The Advanced Hydrotest Facility Overview

Arch Thiessen

LANSCE-AHF

Accelerator Team Leader

Presentation for Snowmass Meeting

July 11, 2001

The AHF Facility Team

(Incomplete List)

- Los Alamos
  - Dave Barlow, Barbara Blind, Dave Bowman, Pat Colestock, Louis Guillebaud, Debbie Horne, Andy Jason, Pat Kelley,Tony Ladino, John Lyles, Filippo Neri, Milan Njegomir, Mark Parsons, Larry Rybarcyk, Lorraine Sanford, Nan Sauer, Arch Thiessen, Pete Walstrom, Tai-Sen Wang, Joe Waynert
- Livermore
  - Ed Cook, Jeff Paisner, John Pastrnak, Dennis Slaughter
- Indiana University
  - Dennis Friesel, Peter Schwandt
- SAIC
  - Roy Little, Ben Prichard
- General Atomics
  - Martin Schulze
- MIT Plasma Fusion Lab
  - Joel Schulz
- BNL
  - Mike Harrison, Peter Wanderer
- Holmes, Narver, Raytheon
  - New AE team

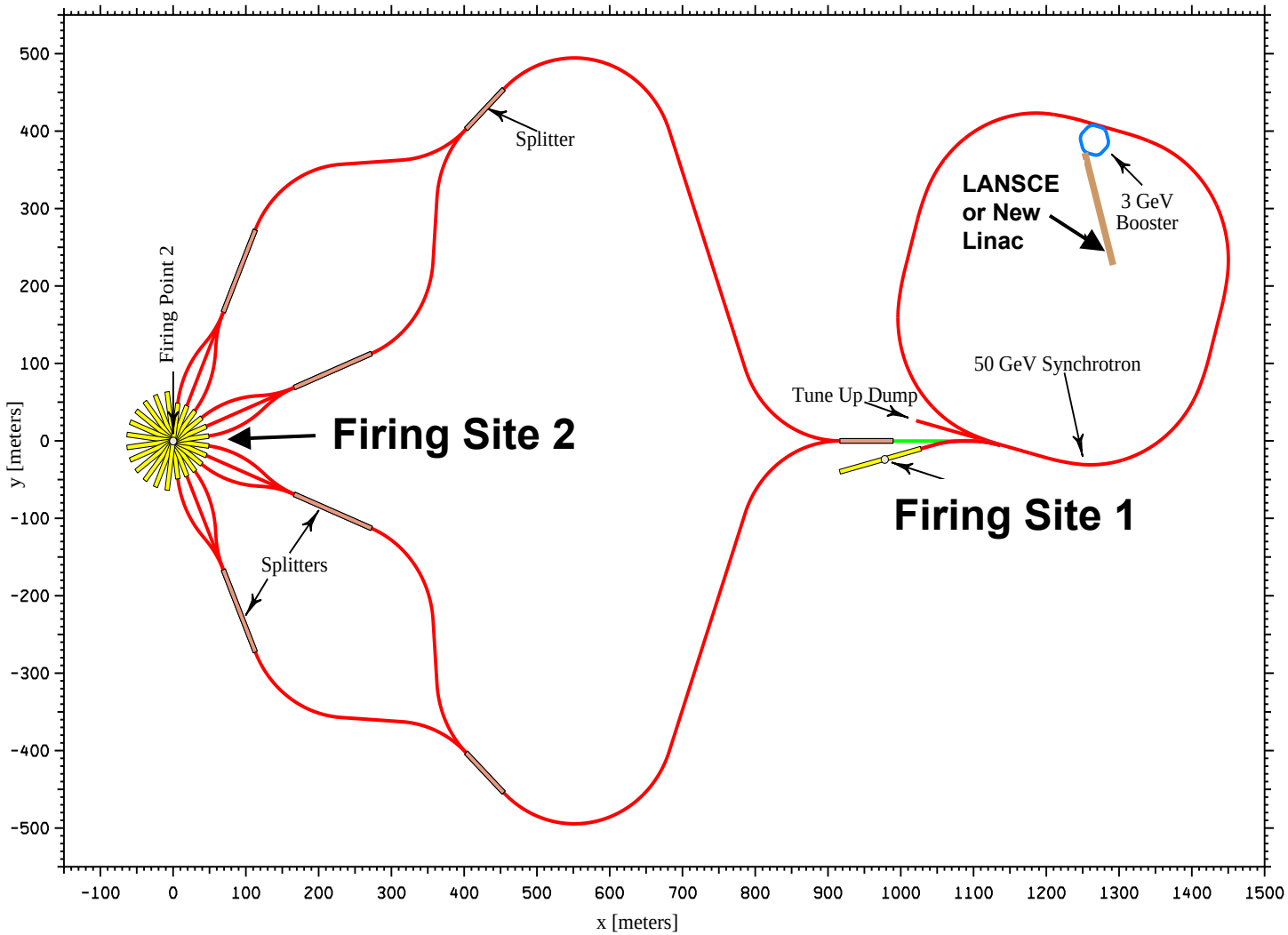
Outline

- Site Independent Facility Concept
- The Inventions That Make Proton Radiography Possible
- Why DOE Wants AHF
- AHF Design Goals and Requirements
- 140 MeV Linac
- 4 GeV Booster
- 50 GeV Main Ring
- Superconducting Lenses
- AHF Containment/Confinement
- AHF ED&D Plan
- Summary and Conclusions

New Topic

- Site Independent Facility Concept

AHF Facility Concept FY-2001: A Site-Independent Production Facility

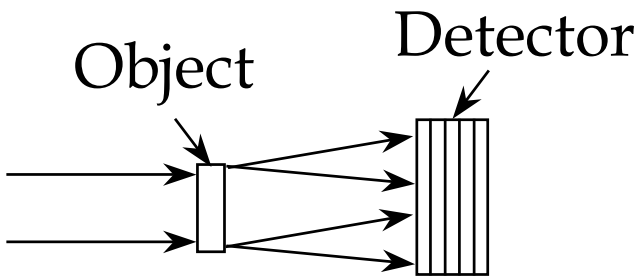


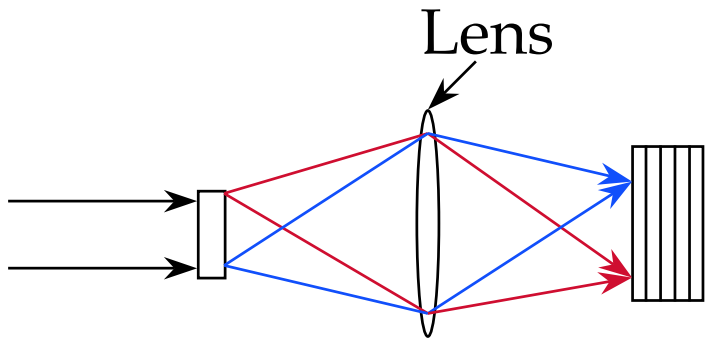
New Topic

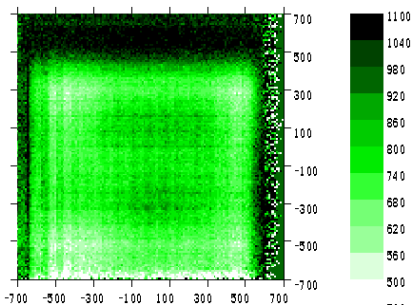
- Inventions that make Proton Radiography Possible

Invention #1: Use Magnetic Lens (C. Morris FY-95)

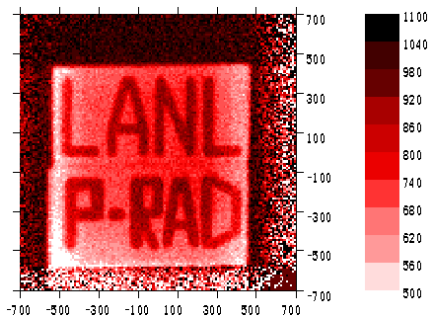
demo with 188 MeV protons



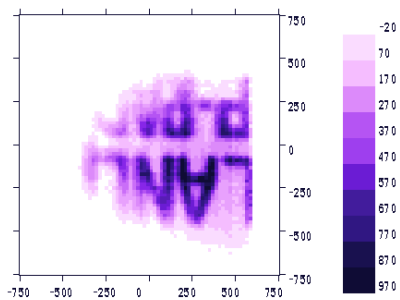




At the detector



Projected to the object



After a lens

Invention #2: Beam Matching (Mottershead FY-96)

Cancels Chromatic Aberrations of Lenses

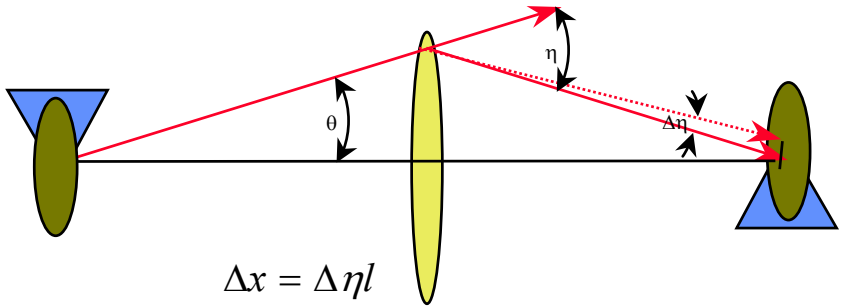
The leading aberations are chromatic :

$$x_{image} = x_{object} + (x \mid \theta\delta)\theta\delta + (x \mid x\delta)x\delta + ☹$$

Setting :

$(x \mid \theta\delta)\theta\delta = -(x \mid x\delta)x\delta$ gives :

$$\theta = \frac{-(x \mid x\delta)}{(x \mid \theta\delta)} x$$



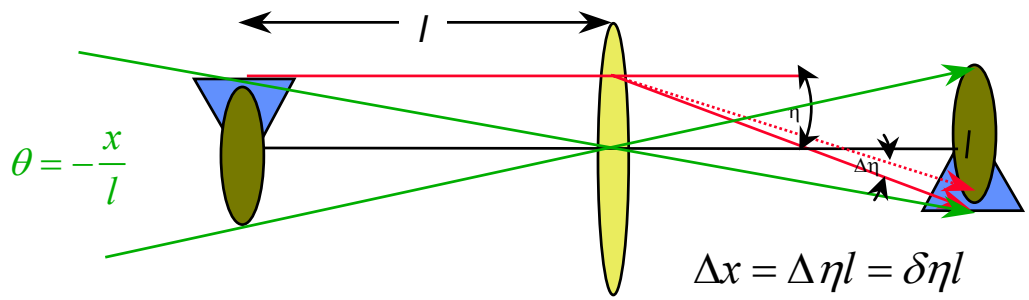
$$\Delta x = \Delta\eta l$$

$$\delta = \frac{p - p_0}{p_0}, \ \eta = 2\theta, \ \Delta\eta = \delta 2\theta, \text{ so}$$

$$\Delta x = \delta 2\theta l$$

$$(x \mid \theta\delta) = 2l$$

- Uniform acceptance
  - analysis simple
- Reduced aberrations
  - Like pin hole camera

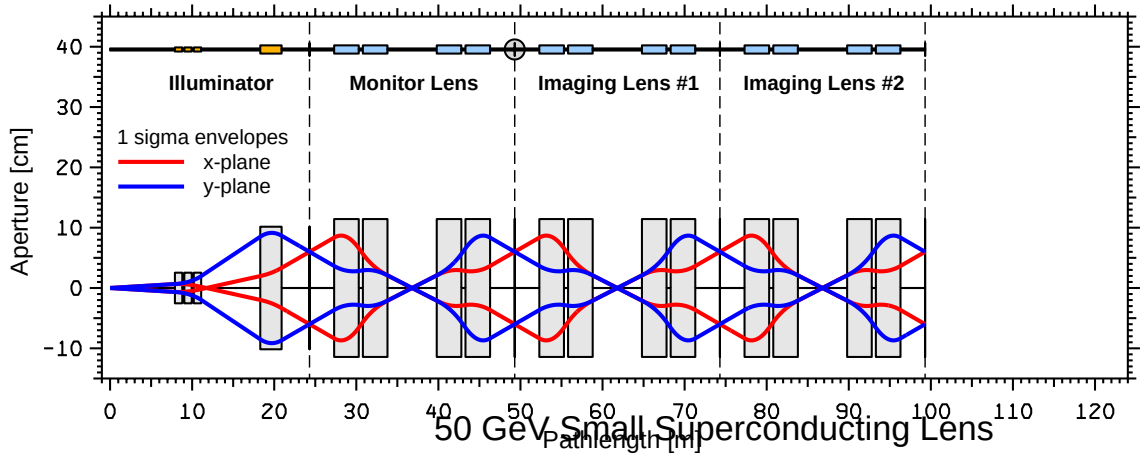


$$\Delta x = \Delta\eta l = \delta\eta l$$

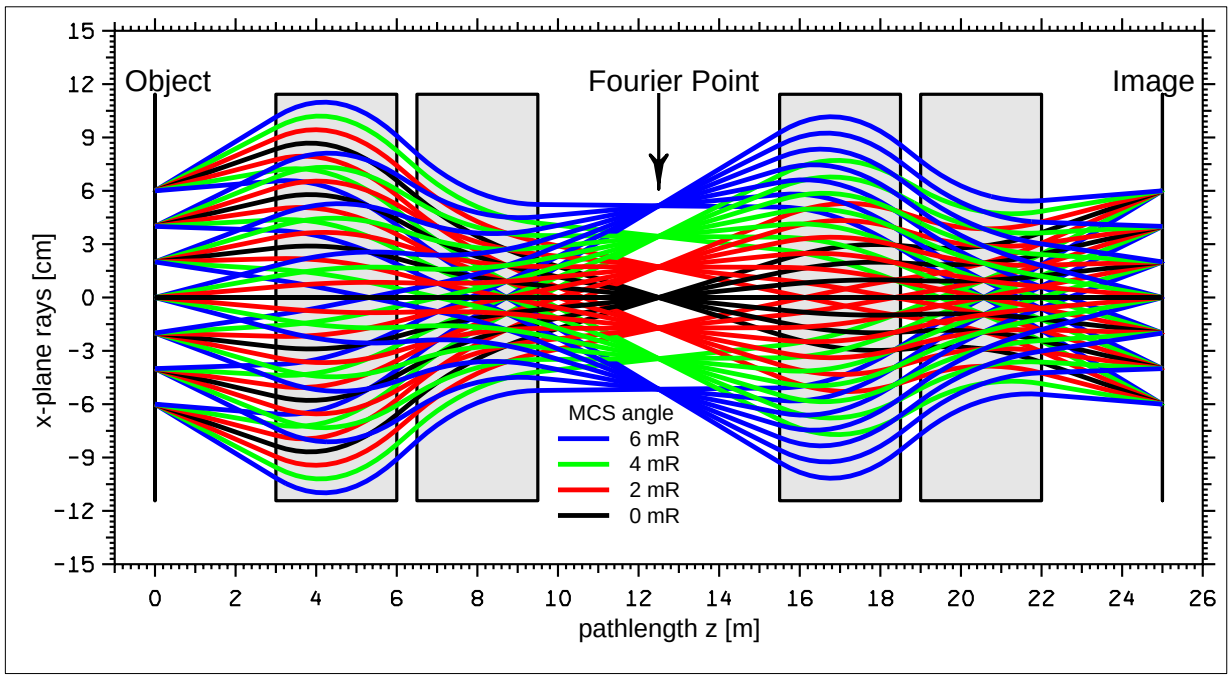
$$\eta = \frac{2x}{l}, \text{ so}$$

$$(x \mid x\delta) = 2$$

The AHF Lens Optics Incorporates Chromatic Corrections, Material Identification, and Monitor Lenses



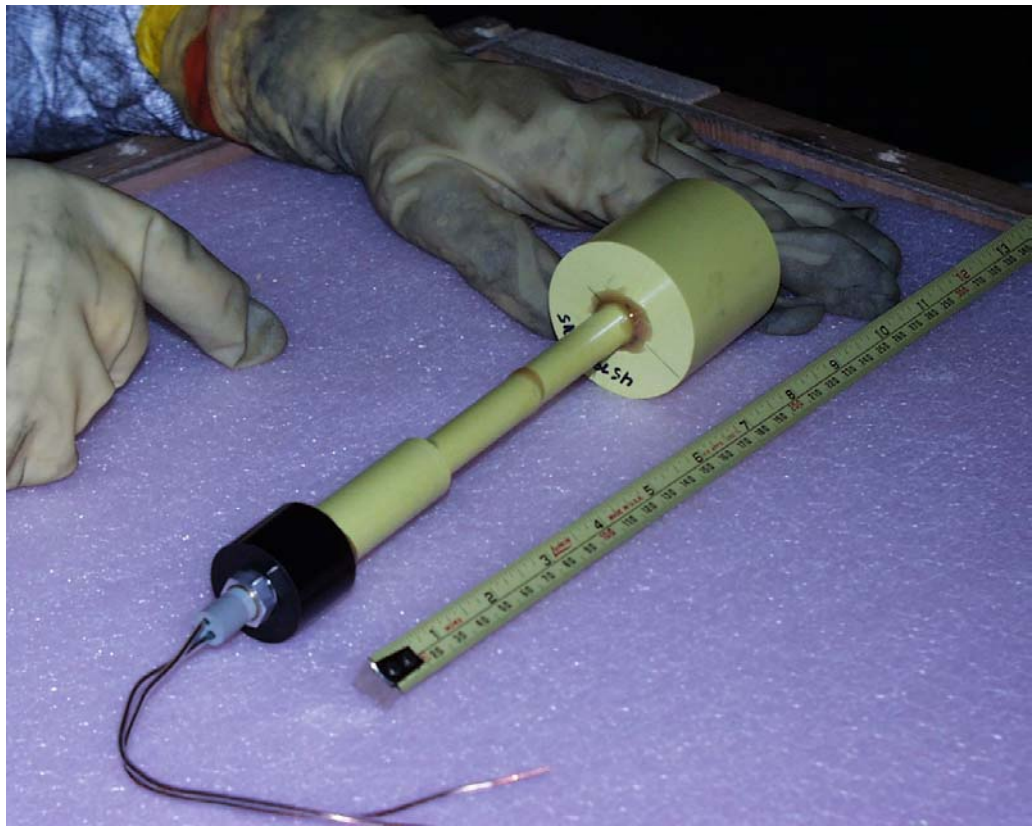
50 GeV Small Superconducting Lens



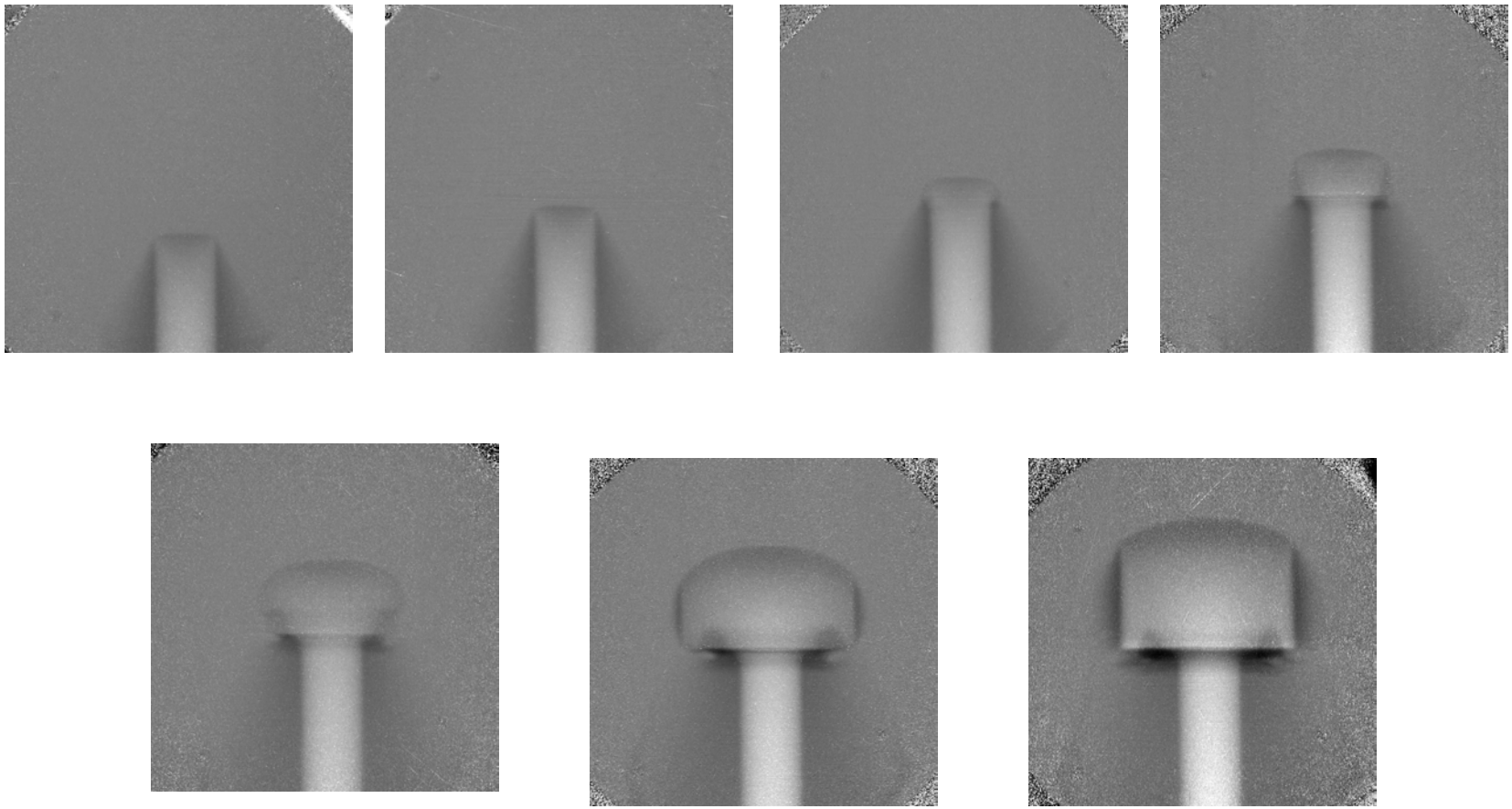
New Topic

- Why DOE Wants AHF

An Explosive Device ("Corner Turner")

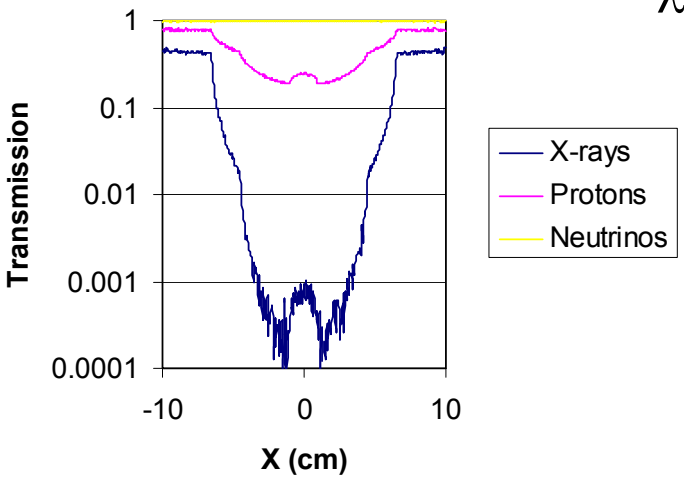


Motion Picture of Explosive Device

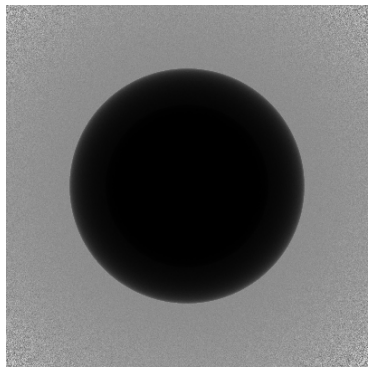


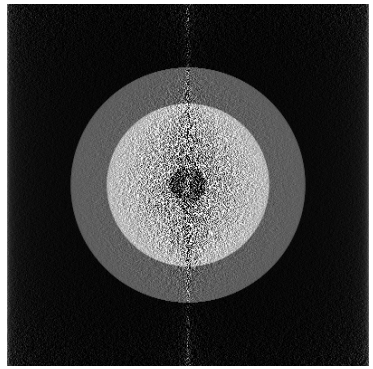
Different probes-1.×10^9 incident particles.

French test object (FTO)

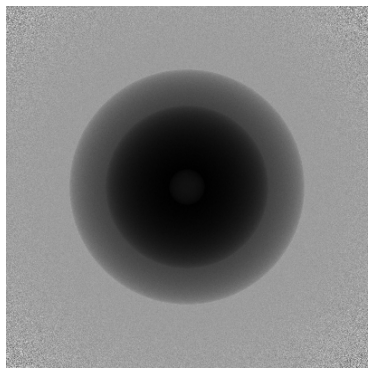


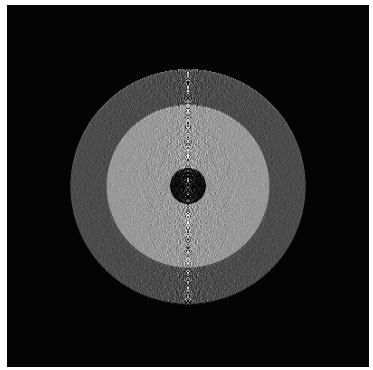
X-rays
λ=25. gm/cm^2



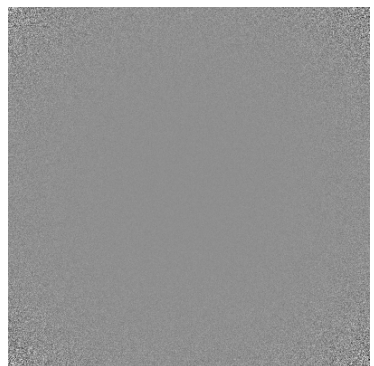


Protons
$\lambda\approx$185. gm/cm^2





Neutrinos
$\lambda=\infty$ gm/cm^2



New Topic

- AHF Design Goals and Requirements

AHF Design Goals and Requirements

- Goal: Quantitative Radiography of a Dynamic Experiment with Plutonium
  - Quantitative – with **intensity precision (1%)** and **resolution (<1mm)**
  - Containment – as required for **safe experiment with Plutonium**
- Use standard accelerator technology on greenfield site
  - No new inventions unless required
- Accelerator Design Requirements
  - **50 GeV Protons**
  - **>10 bunches at 200 ns** spacing, less than 50 ns bunch width
    - » Single-bunch extraction on demand
  - **12 Axes for 3-D** Tomography
  - 1×10^{11} protons per frame per axis
    - » With 12 axes, 20 bunches, 20% loss in beam splitting
      - + **3×10^{13} protons per accelerator cycle**
  - Longitudinal emittance **< a few eV-sec**
    - » No requirement on transverse emittance
  - Low Repetition Rate - **~30 sec per cycle ok**
  - Robust design – allow for future upgrades
- Lens Design Requirements
  - **<0.5 mm fwhm** spatial resolution
  - Field-of-View **12 cm (8 axes), 30 cm (4 Axes)**

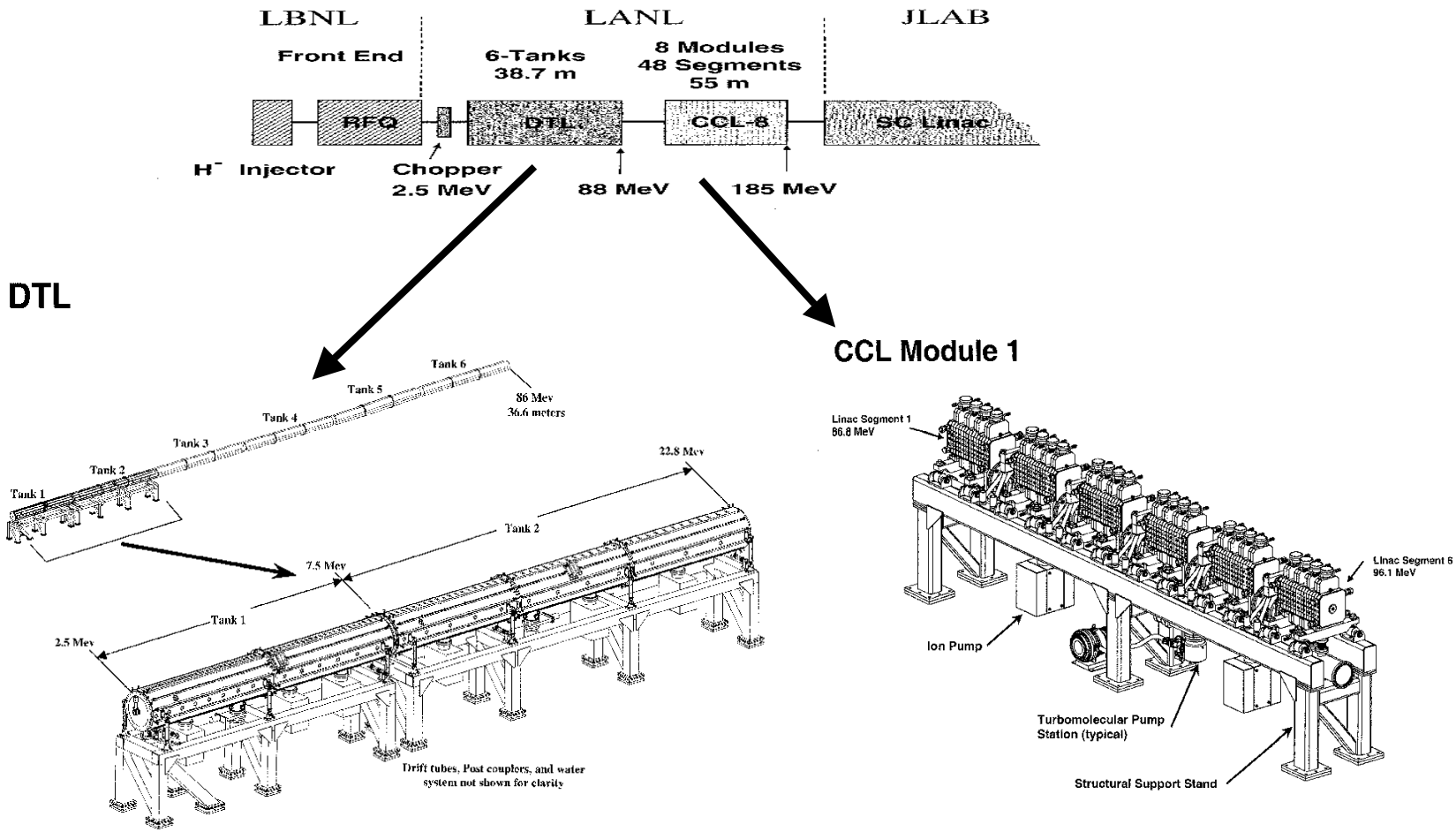
AHF Reference Design Proton Budget

Linac	Booster	Main Ring
140 MeV Linac or LANSCE Linac $2x10^{12}$ protons/pulse (402.5/805 MHz) With Chopper 5 Hz rep. rate	4 GeV Booster $1.7x10^{12}$ protons/pulse Harmonic # = 1 (0.9-2 MHz) 5 Hz. rep. rate	50 GeV Main Ring $1x10^{11}$ protons/frame/axis $1.5x10^{12}$ protons/bunch $3x10^{13}$ total protons Flexible single bunch extraction Harmonic # = 24 (4.8-5 MHz) 26 sec. cycle

New Topic

- 140 MeV Linac

AHF Reference Linac is Adapted from the SNS Room-Temperature Linac



RF system – adapted from new FNAL linac to match 100 microsecond pulse

AHF Linac Parameter List

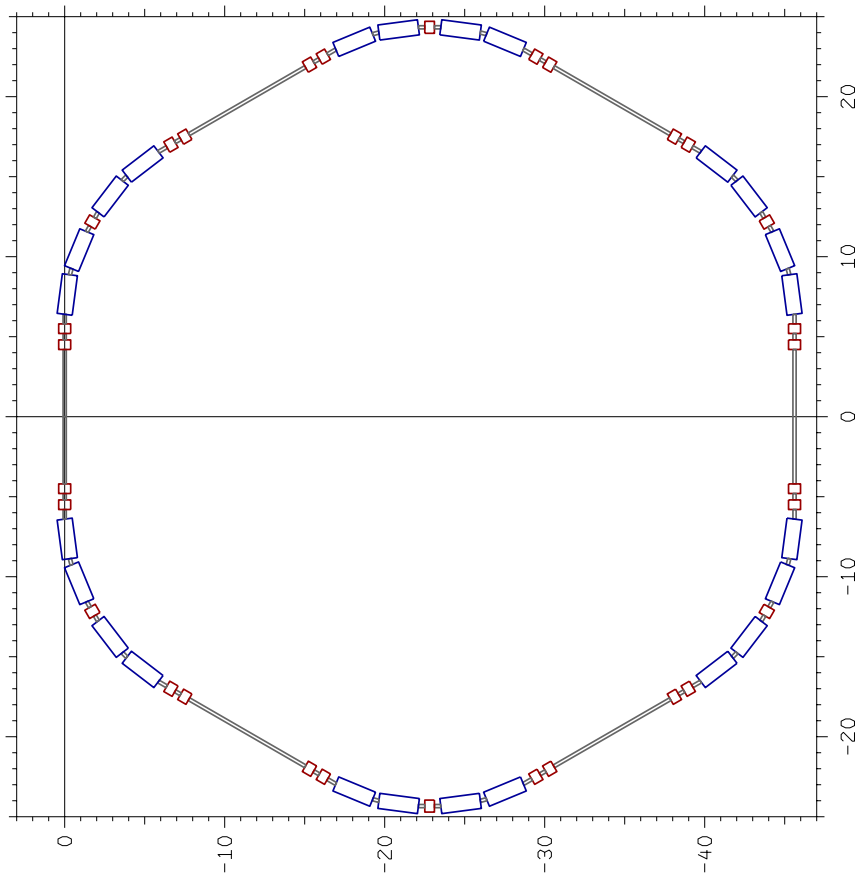
• Energy	140 MeV
• Peak Current	25 mA H^-
• Chopping Factor*	0.5 (2 holes per μsec)
• Beam(RF) Pulse Length	25(100) μsec
• RF Frequency	402.5 (805) MHz
• Repetition Rate	5 Hz
• Transverse Emittance	TBD
• Energy Spread of Beam	<+-0.05%
• Energy Stability	TBD

- *Chopper synchronized with ring rf, linac not synchronized

New Topic

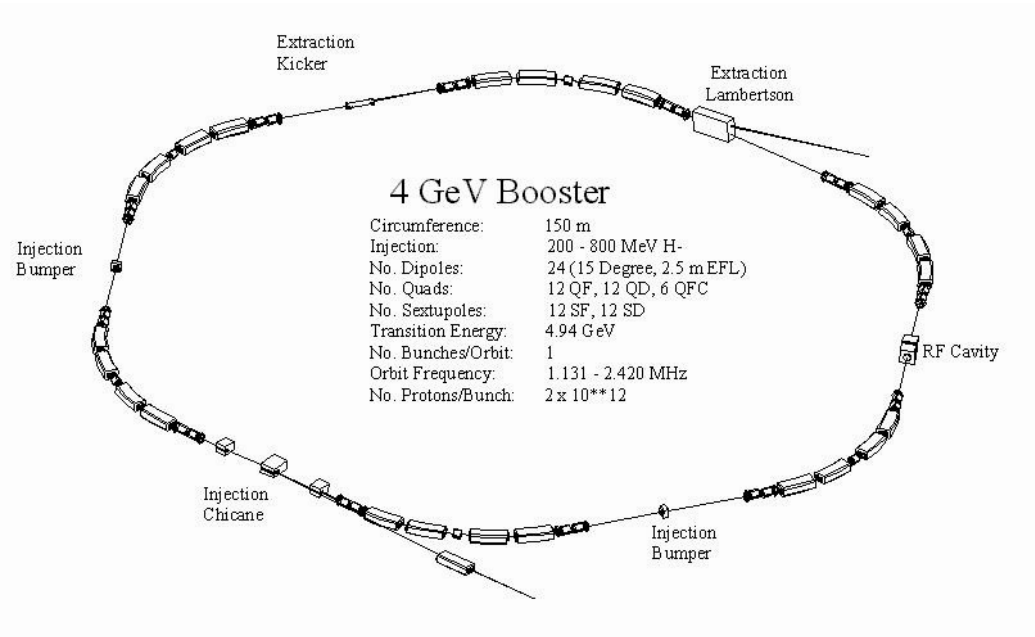
- 4 GeV Booster

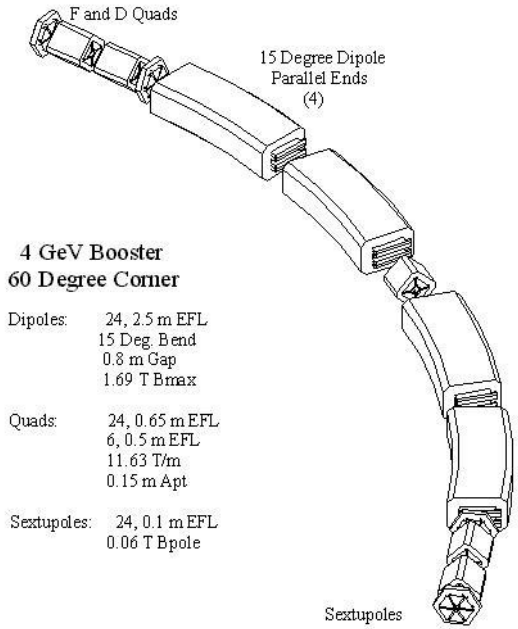
IUCF/LANL Booster Design



- Dimensions in Meters
- 156 Meter Circumference

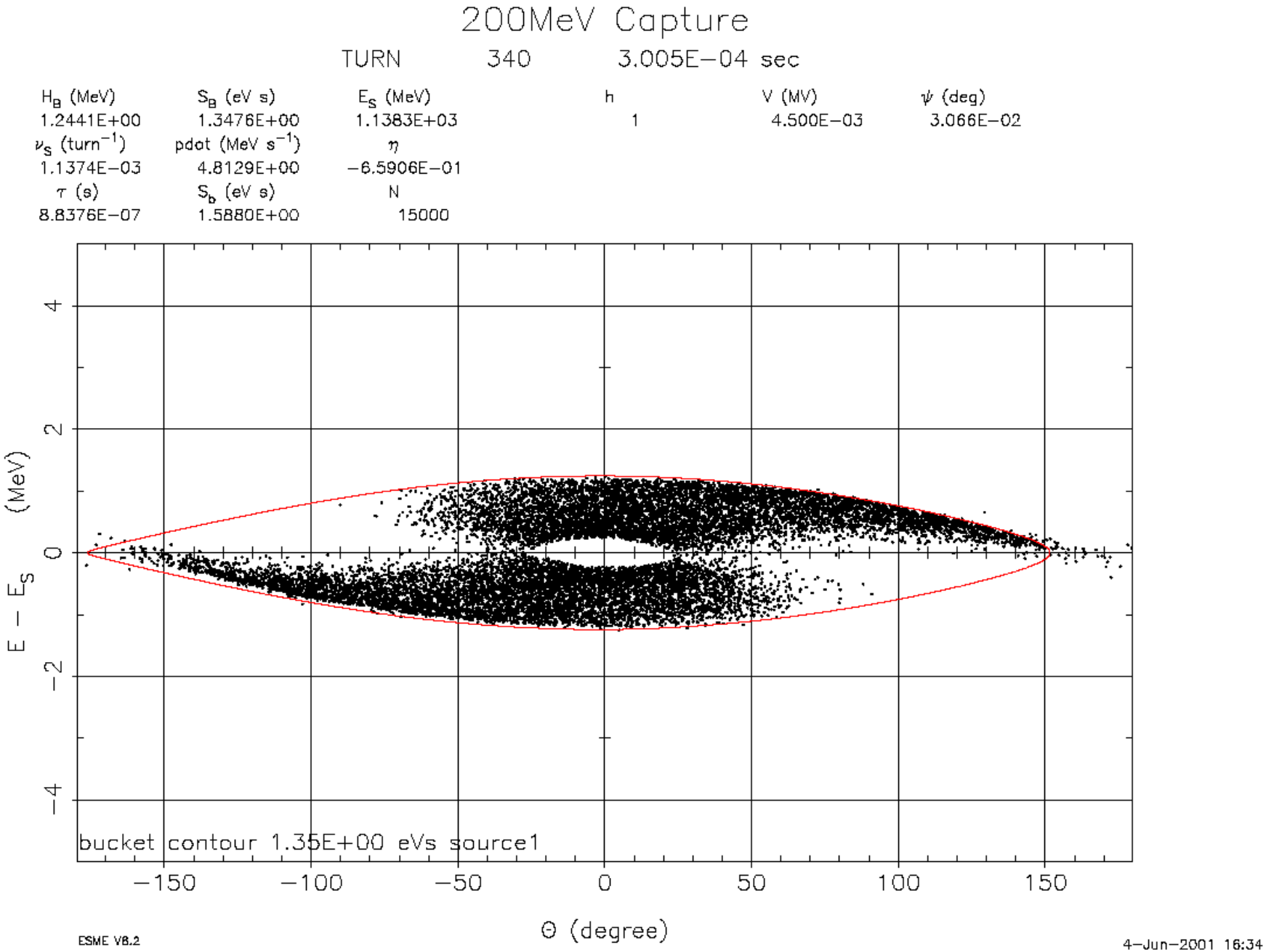
IUCF/LANL Booster Design



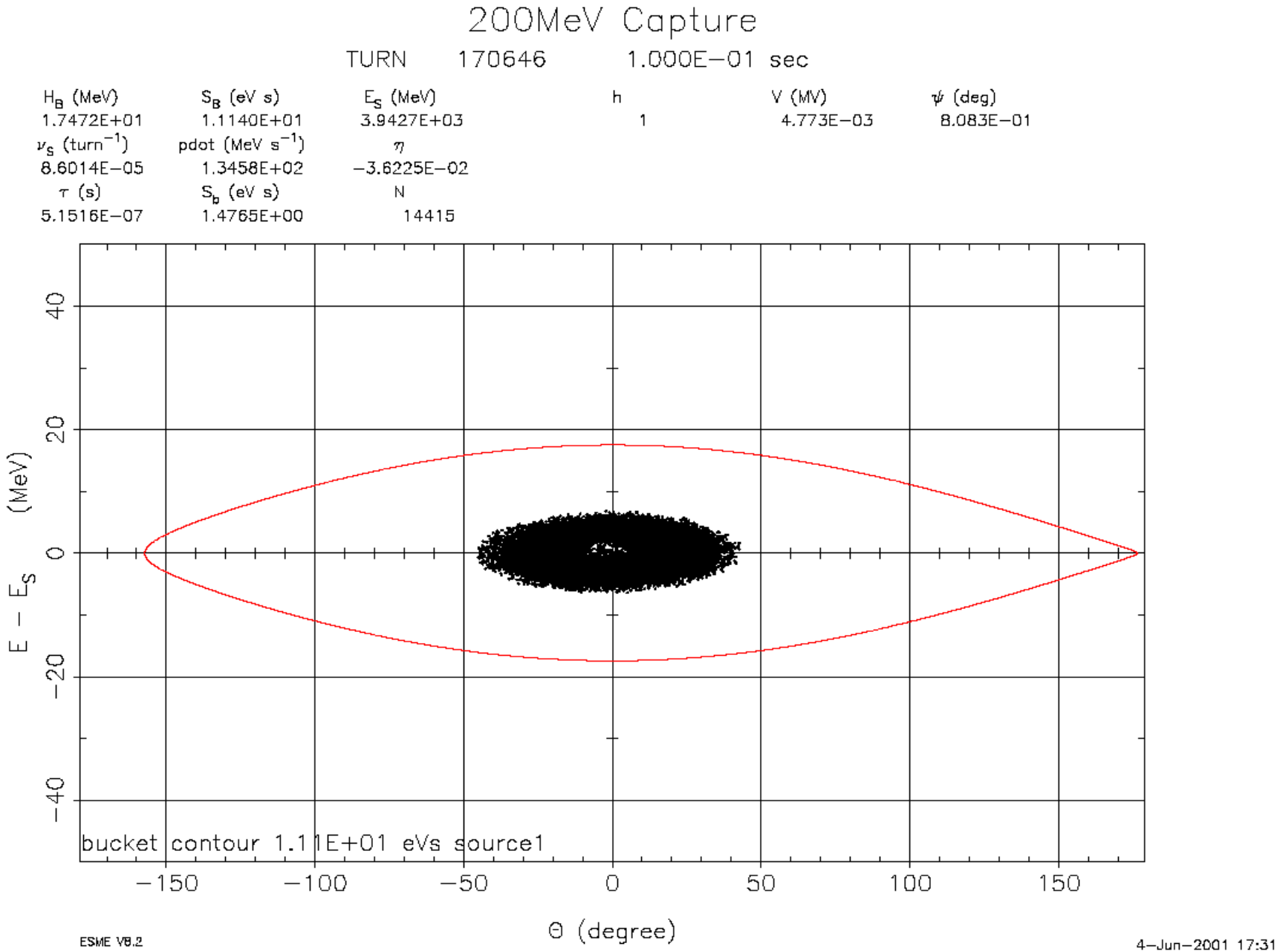


Booster Parameter Table

• Injection Energy	140 MeV (800 MeV)
• Extraction Energy	4 GeV
• Protons per Cycle	1.7×10^{12}
• Normalized Transverse Emittance (Acceptance)	20 (30) π mm-mrad
• Longitudinal Phase Space	1.5 eV-sec
• Bunching Factor at Injection	0.34
• Laslett Tune Shift	0.2
• Harmonic Number	1
• Repetition Rate	5 Hz
• Synchrotron Circumference	156 meters
• Betatron Tune	4.38 H / 2.42 V
• Number of Cells	6
• Cell Length	26 meters
• Transition Gamma	6.5
• Number of Dipoles (Full / Half-Length)	24
• Dipole Length	2.5 meters
• Dipole Field at 4 GeV	1.7 T
• Number of Quadrupoles	30
• Quadrupole Length/ Bore Diameter	0.6 m / 15 cm
• Quadrupole Gradient at 4 GeV	1.2 T/m
• RF Frequency	0.93-1.94 MHz
• RF Volts per Turn	<45 kV



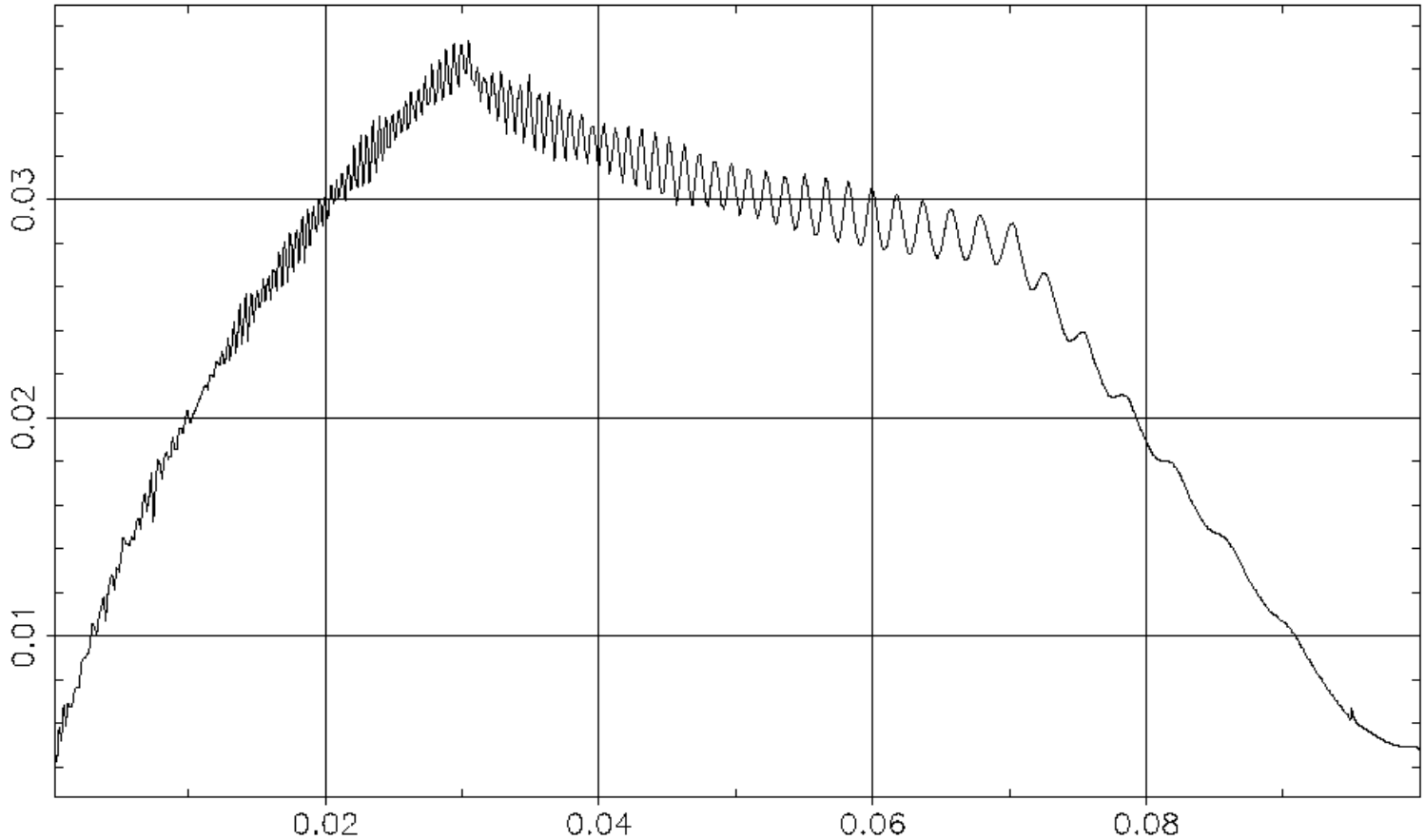
ESME 3 GeV Booster, Preliminary



ESME 3 GeV Booster, Preliminary

200MeV Capture

EV(1) VS IME



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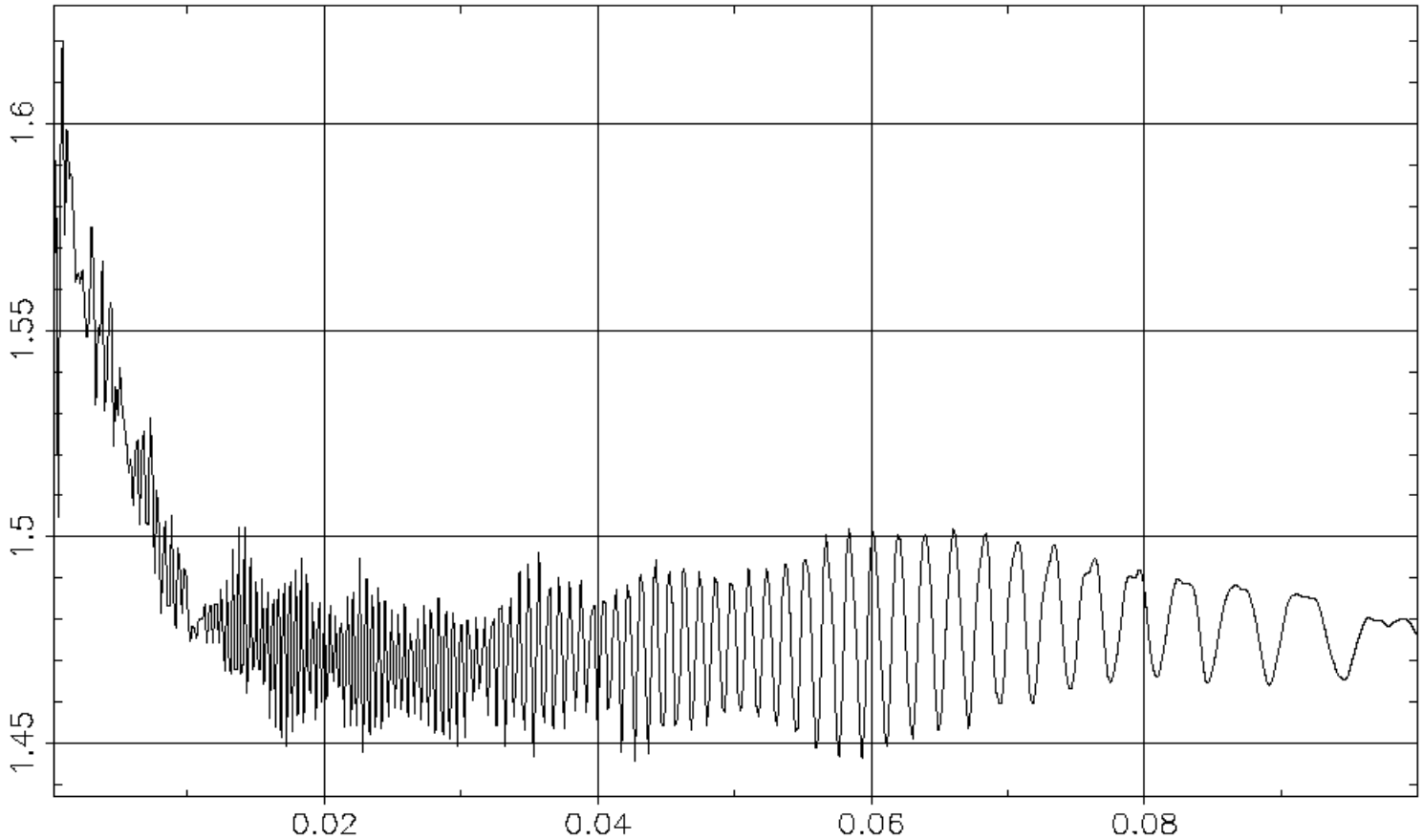
200MeV Capture

EPSILON VS IME



ESME V8.2

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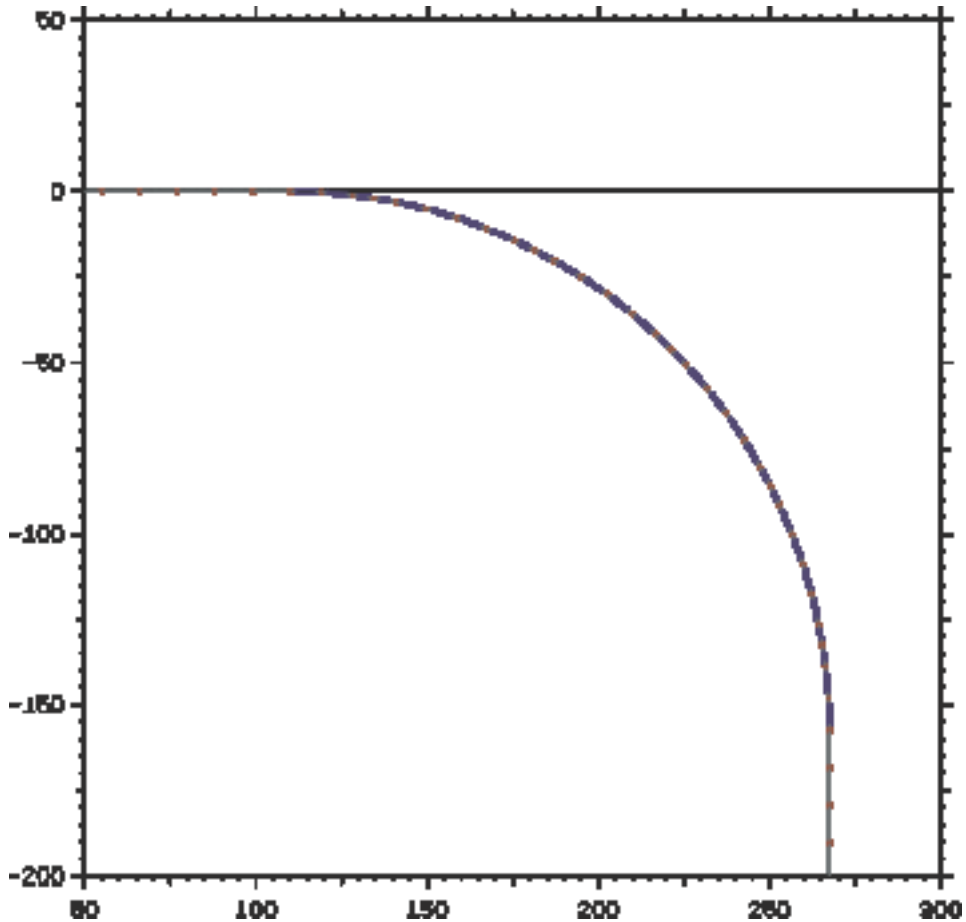
New Topic

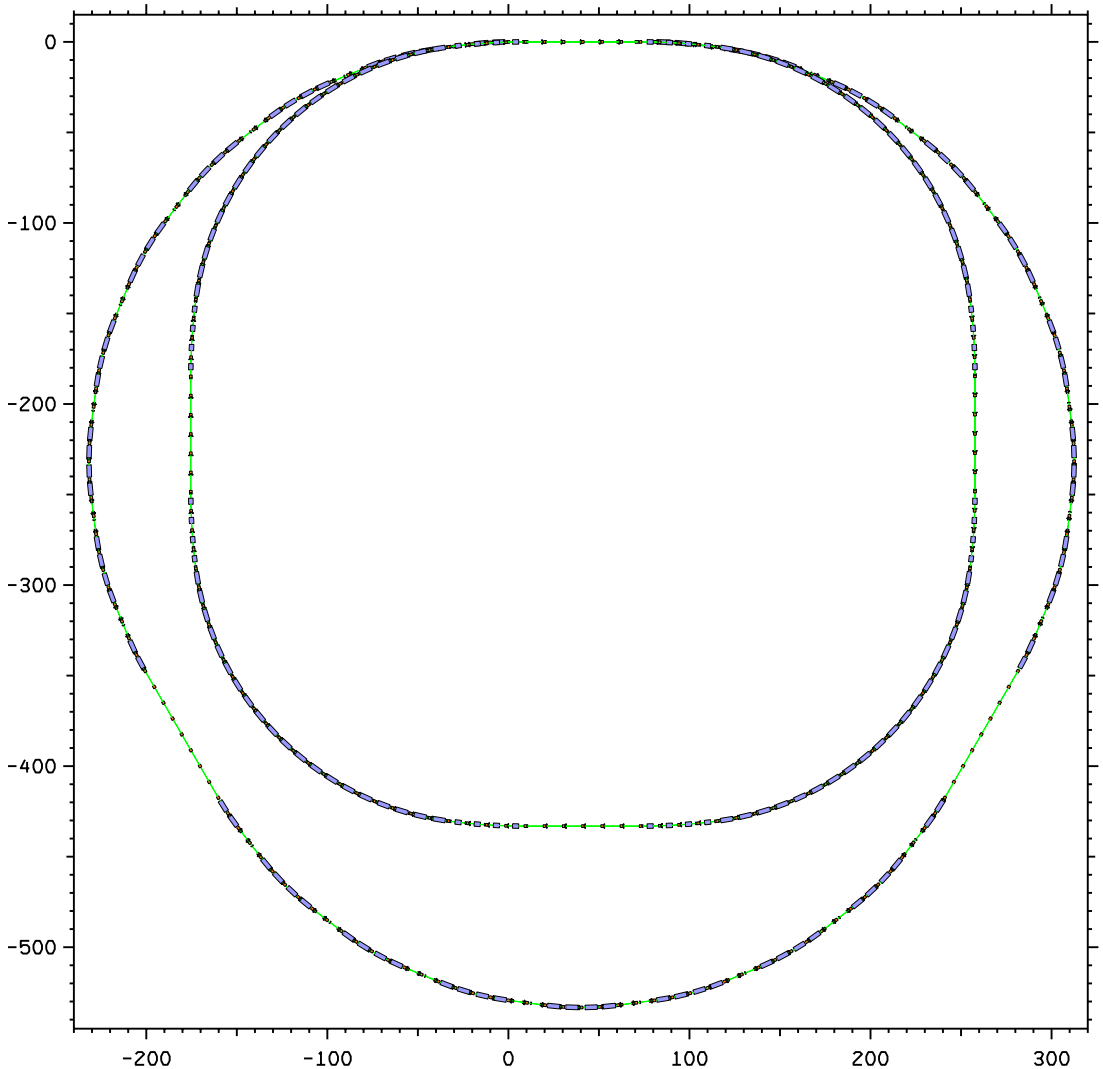
- 50 GeV Main Ring

AHF Reference Main Ring Lattice Based on Fermilab Main Injector Magnets

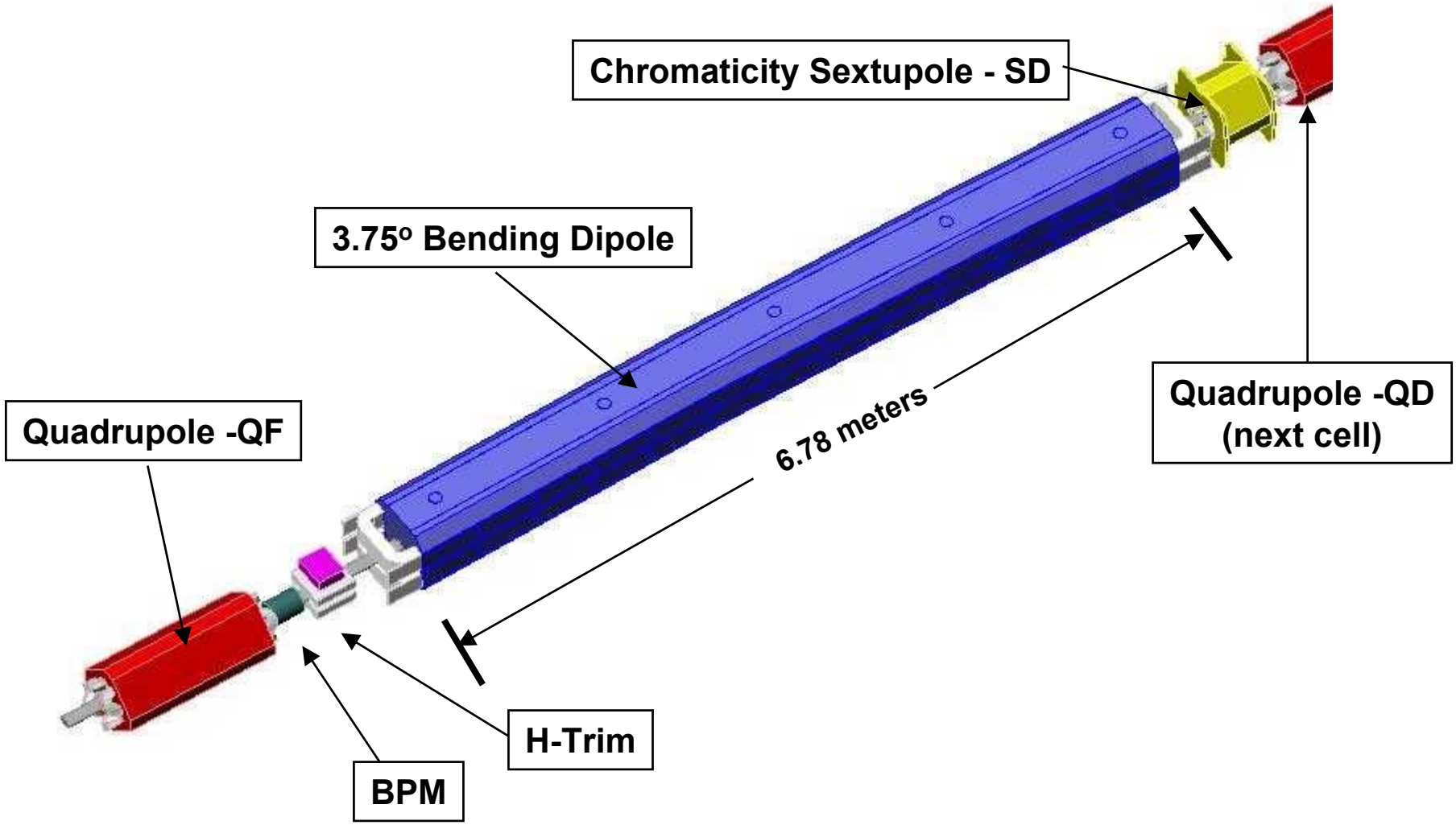


- ¼ of Lattice, Scale in meters

Alternative Transitionless Lattice (See Peter Schwandt Talk)



The AHF Main Ring Lattice is based on the FNAL Main Injector Magnets



The AHF Main Ring Dipole is Adapted from FNAL Main Injector Dipole

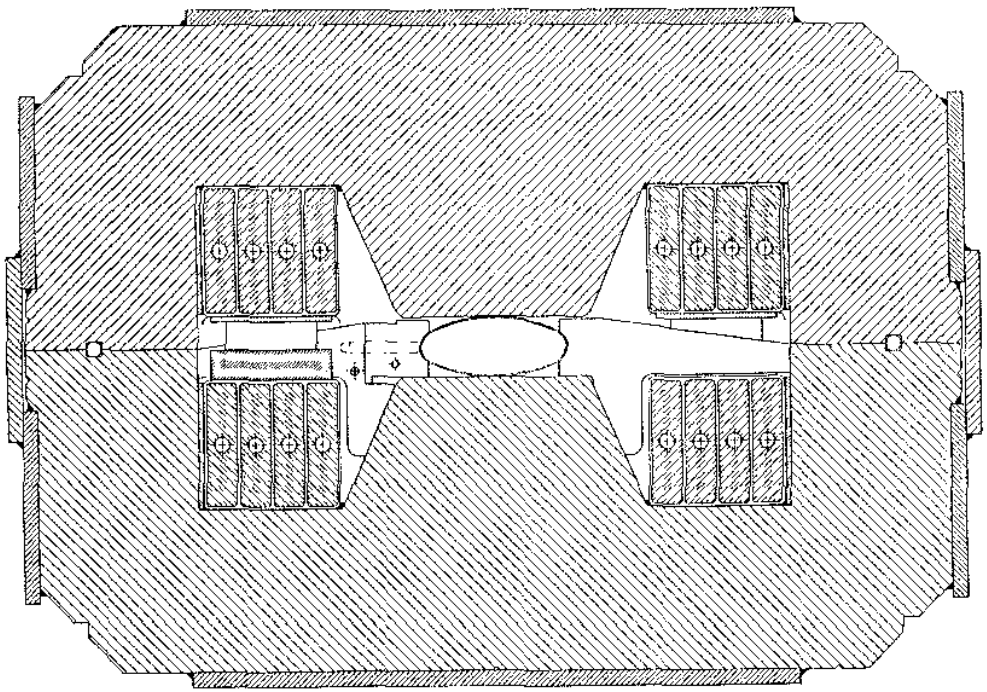
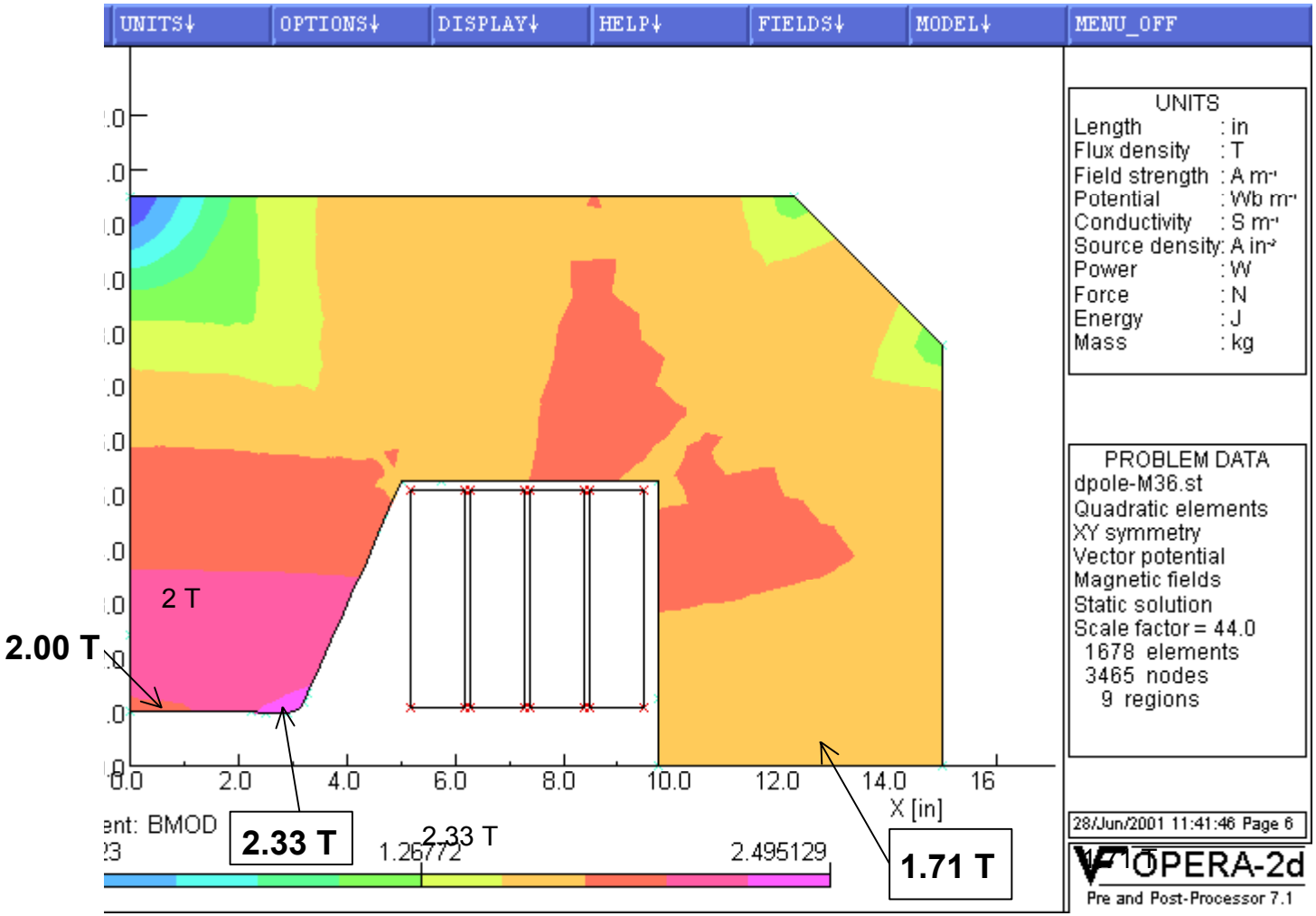


Figure 3.1-2. Cross-Section of the Main Injector Dipole Magnet.

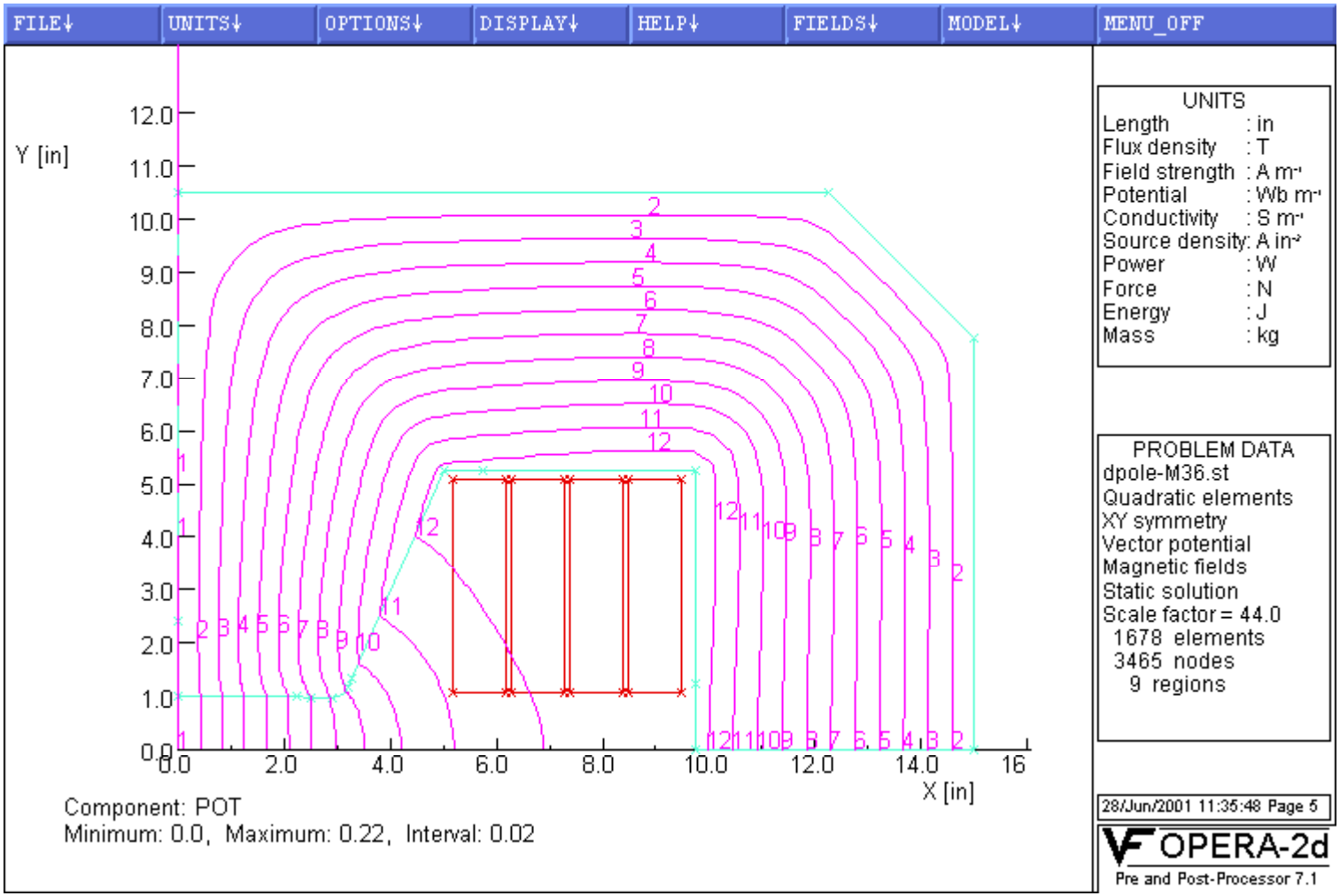
- 56 cm h x 84 cm w x 678 cm long – weight 21.2 tons

Main Injector Dipole Field Distribution at High Field



LTV.bh iron; Bmod (T) in iron at N*I = 88935.88 (A-turns); field in gap By = 1.78 (T)

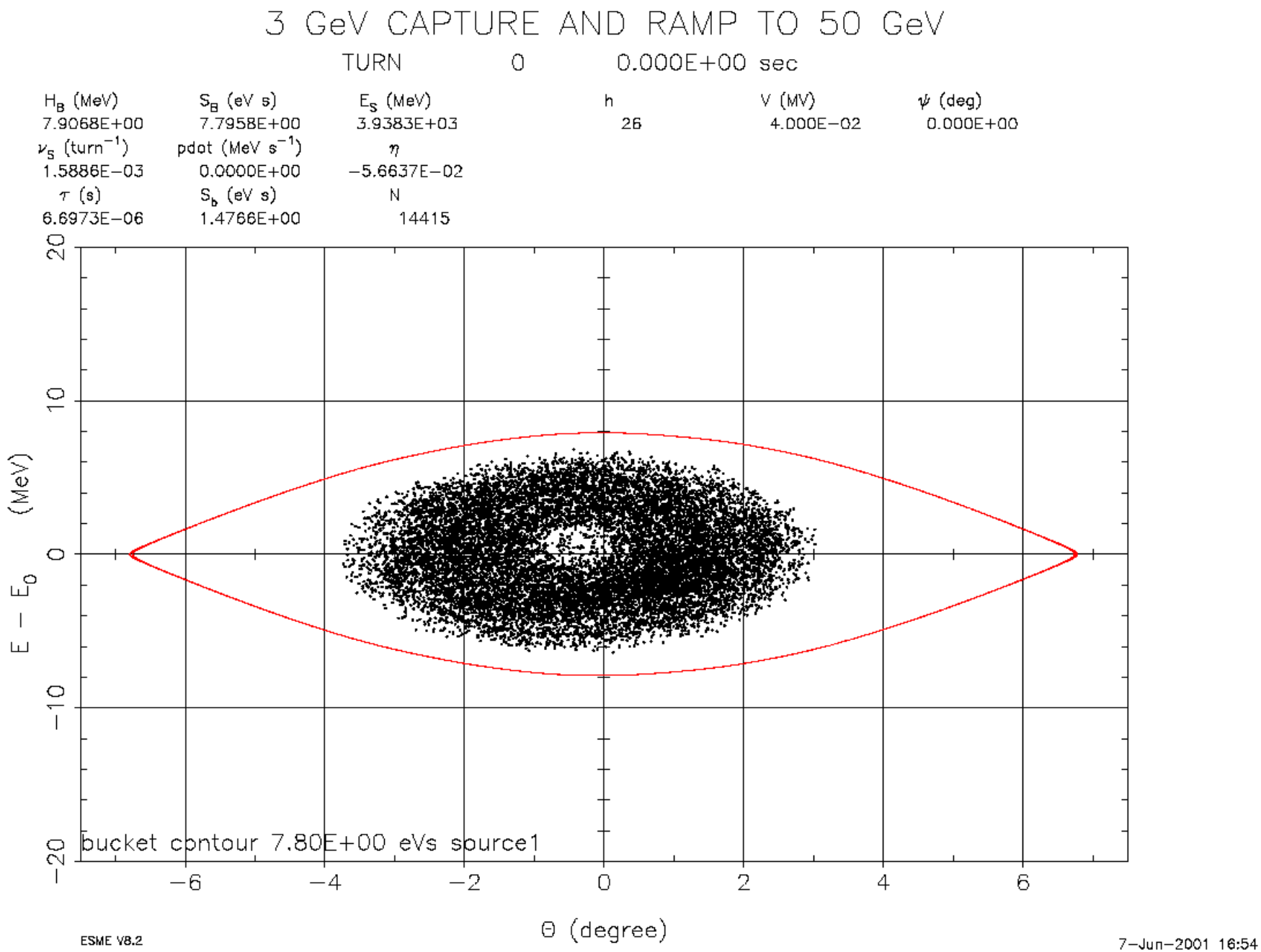
Main Injector Field Lines at High Field



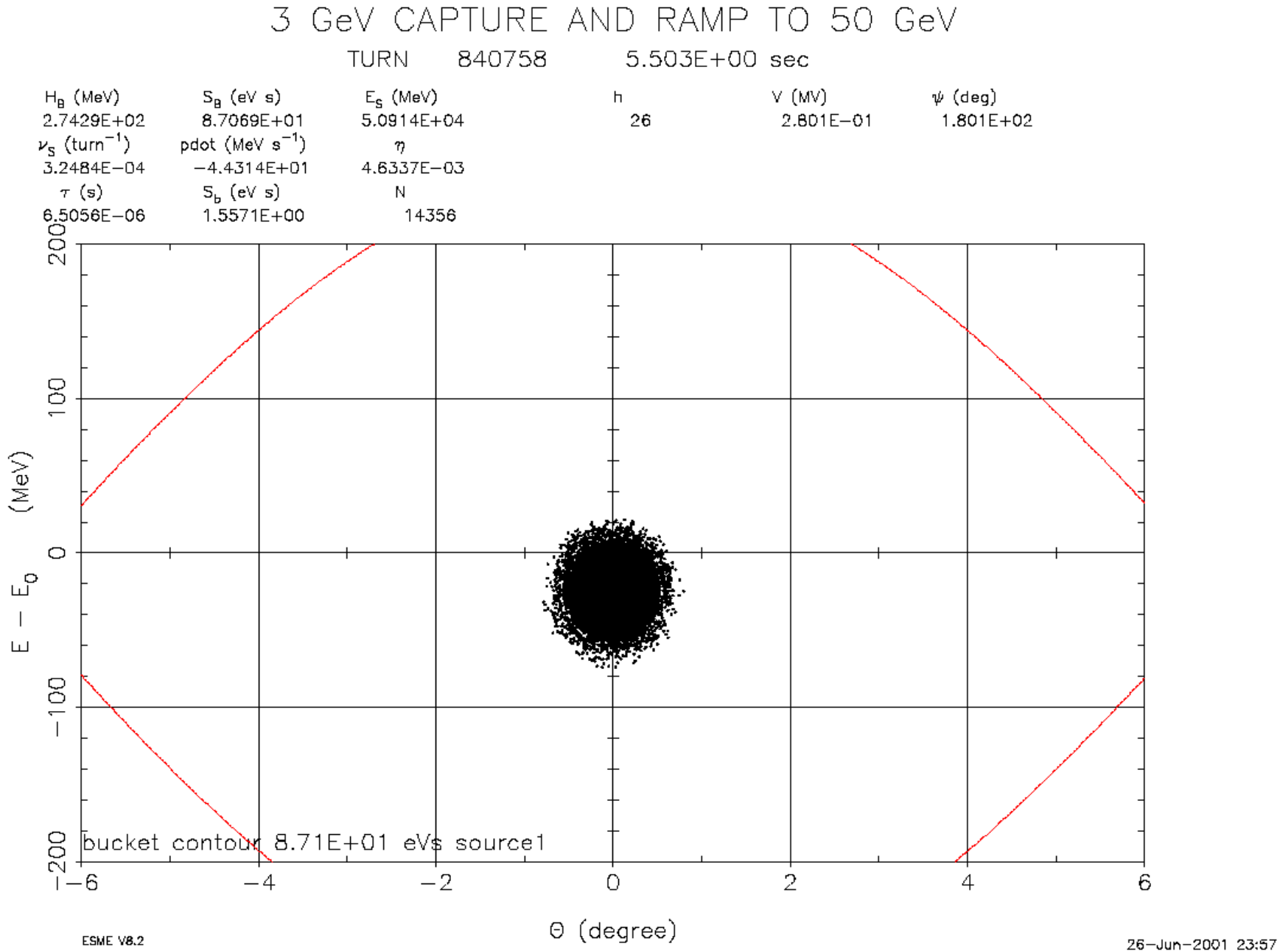
LTV.bh iron; Bmod (T) in iron at N*I = 88935.88 (A-turns); field in gap By = 1.78 (T)

50 GeV Reference Main Ring Parameter Table

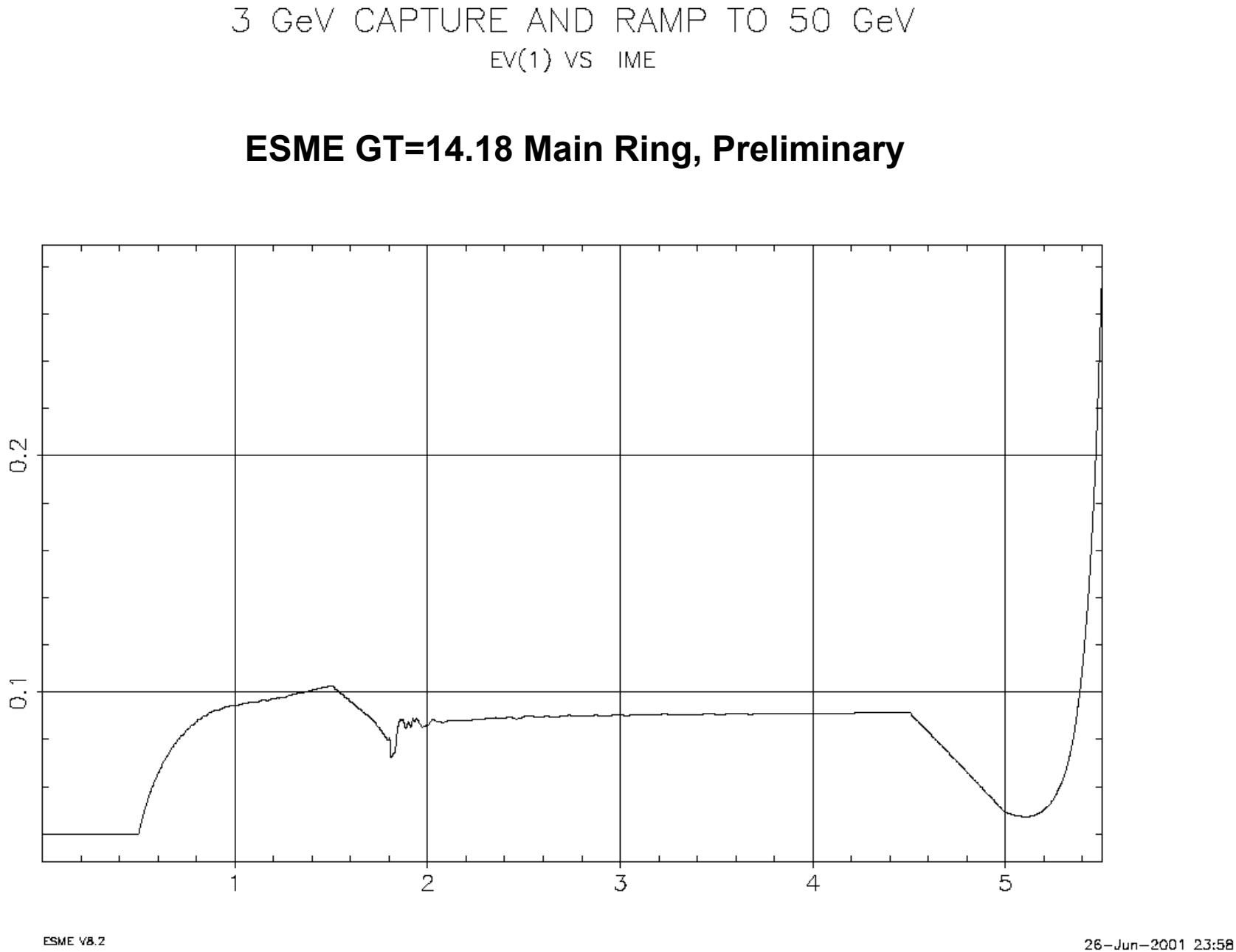
• Injection Energy	4 GeV
• Extraction Energy	50 GeV
• Normalized Transverse Emittance (Acceptance)	20(40) π mm-mrad
• Longitudinal Phase Space (per Bunch)	1.6 eV-sec
• Protons per Cycle	3×10^{13}
• Bunching Factor at Injection	0.16
• Laslett Tune Shift	0.2
• Harmonic Number	24
• Repetition Time	26 sec
• Synchrotron Circumference	1443.6 meters
• Betatron Tune	18.36 H / 18.46 V
• Number of Cells	68
• Cell Length	21.23 meters
• Transition Gamma	14.18
• Number of Dipoles (Full / Half-Length)	80/32
• Dipole Length	6.783/3.3915 meters
• Dipole Field at 50 GeV	1.635 T
• Number of Quadrupoles	136
• Quadrupole Length/ Bore Diameter	1.295 m / 10 cm
• Quadrupole Gradient at 50 GeV	18.53 T/M
• RF Frequency	4.84-4.99 MHz
• RF Volts per Turn (max)	<140 kV



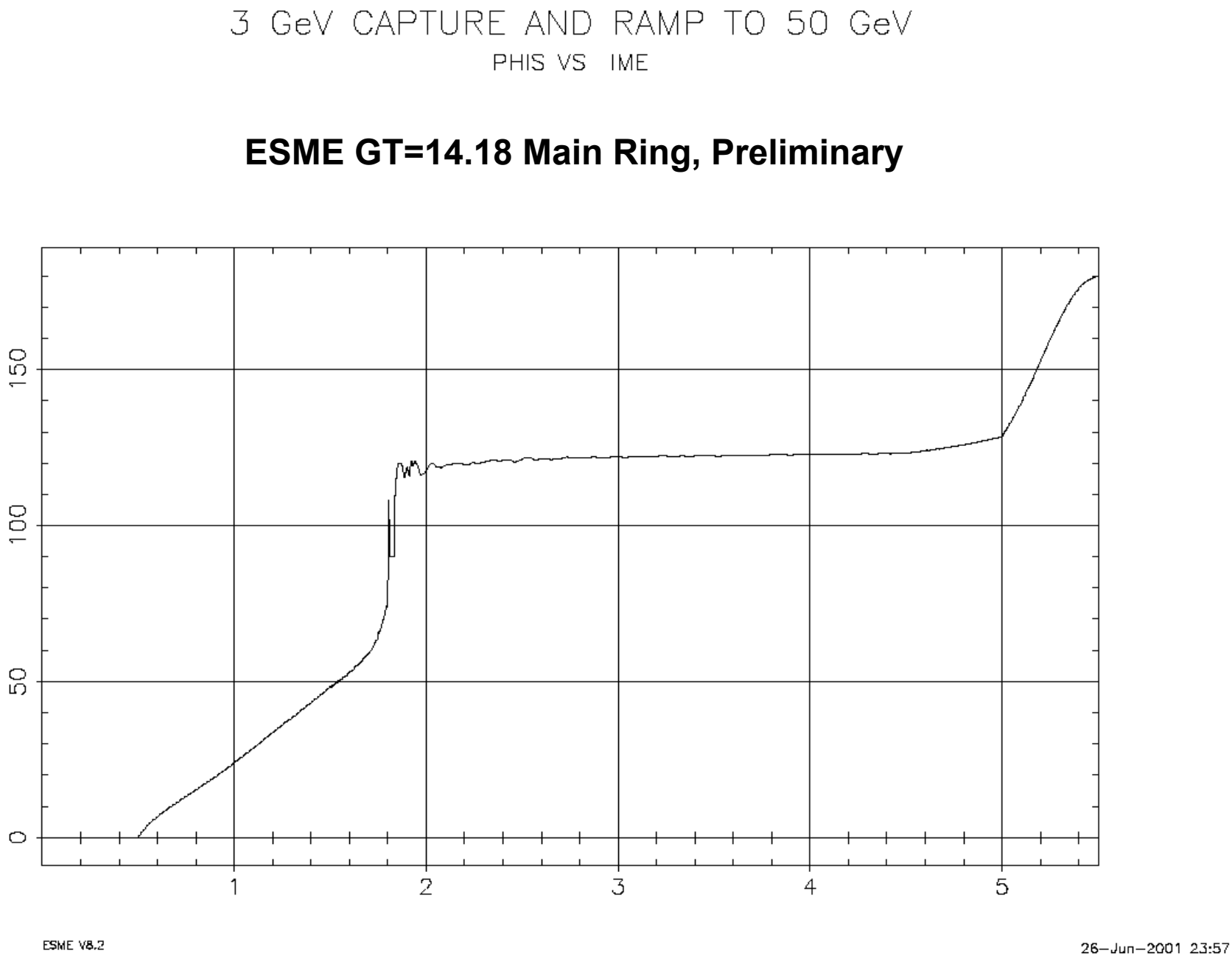
ESME GT=14.18 Main Ring, Preliminary



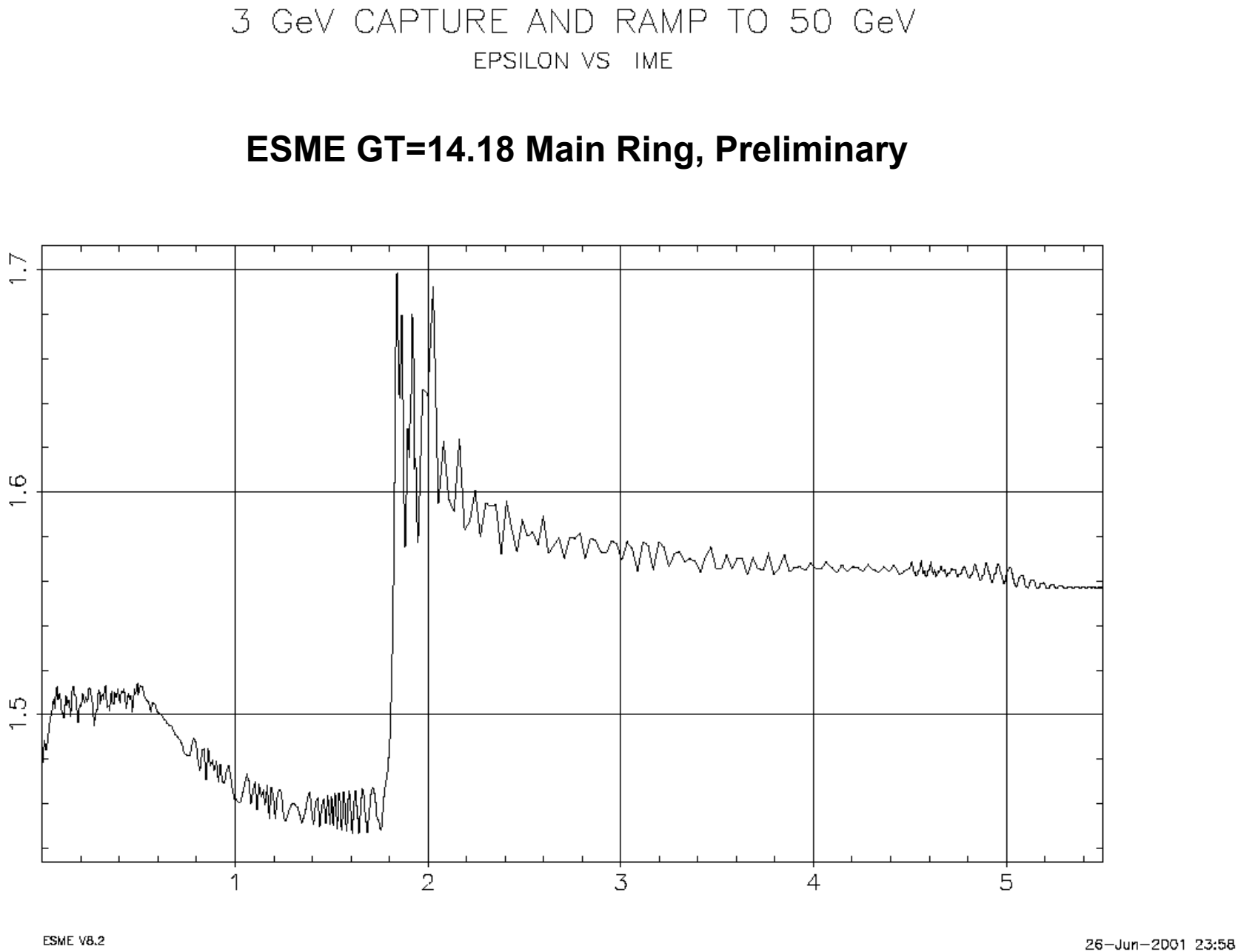
ESME GT=14.18 Main Ring, Preliminary



ESME GT=14.18 Main Ring, Preliminary

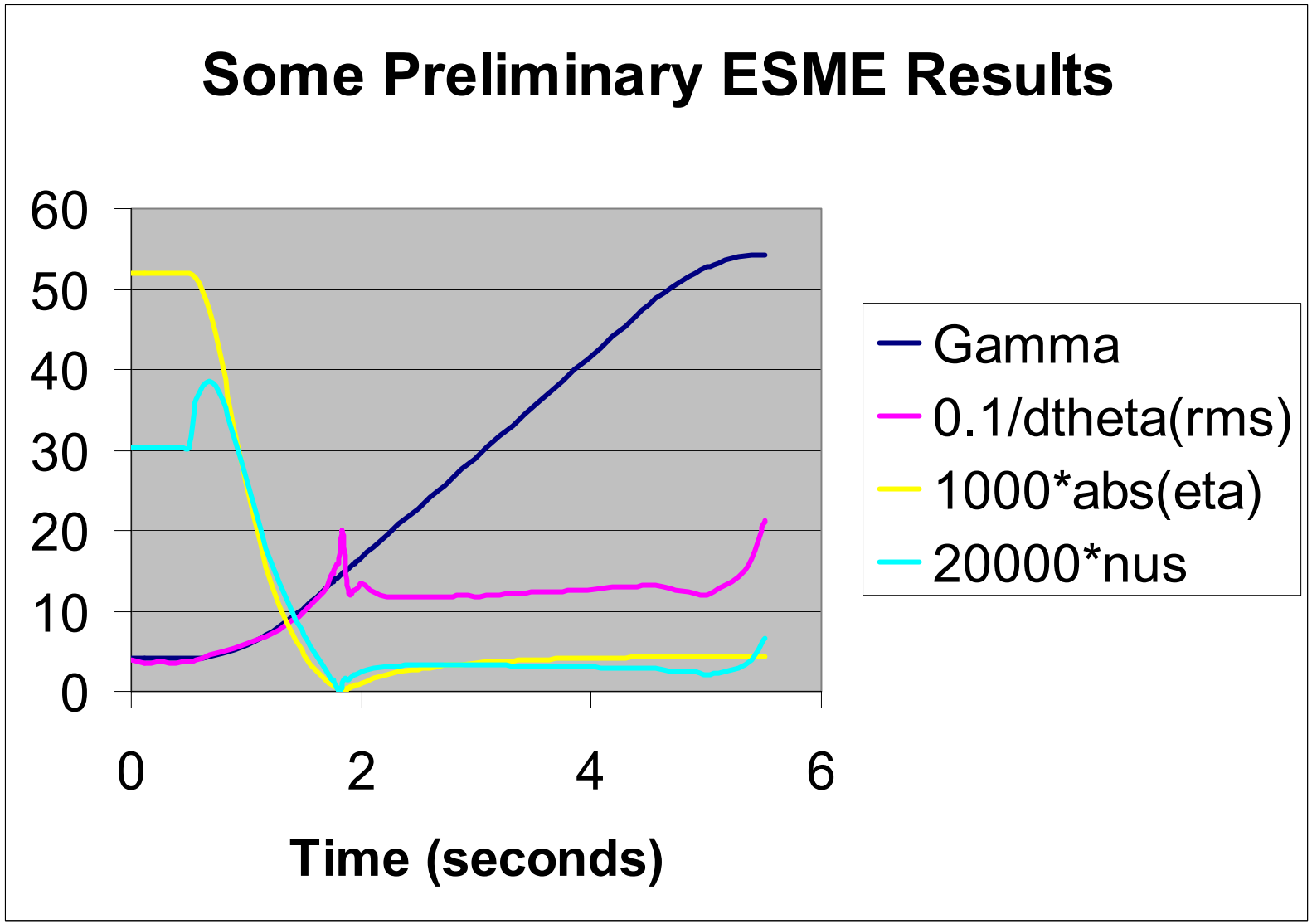


ESME GT=14.18 Main Ring, Preliminary



ESME GT=14.18 Main Ring, Preliminary

Main Ring RF Bunching (Preliminary)



New Topic

- Kicker Modulator

The Kicker Modulator for AHF is Adapted from the LLNL/DARHT Modulator

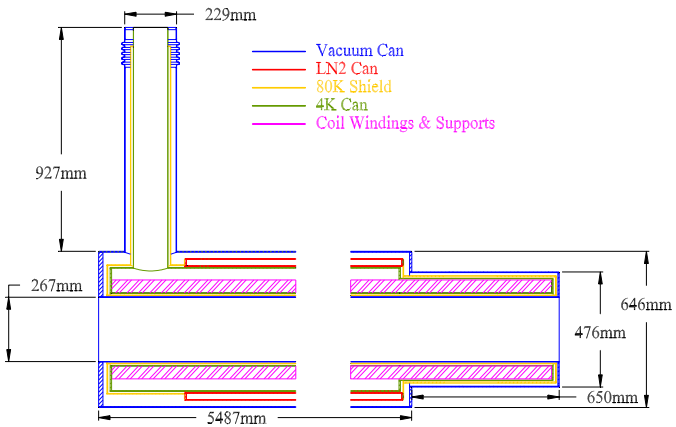
- Stacked MOSFET Modulator
  - 20 ns 10-90% rise and fall times
  - 20 pulses max
  - +-50 kV in 50 Ohms
- See Pete Walstrom Talk, July 14

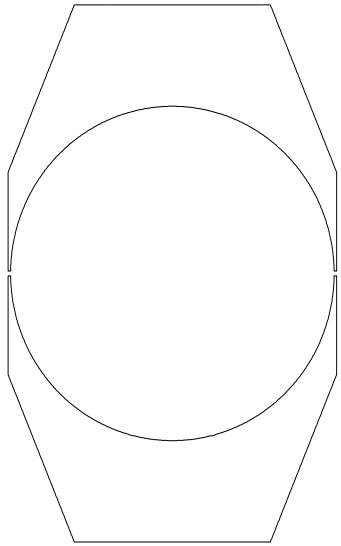
New Topic

- Superconducting Lenses

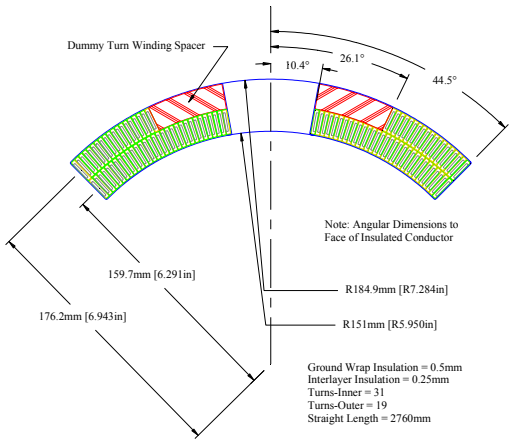
The Large-Bore SC Lens Quads have been Studied by the MIT Plasma Science and Fusion Center

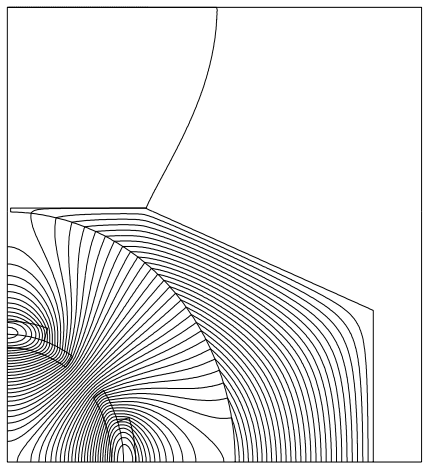
MIT design for high-gradient quad





Los Alamos Yoke Concept



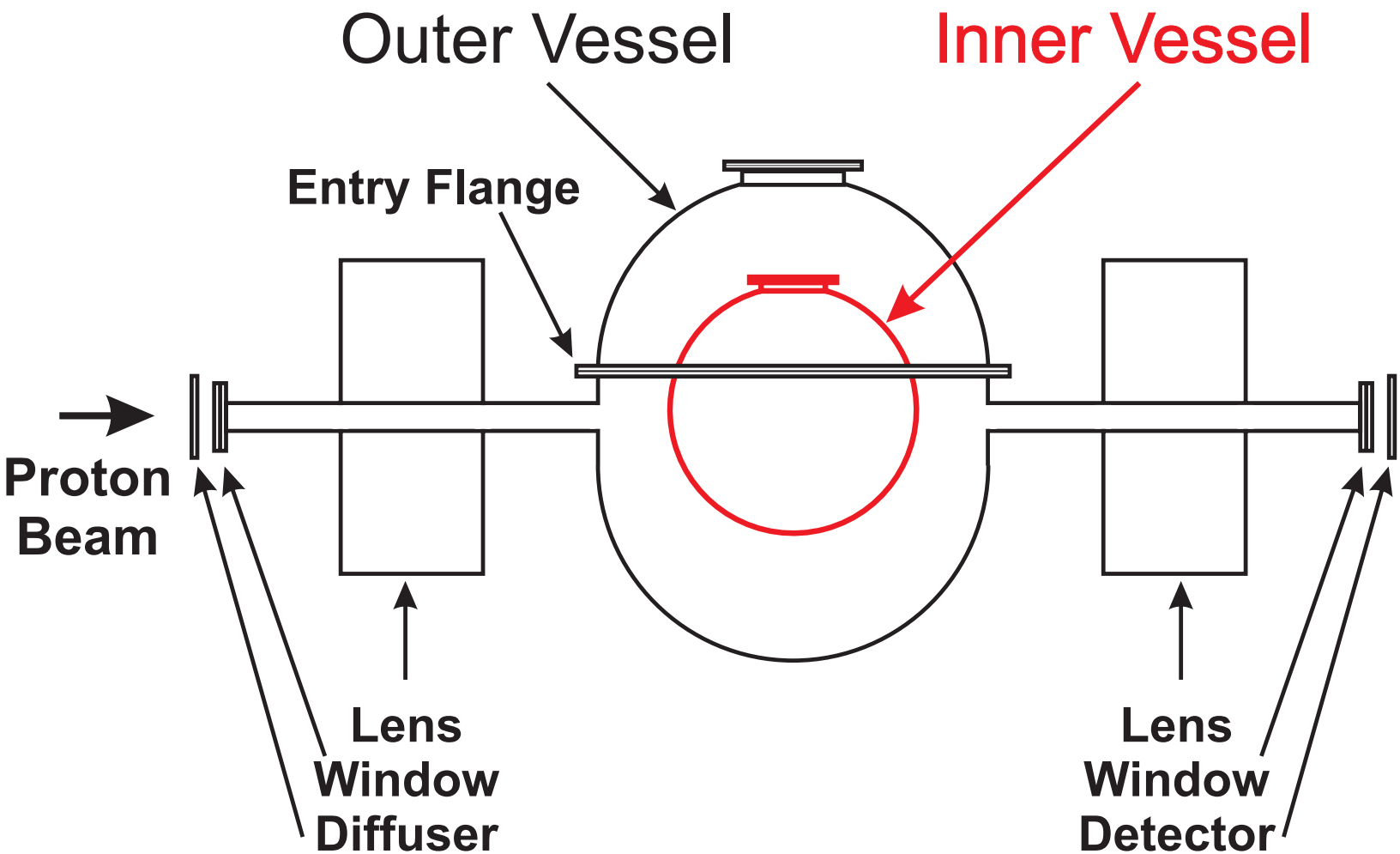


Note: we are talking with BNL about "small bore" lenses

New Topic

- AHF Containment/Confinement

Proton AHF Concept for Containment/Confinement

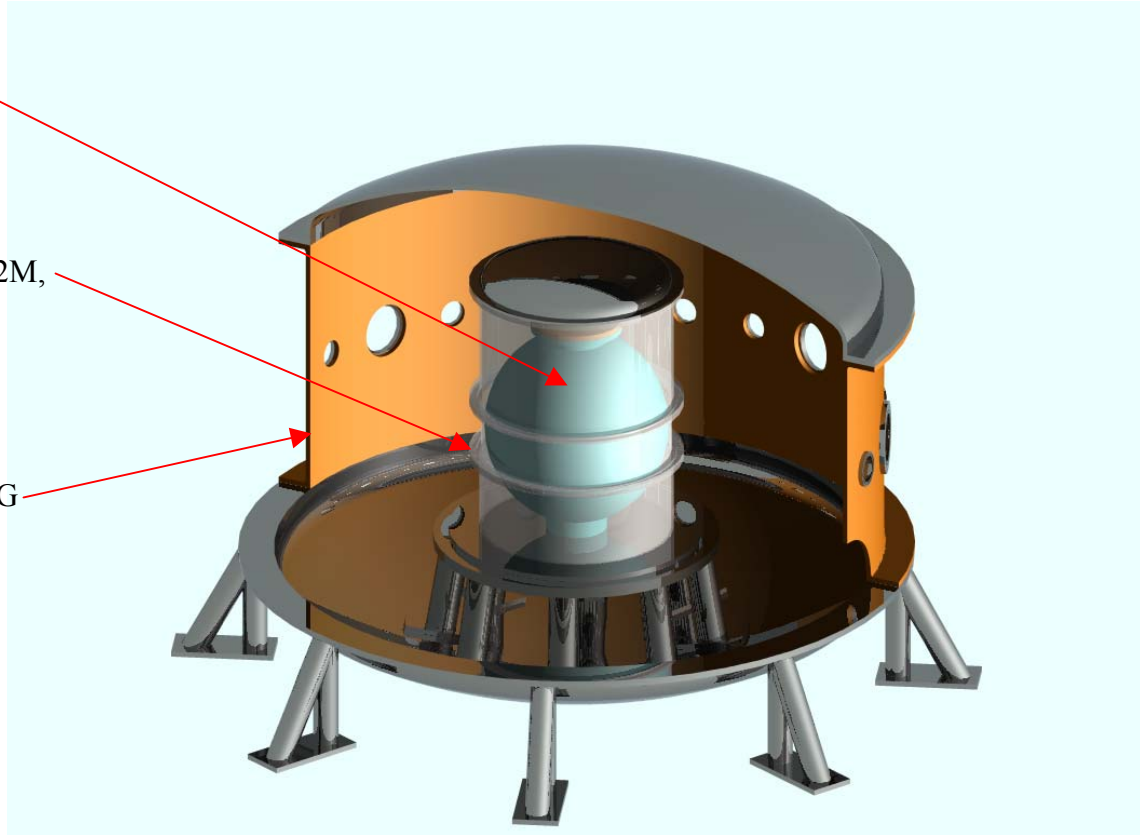


AHF Confinement/Containment Concept

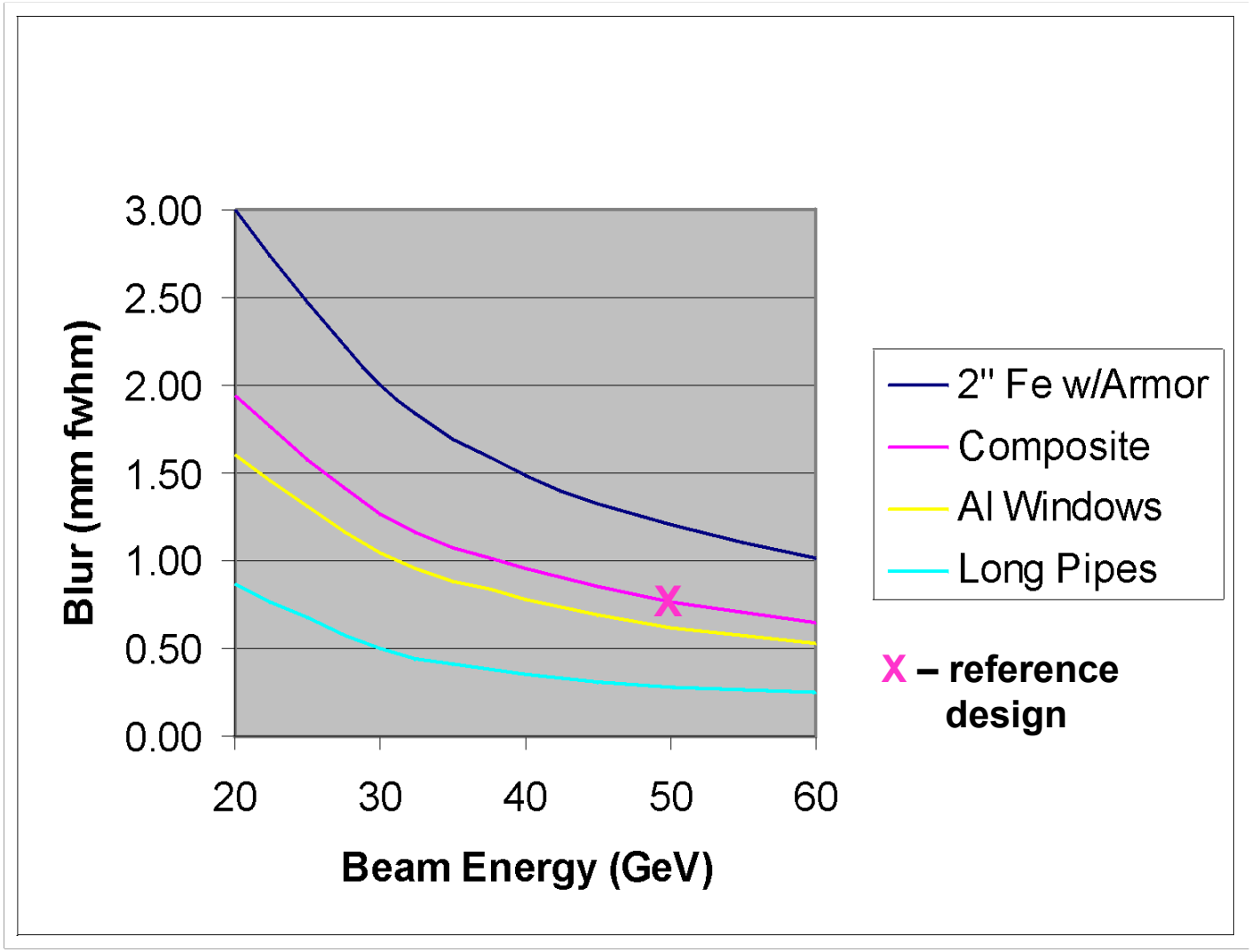
V1-COMPOSITE, SINGLE USE, 1M RADIUS, SHRAPNEL BLAST

V2-ALUMINUM, MULTIPLE USE, 1M-2M, GAS LEAKAGE (ASME)

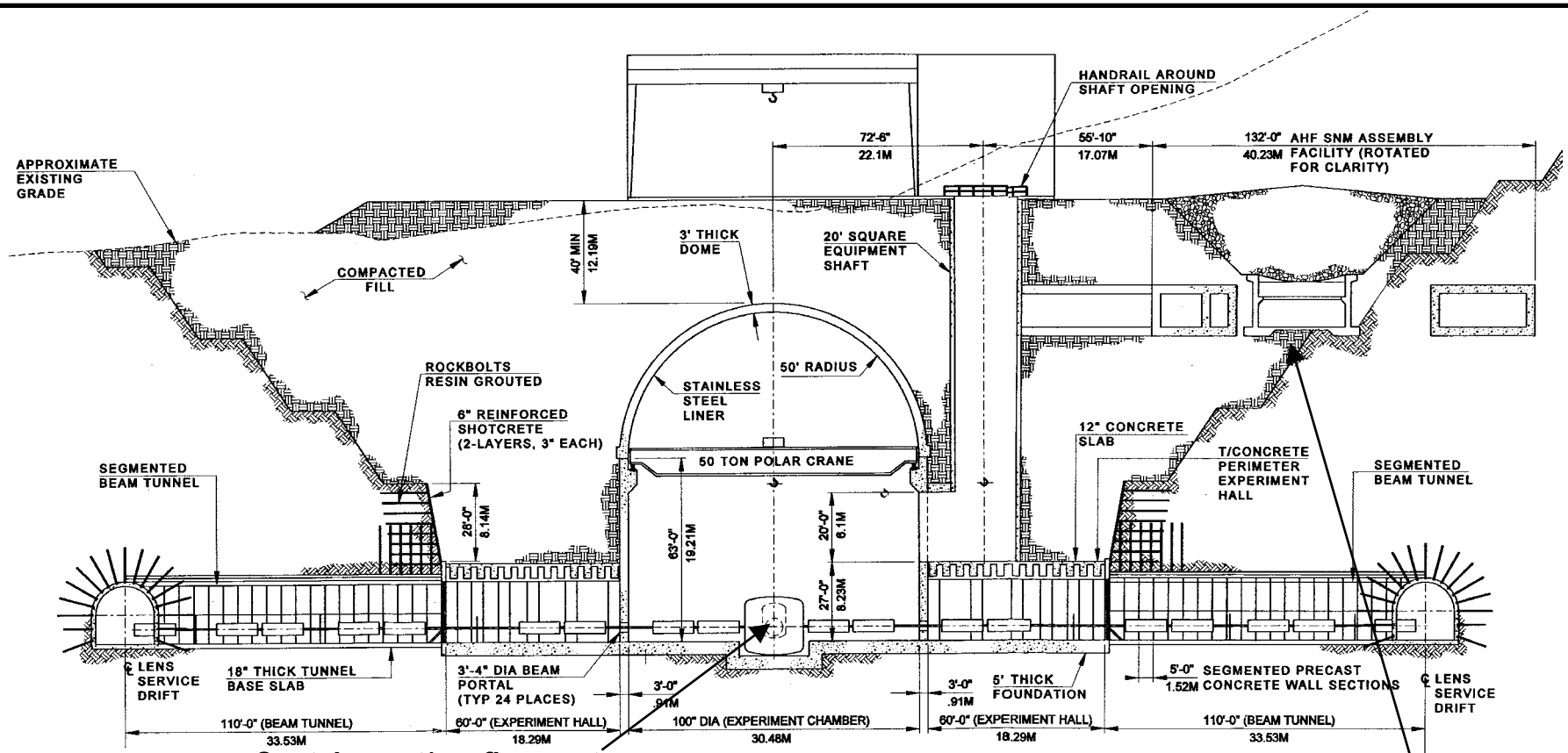
V3-SST, MULTIPLE USE, 2M-3M, LONG TUBES (ASME)



AHF Resolution for Various Confinement Options



We Have an Underground Firing Site



Example features

- **Underground site provides tertiary confinement**
- **Underground test assembly facility is integrated into firing site structure**
- **Mortandad Canyon site would be accessible to TA-55 without crossing public land**

Note: the final site will be chosen after a public NEPA and formal site selection process by DOE/NNSA

New Topic

- AHF ED&D Plan

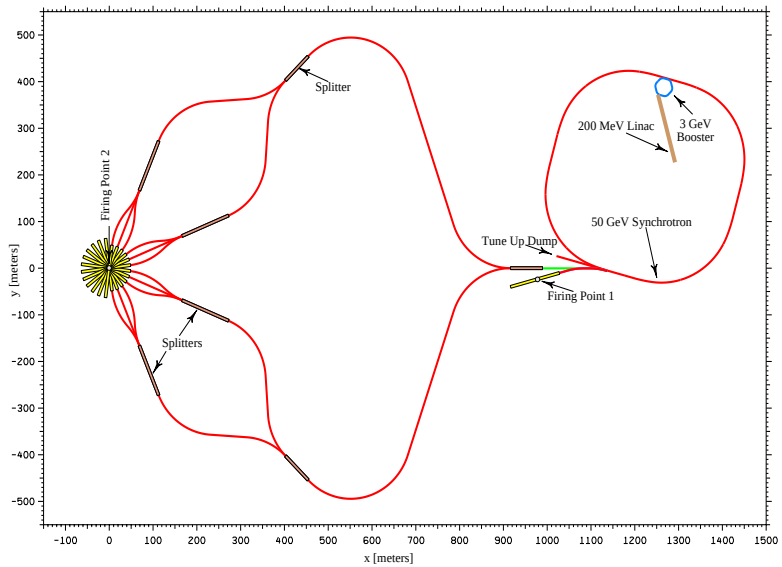
AHF ED&D Plan

- Accelerator
  - **Beam Dynamics Study** - Pat Colestock/T-S Wang
    - » *What would it take – impedances, kickers, rf, dampers, transition crossing,… – to avoid large longitudinal dilution needed for stability at AGS ?*
    - » Choose between traditional and transitionless lattice
    - » Tracking and tolerances
  - **Kicker Modulator**
  - **Flexible Extraction Modes** (More Low-Intensity Pulses on Target)
  - **Magnets** – Initial study of temperature dependence, saturation, remnant multipoles, end packs, IGBT magnet power supply
  - **RF** – what are feedback requirements, design of ferrite-tuned cavities,ferrite choice, figure-eight or quadrupole bias? RF Workshop July 19 in Los Alamos.
  - **Linac** – minimize linac cost, especially rf
- **Superconducting Quadrupole Lenses**
  - 30 cm diameter (12 cm field-of-view) superconducting quadrupoles
  - 50 cm diameter (30 cm field-of-view) superconducting quadrupoles
- **Detectors** – rapid-readout silicon photodiode detectors
- **Containment/Confinement** – Multi-Layer Composite Vessel Under Test
- **Stockpile Certification** – What Is Program of Measurements Required?
- **Other Basic and Applied Research** Uses of AHF - Workshop in November?

New Topic

- Summary and Conclusions

Summary: The technical path to an AHF is becoming solidly established



Baseline architecture selected:

- *50-GeV proton energy*
- *Room-temp accelerator – >20 independent pulses, < 30-ns time resolution*
- *Synchronous beam transport – 12 axes, 165° coverage*
- *Superconducting lenses – to 30-cm field of view*
- *Underground firing sites with nested vessel systems for "defense-in-depth"*

AHF expected to have ultimate capability to infer criticality, cavity shape and mix:

- 3-D tomographic reconstruction
- >75 μsec time history
- ~1% density resolution
- <1 mm resolution with composite inner vessel system
- ~50 μm edge resolution
- material identification with second detector
- >5x magnification possible

Engineering development initiated for critical components