool1.ps

- **P.G. Simplify by leaving out the magnetic complications but keep cavity and absorber.
- **J.N. Make a well bunched muon test beam at quite low energy to make cooling apparatus to be tested less expensive.

PRODUCTION & RADIATION CALCULATIONS - HANDLING

- **N.M. MARS studies of all facets of production and consequences of very high power beams on target.
- **S.C. Target facility massive but similar to SNS

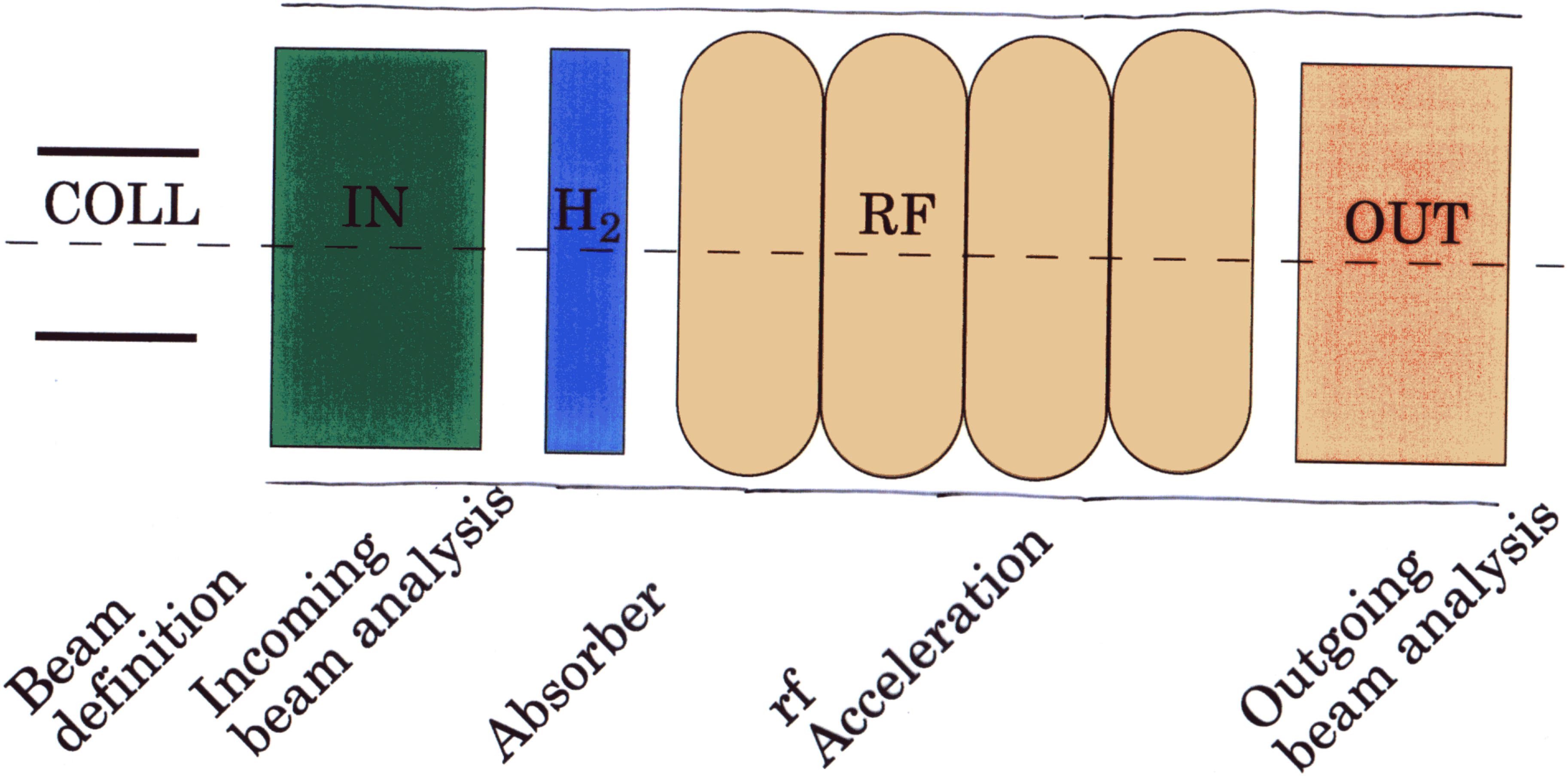
PEAK CURRENT EXPERIMENTS IN EXISTING p MACHINES

- High charge and short bunches ~ 1ns desired. Brighter than existing machines. Prospects for NuFac requirements seem good. MuMu will be yet tougher.
- **W.C. Surveyed field – progress is steady
- **R.C. Discussed CERN measurements – more to follow

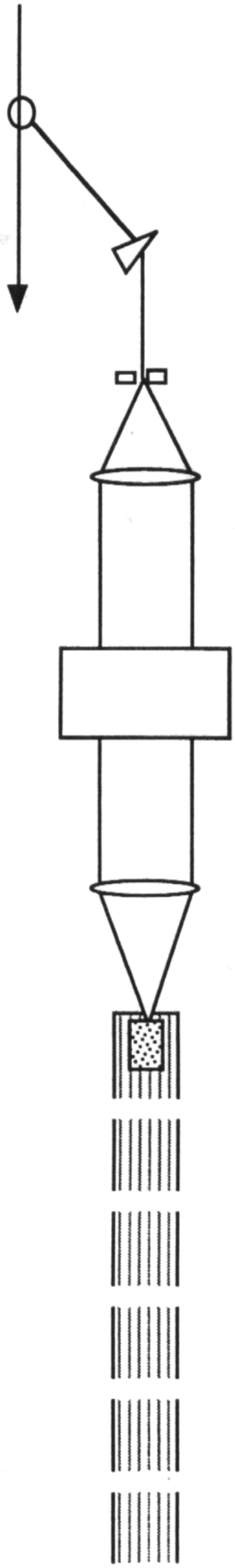
SOLENOIDS

- New technology for accelerators – many tricks for us yet to learn. At the moment they are cost drivers – some ideas for improvement
- **N.H. Cooling channel must rely on large, high U solenoids.
- **J.M. 20T bitter+SC solenoid for targeting is doable

Cooling experiment setup



A High Power Bunched Beam Cooling Facility



FNAL Booster Proton line $3 \cdot 10^{12}$/pulse
83 bunches, $4 \cdot 10^{10}$/bunch $\underline{\sigma = 0.2 \text{ ns}}$

Magnetic analysis for ~400 MeV/c
eliminates high energy backgrounds
cleans up longitudinal phase space

Pion decay line, FODO
Length ~ 50 - 80 m

RF system, modest rf maintains bunch
Total voltage ~ $2\sigma_E$,

Degrades momentum to 120 - 180 MeV/c
Mult. Scat. θ ~ 0.1
Filters pions at $\Delta(1232)$

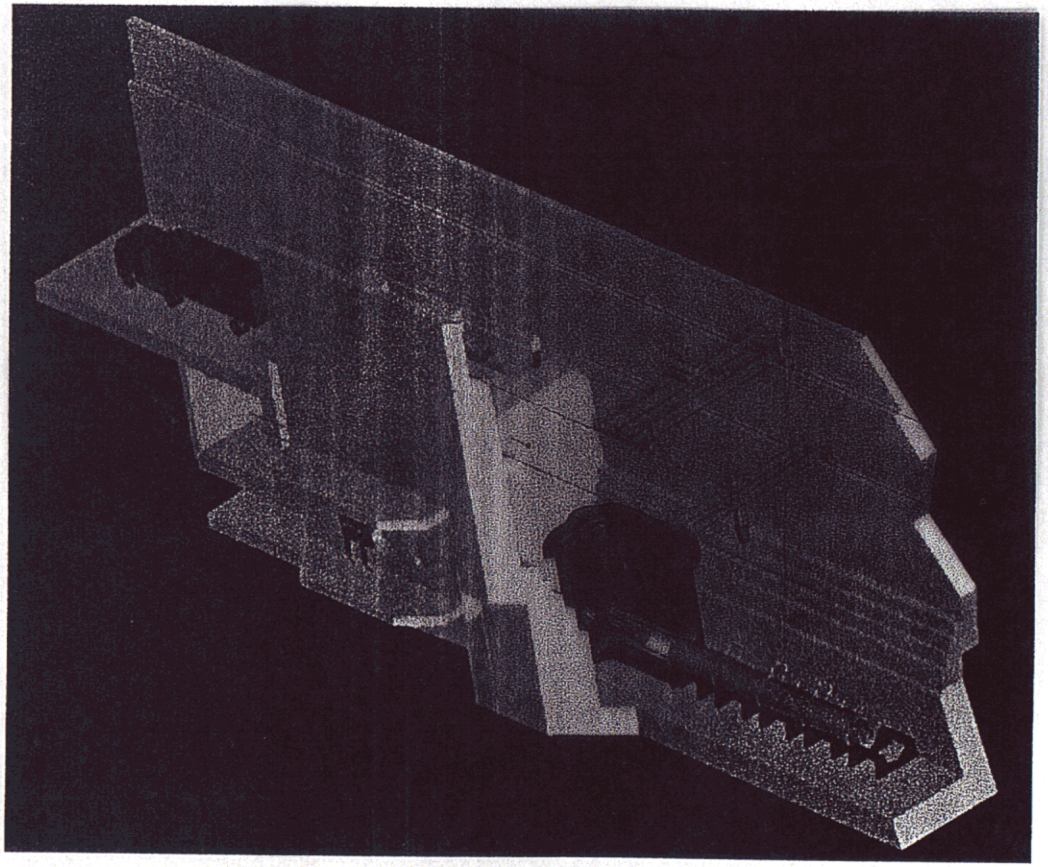
Test Section: FOFO, SOSO etc
Experiments at reduced momentum are
less expensive and more sensitive.

805 MHz ?

Diagnostics: SEMS and Faraday cups

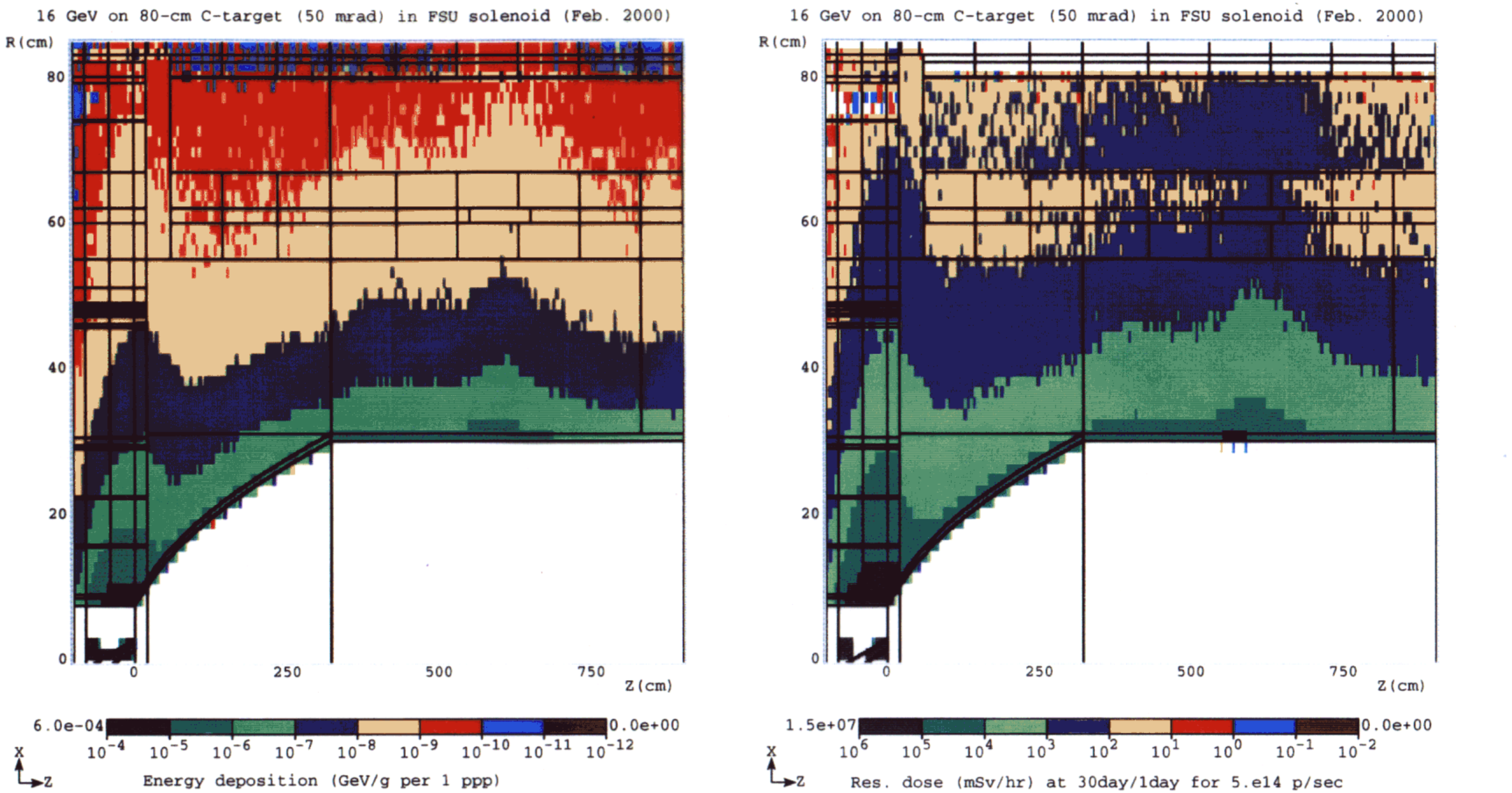
A Conceptual Design for a Support Facility Was Developed for the Fermilab Study

- Graphite target
- Hybrid solenoid system *(National High Magnetic Field Laboratory)*
- Decay channel
- Nuclear shielding
- Radiation handling



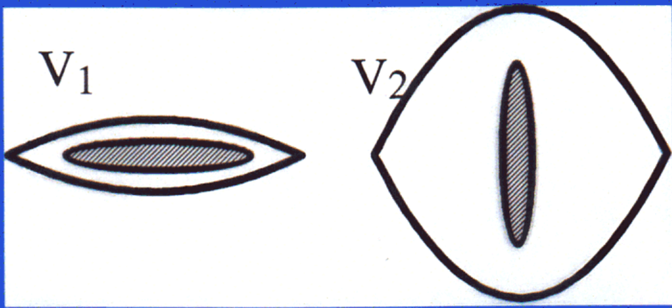
$D(\mathrm{Gy/yr}) = 1.8 \cdot 10^{15} \cdot \mathcal{E}\left(\frac{\mathrm{GeV}}{g \cdot 1\,\mathrm{ppp}}\right)$ @ 1.5 MW

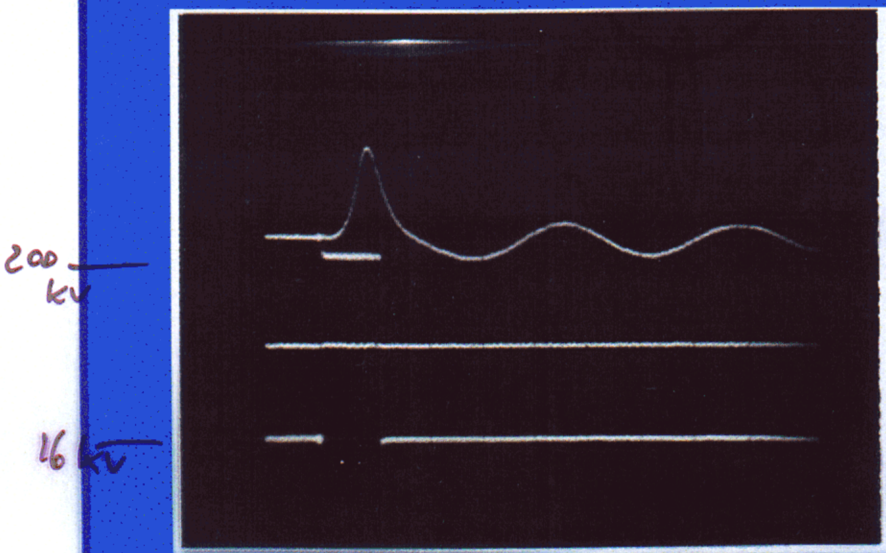
ENERGY DEPOSITION AND RESIDUAL DOSE



Energy deposition in GeV/g per 1 ppp (left) and residual dose rate after 30 day irradiation and 1 day cooling at 5×10^{14} p/sec (right)

Bunch compression experiment





200μs/div

Single bunch

T=1 GeV, V_{RF}=16→200kV, h=8, N_b=2 10^{12}p/b

T_s=1270→400μs

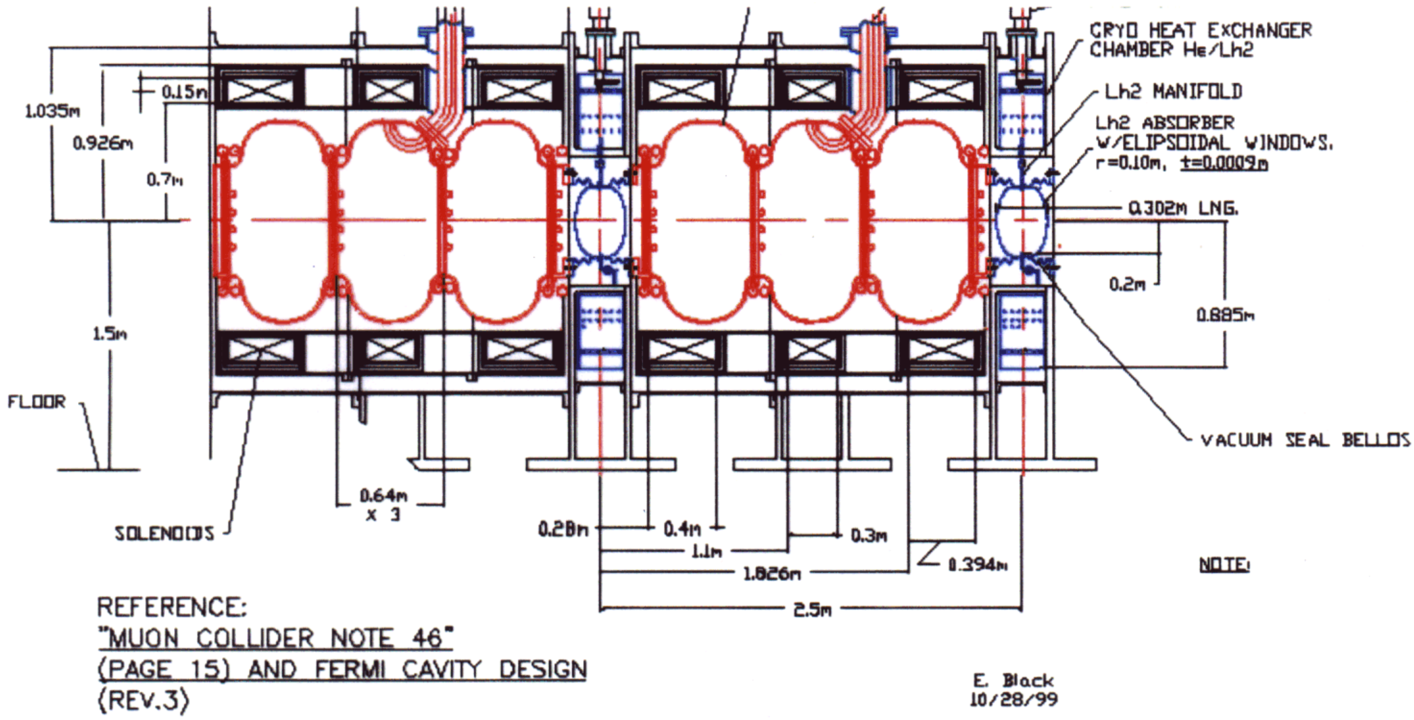
bunch compression ~$(V_2/V_1)^{1/2}$ ~3.5

The Cooling Cell used for the Engineering Approach

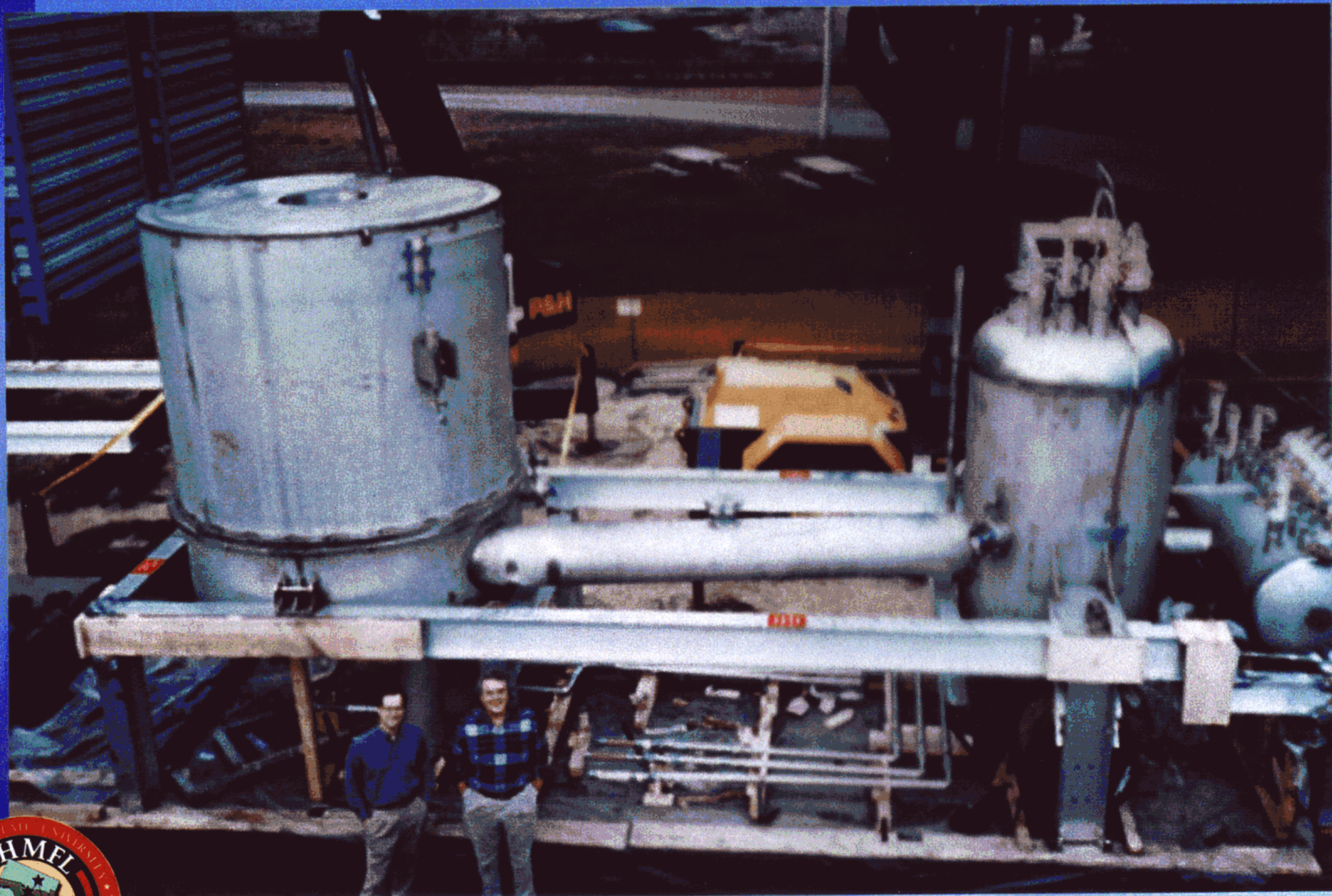
- Had to pick an example for the engineers
- 1.1 m cell length with 2.2 meter periodicity

B_z ~ 3.6-5.5 T max (flip), 7 T max (straight)

E_{acc} ~ 15 MV/m @ 200 MHz



Outsert cryostat delivered to NHMFL, March 1995



LIQUID HYDROGEN ABSORBER TECHNOLOGY

- **D.K. Heat deposition from ionization and need for thin windows a challenge – considerable progress in design continues.

INDUCTION LINAC + PULSED MAGNETS

- **S.Y. modules similar to past examples. Rapid pulsing particular.

- **Y.S. IGBT switch for 1 kHz, high power kicker

RF TECHNOLOGY (J. Corlett,Y. Iwashita, K. Koba, H. Padamsee, Y. Zhao)

- Wide variety of developments from 5 MHz to 805MHz, high gradient, NC to 200 MHz and up SC. All push capabilities in gradient (and power) w.r.t. current technology. Main line for NuFac cooling now seems to be 200MHz, NC

TARGET THEORY

- P.S. offered some results on stress introduced by fast heat deposition of heat in solids and liquids

HIGH ENERGY BEAM COOLING

- **F.DeJ. – discussed possibility of cooling TeV beams by back scattering high power laser light from the beam, reducing its energy and transverse geometrical emittance upon reacceleration.- difficult.

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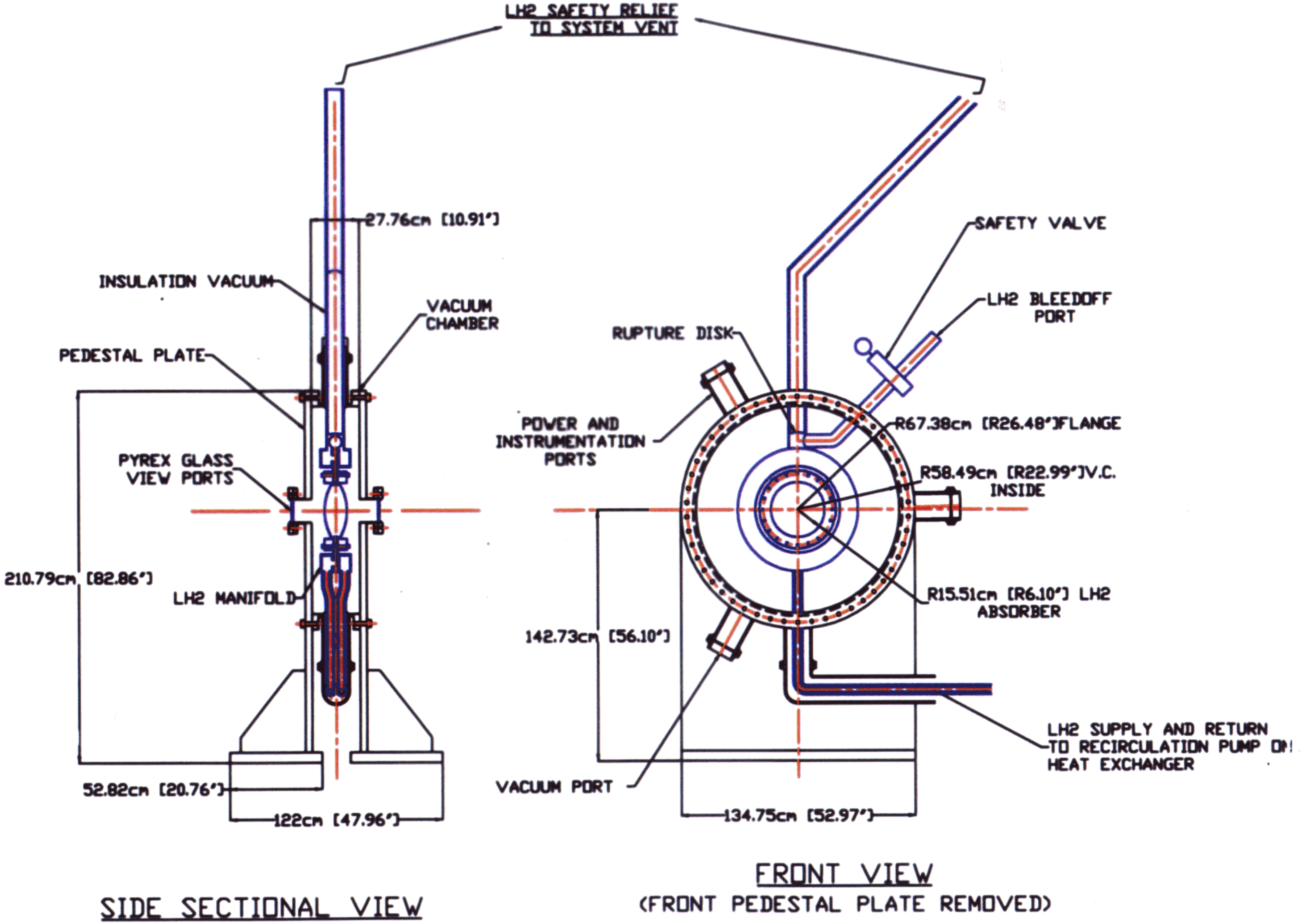
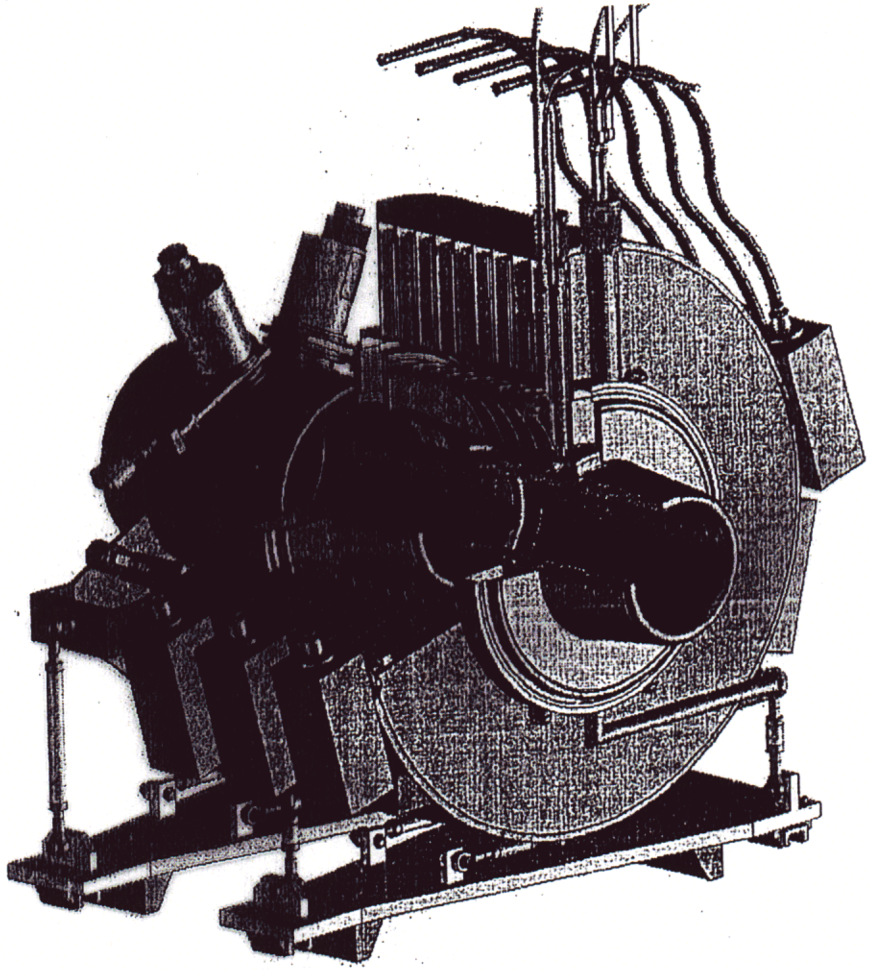


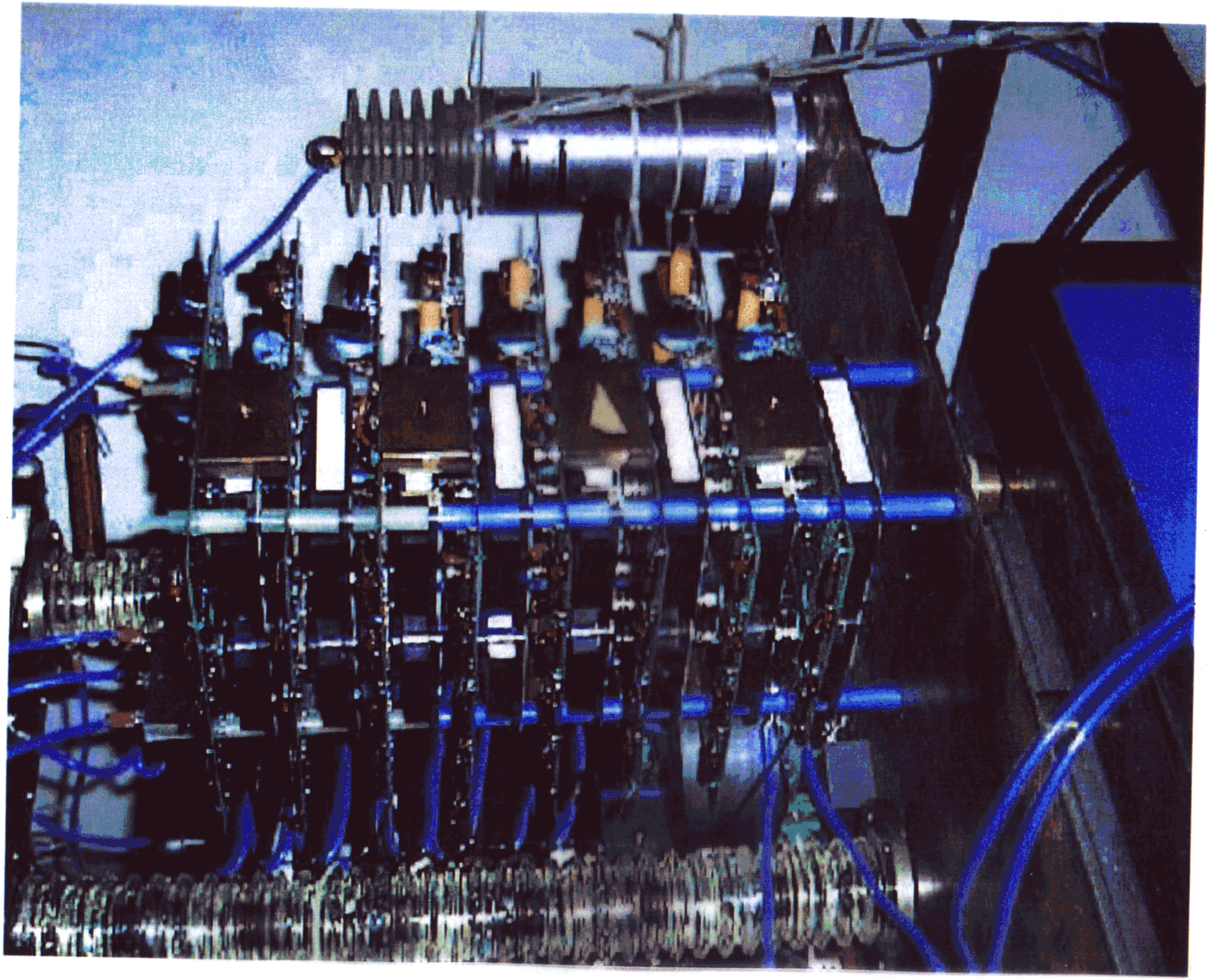
E. Black
IIT/FNAL
5/8/2000

TEST STAND FOR THE FOFO ABSORBER

Prototype Module Cell

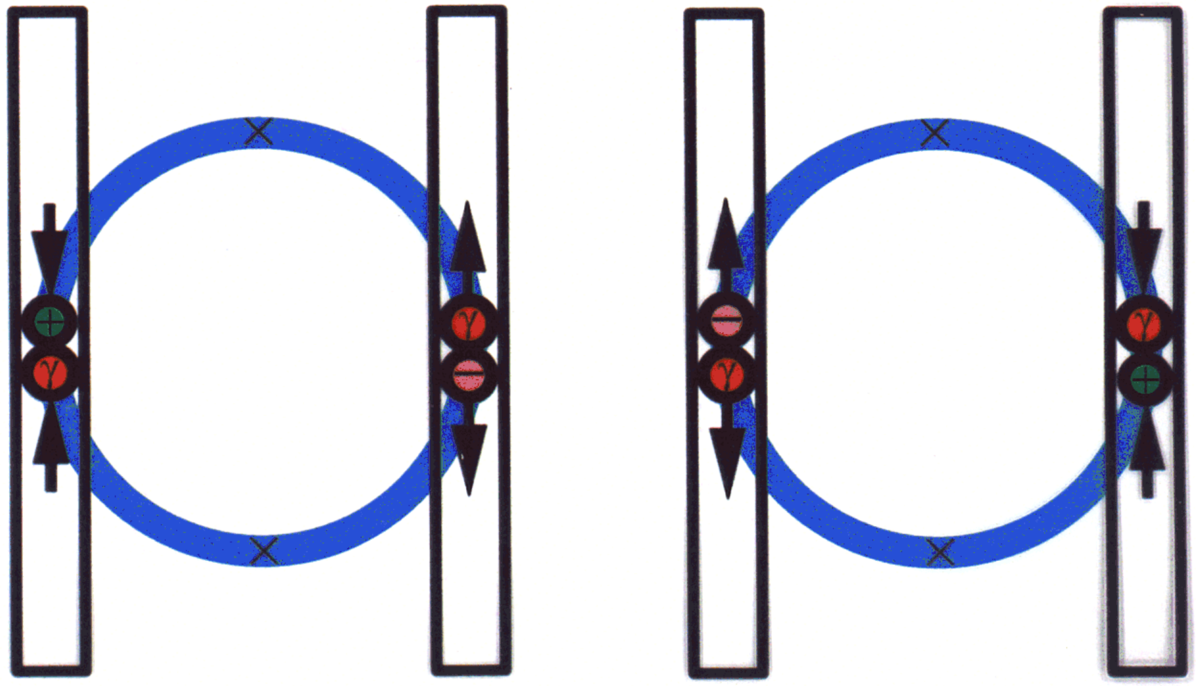
Consists of
- 1 m Induction cell
- Single Superconducting Solenoid Magnet





Use with 1.5 TeV/beam Storage Ring

Assume 4 bunches → 1 bunch



Parameters from status report:

- circumference = 6 km
- $\beta^* = 3$ mm
- $\sigma_z = 3$ mm
- $\sigma_r = 3.2\ \mu$m
- $\sigma_\theta = 1.1$ mrad
- $L = 7 \times 10^{-34}$ / cm² sec

$$L \propto \frac{N_+ N_-}{\beta^* (\varepsilon_+ + \varepsilon_-)}$$

CONCLUSIONS

- Lots of good ideas but need more
- Outstanding missing item(s) : muon test beams available for NuFac development.
- Task of NuFac design and cost control unusual in its ***novelty*** both in quality and quantity.
- Real world collaboration in its realization thus seems imperative.