Muon Collaboration

High-power Targets

LINAC 2004

Lűbeck, Germany

August 19, 2004

BROOKHAVEN NATIONAL LABORATORY

Harold G. Kirk
Brookhaven National Laboratory

Intense Secondary Beams

New physics opportunities are generating world wide interest in the development of new intense secondary beam.

- Neutron Sources
  - European Spallation Source
  - US Spallation Neutron Source
  - Japanese Neutron Source
- Kaons
  - RSVP at BNL
  - CKM at FNAL
- Muons
  - MECO and g-2 at BNL
  - SINDRUM at PSI
  - EDM at JPARC
  - Muon Collider
- Neutrinos
  - Superbeams
  - Neutrino Factories

Multi-MW New Proton Machines

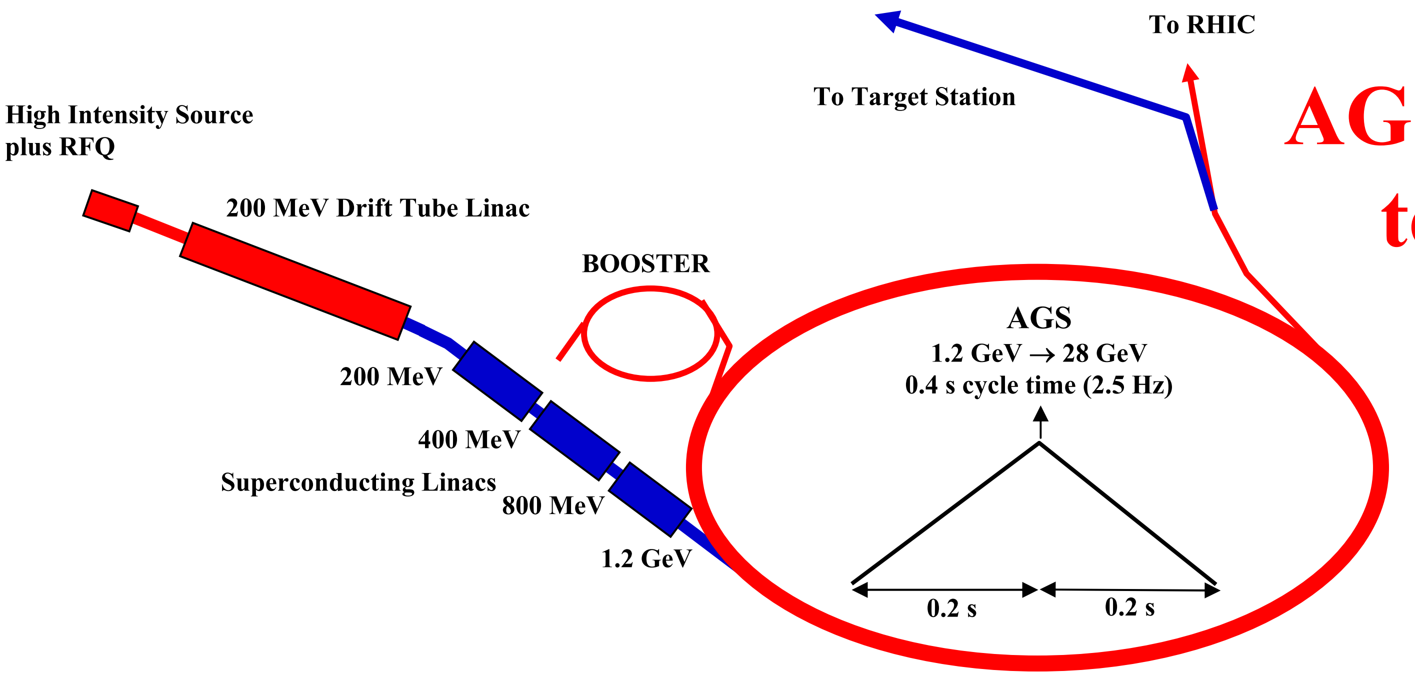
SNS at 1.2 MW → 2.0 MW

JPARC 0.7 MW → 4.0 MW

FNAL 0.4 MW → 1.2 MW → 2.0 MW

BNL 0.14 MW → 1.0 MW → 4.0 MW

AGS Upgrade to 1 MW



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High-power Targetry Workshop
Ronkonkoma, Long Island Sept. 2003

Over 40 attendees from:

- Argonne
- Brookhaven
- CERN
- Fermilab
- FZ-Julich
- KEK
- Los Alamos
- Michigan State
- Oak Ridge
- Princeton
- PSI-Zurich
- Rutherford Lab
- SLAC

Facilities Represented

- AGS
- ESS
- EURISOL
- IFMIF
- ISIS
- JPARC
- LANCE
- Neutrino Factory
- NUMI
- NLC
- RIA
- SINQ
- SNS

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High-power Targetry Challenges

High-average power and high-peak power issues

- Thermal management
  - Target melting
  - Target vaporization
- Radiation
  - Radiation protection
  - Radioactivity inventory
  - Remote handling
- Thermal shock
  - Beam-induced pressure waves
- Material properties

Thermal Management

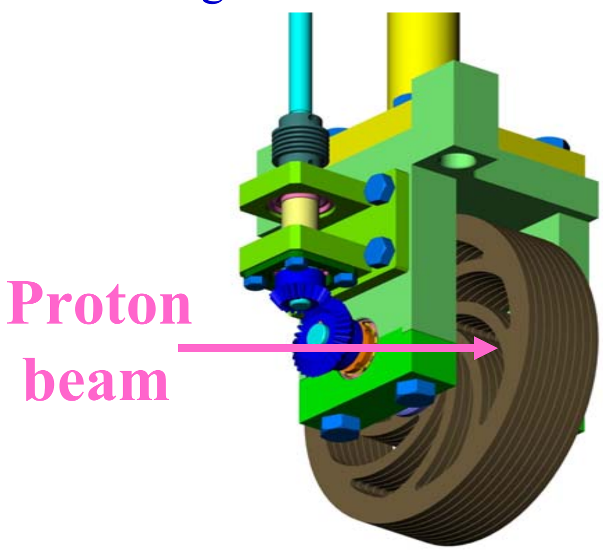
T1 target at JPARC

Kaon Production

Rotating Ni Disks

Water Cooled

590 J/g

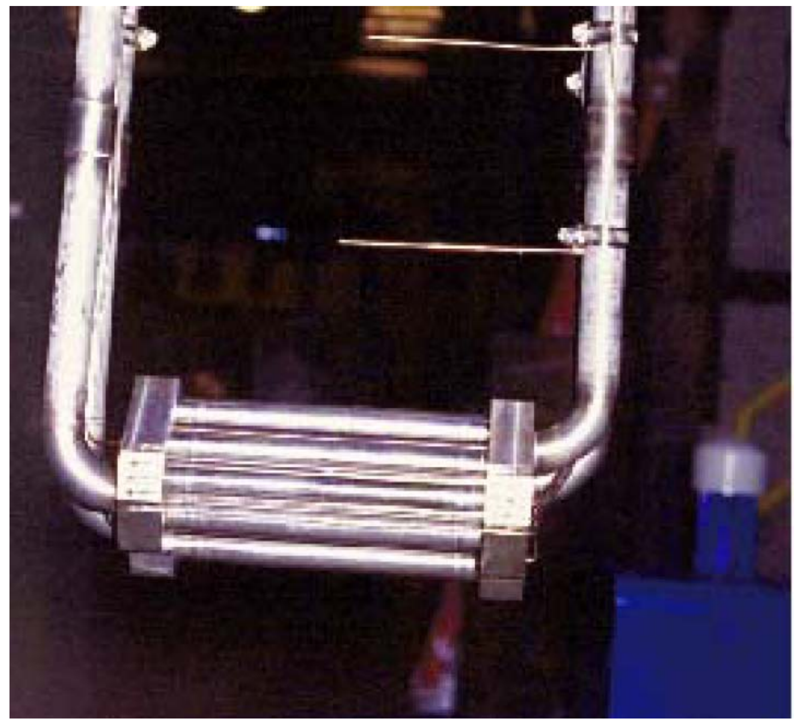


Neutron Spallation Target at LANL

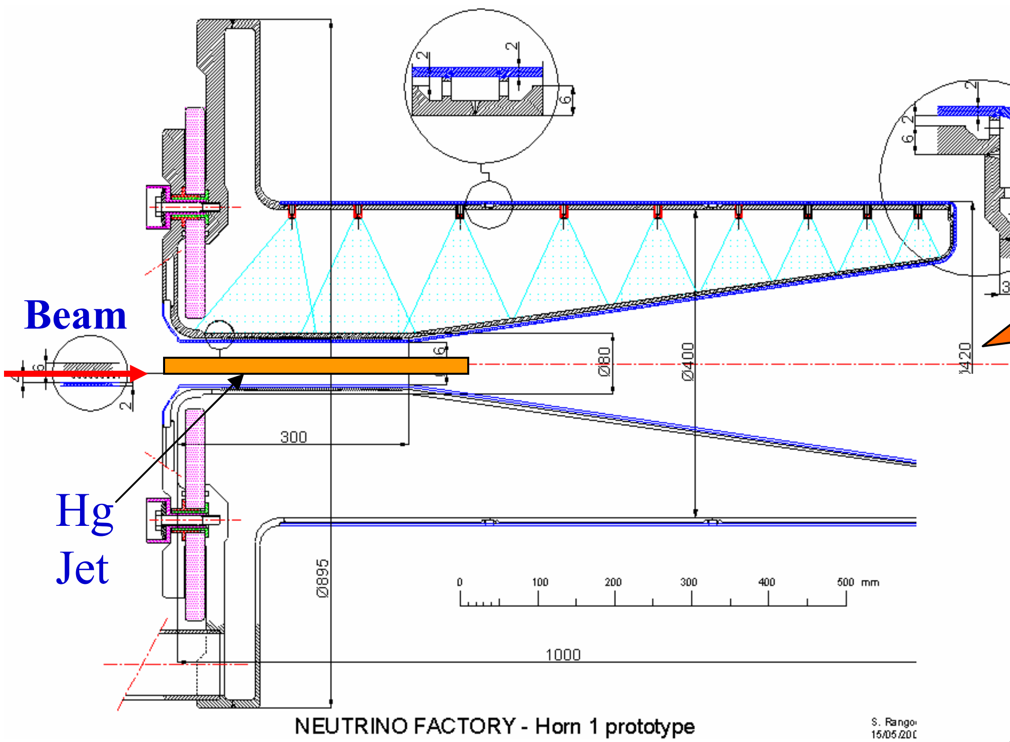
Lance p beam 0.8 GeV 0.8 MW

Stainless Steel Claded Tungsten

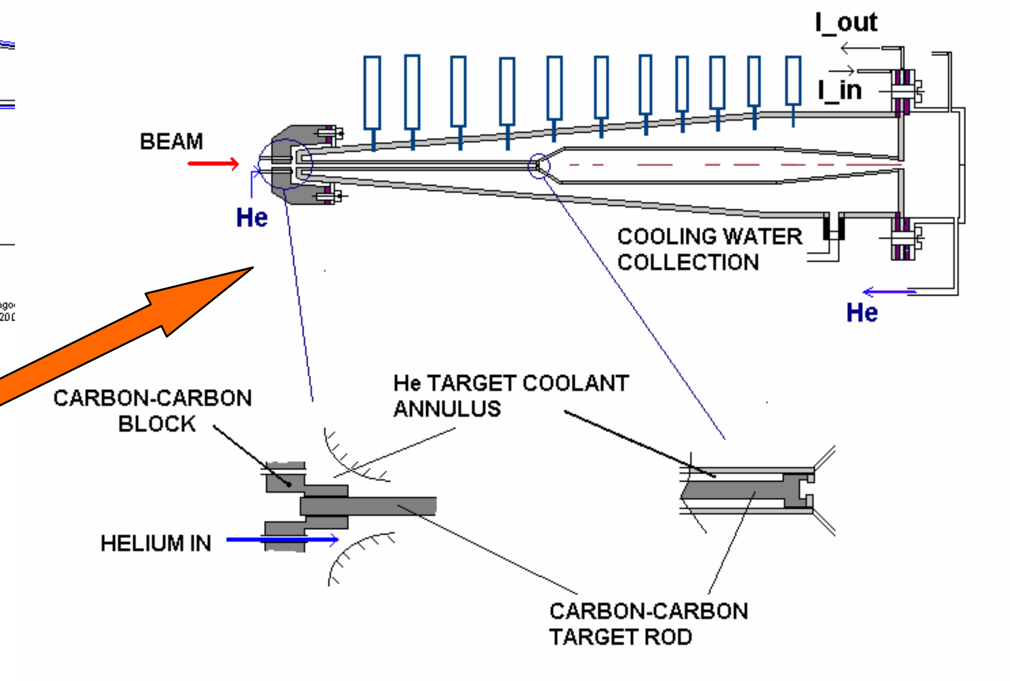
Water Cooled 100 W/g



Neutrino Horns



CERN 2.2 GeV 4MW
SPL Proton Beam
on an Hg target



BNL 28 GeV 1MW
Proton Beam on a
Carbon-Carbon target

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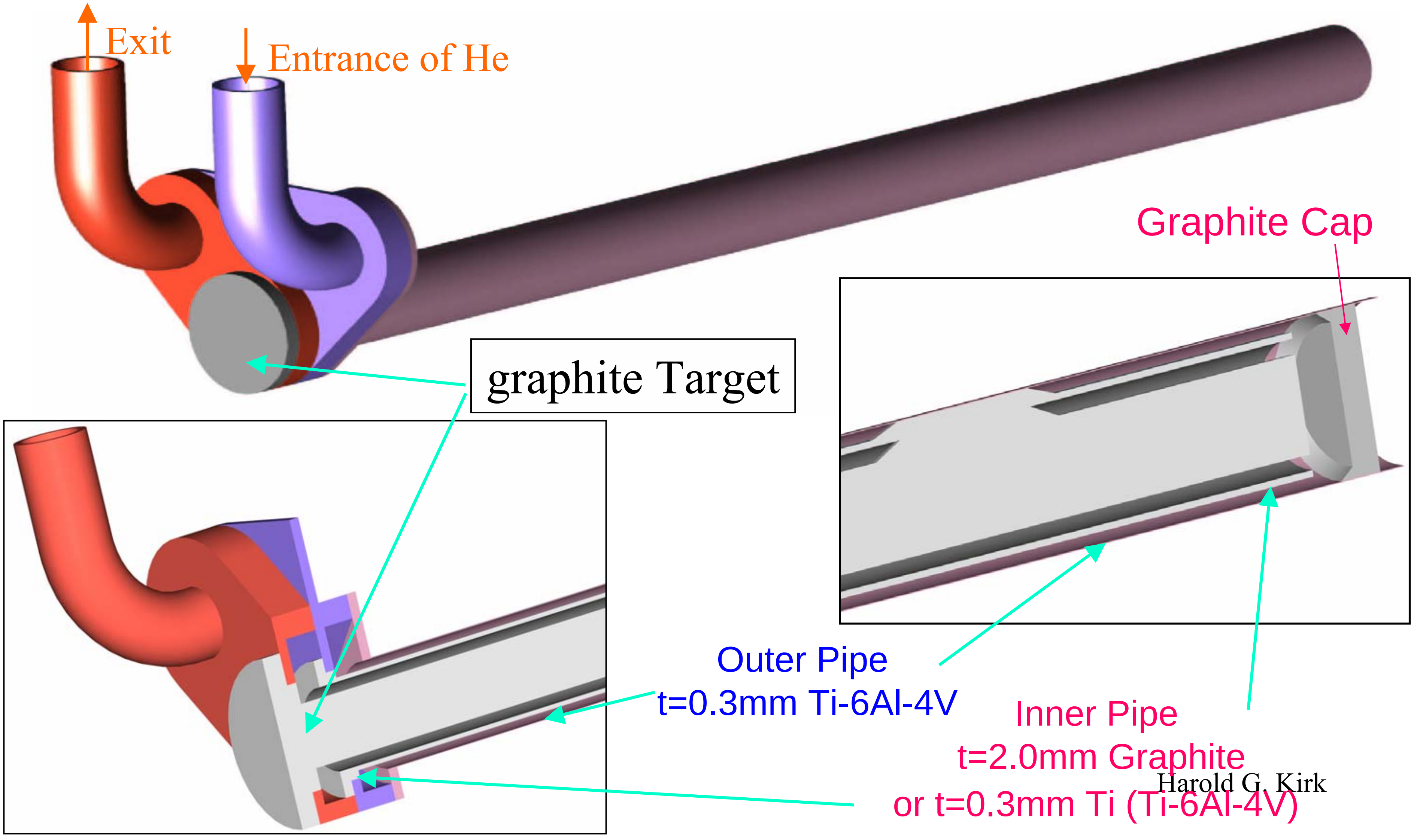
Prototype of T2K Neutrino Target

Prototype design for He cooling pipe is in progress.

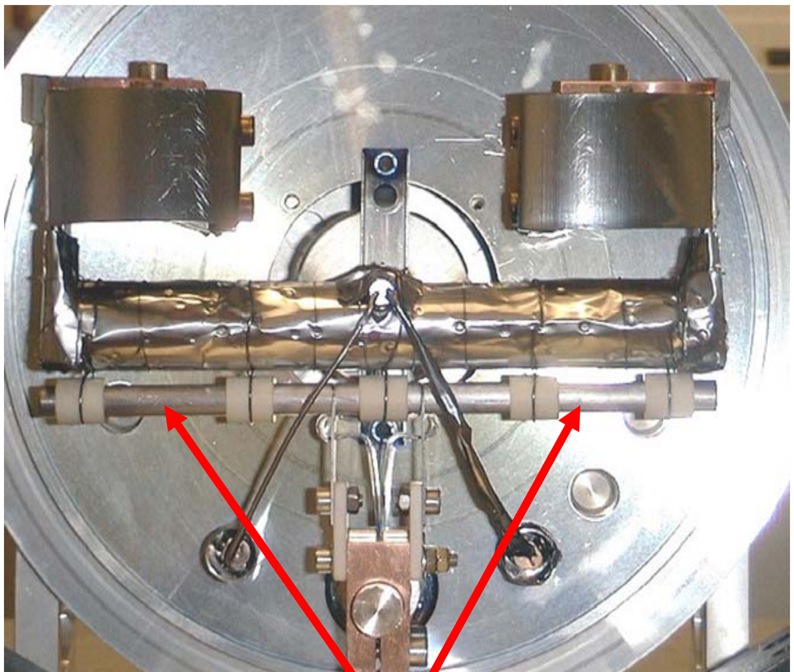


CERN ISOLDE Solid Targets

BEFORE

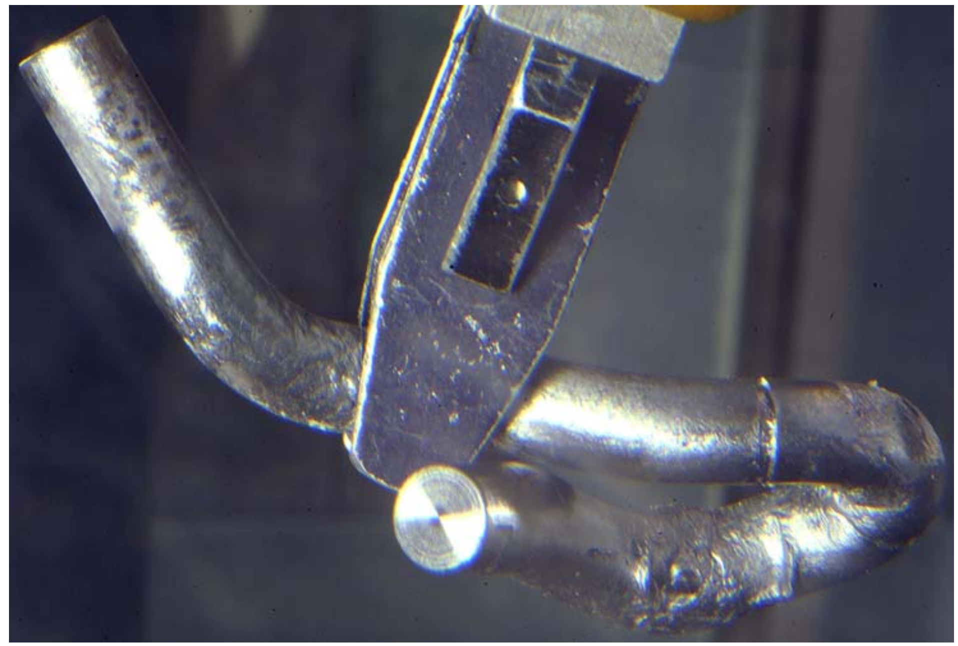
PS-Booster 1-1.4 GeV   0.005 MW

Various targets/materials



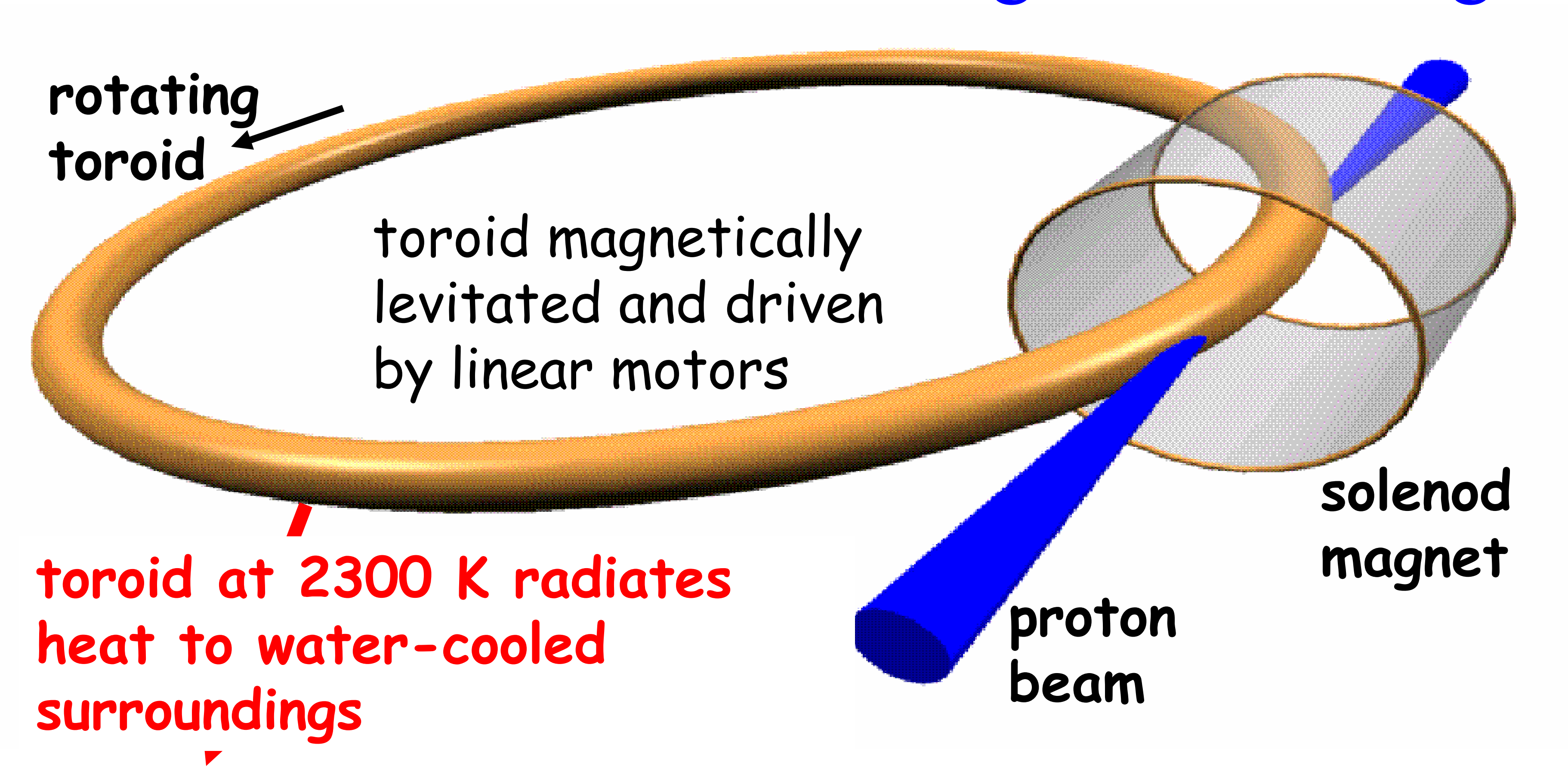
Tantalum Target

AFTER



A Rotating Solid Target

Schematic of a rotating tantalum target

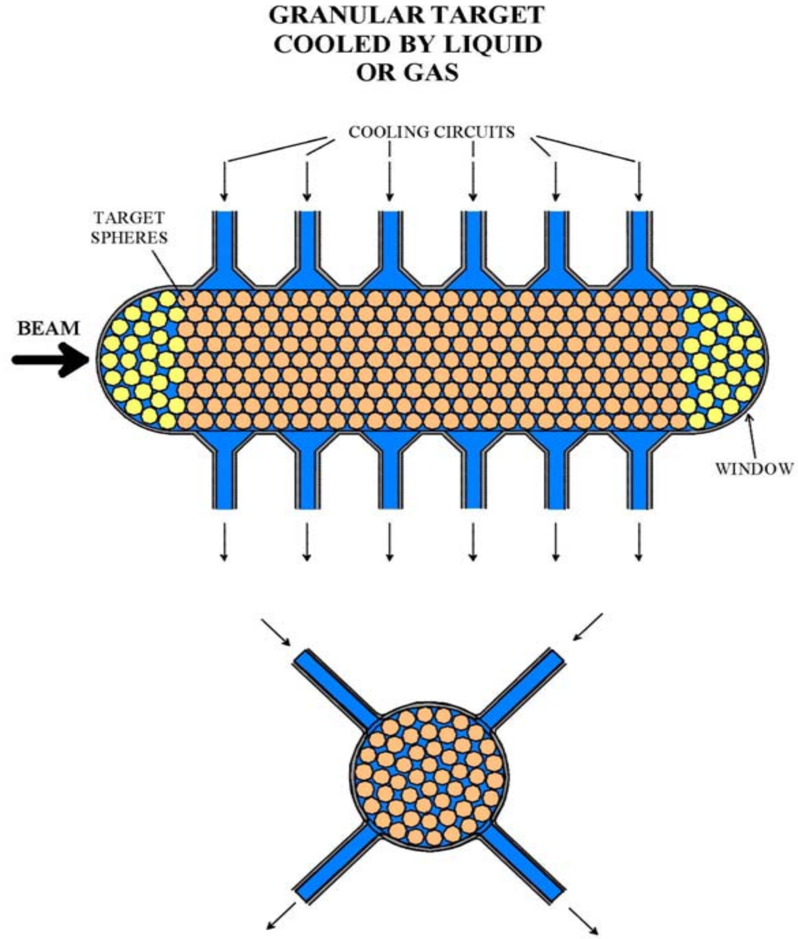


Roger Bennett, RAL

Granular Solid Target

Advantages for a granular approach

- Reduced sample volume results in reduced sample thermal gradient
- Large surface/volume ratio leads to better heat removal
- Better liquid or gas conduction through the target
- Simpler stationary solid target approach
- Could utilize high-Z target material



Peter Sievers, CERN

Liquid Metal Targets—PbBi Eutectic

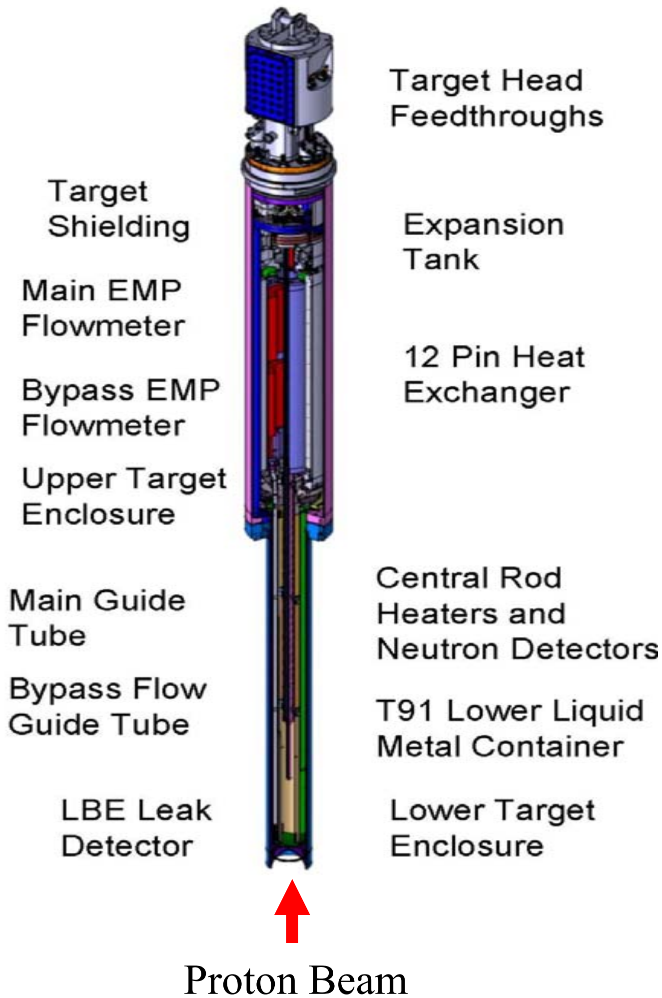
MEGAPIE Project at PSI

0.59 GeV proton beam

1 MW beam power

Goals:

- Demonstrate feasablility
- One year service life
- Irradiation in 2005



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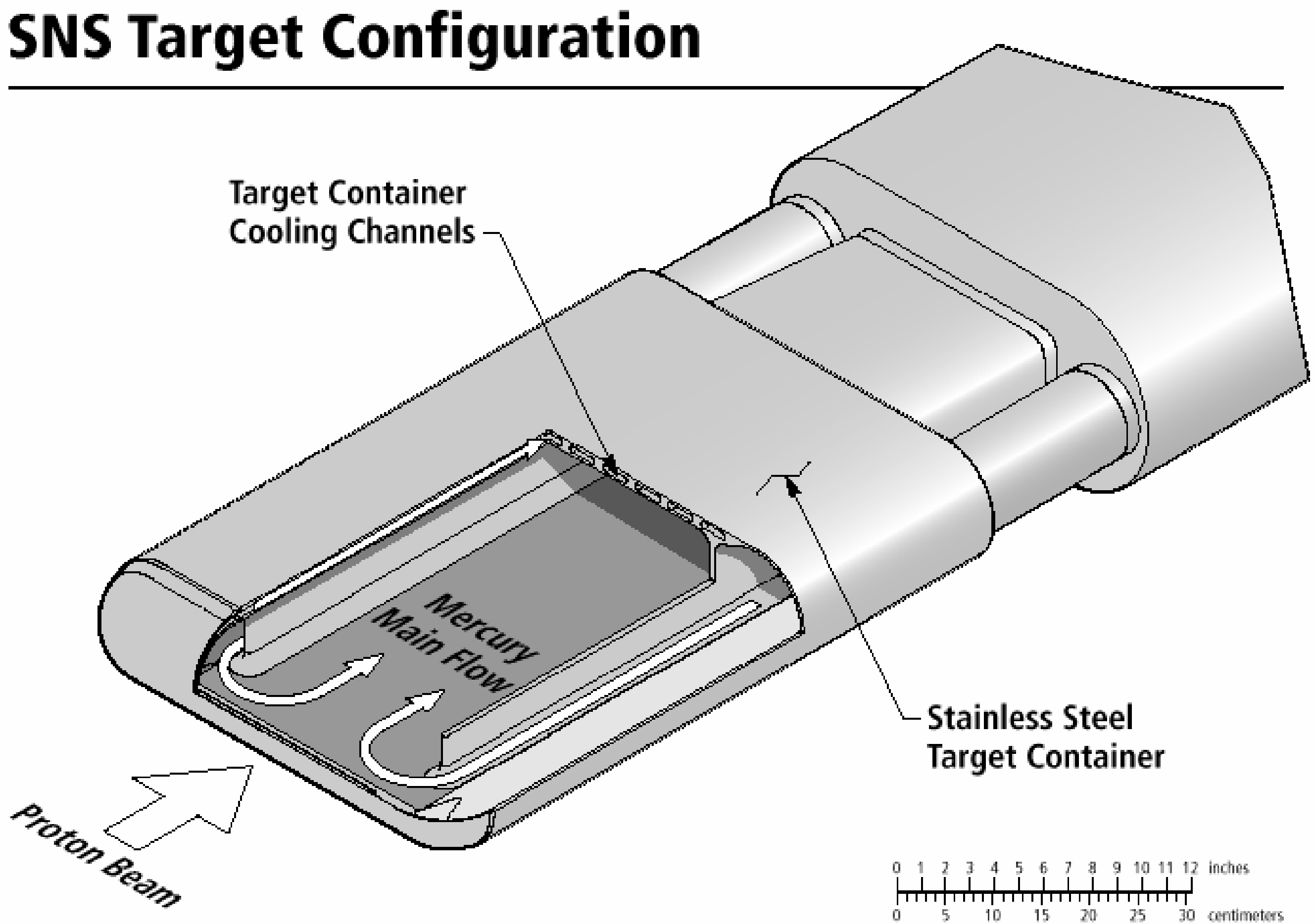
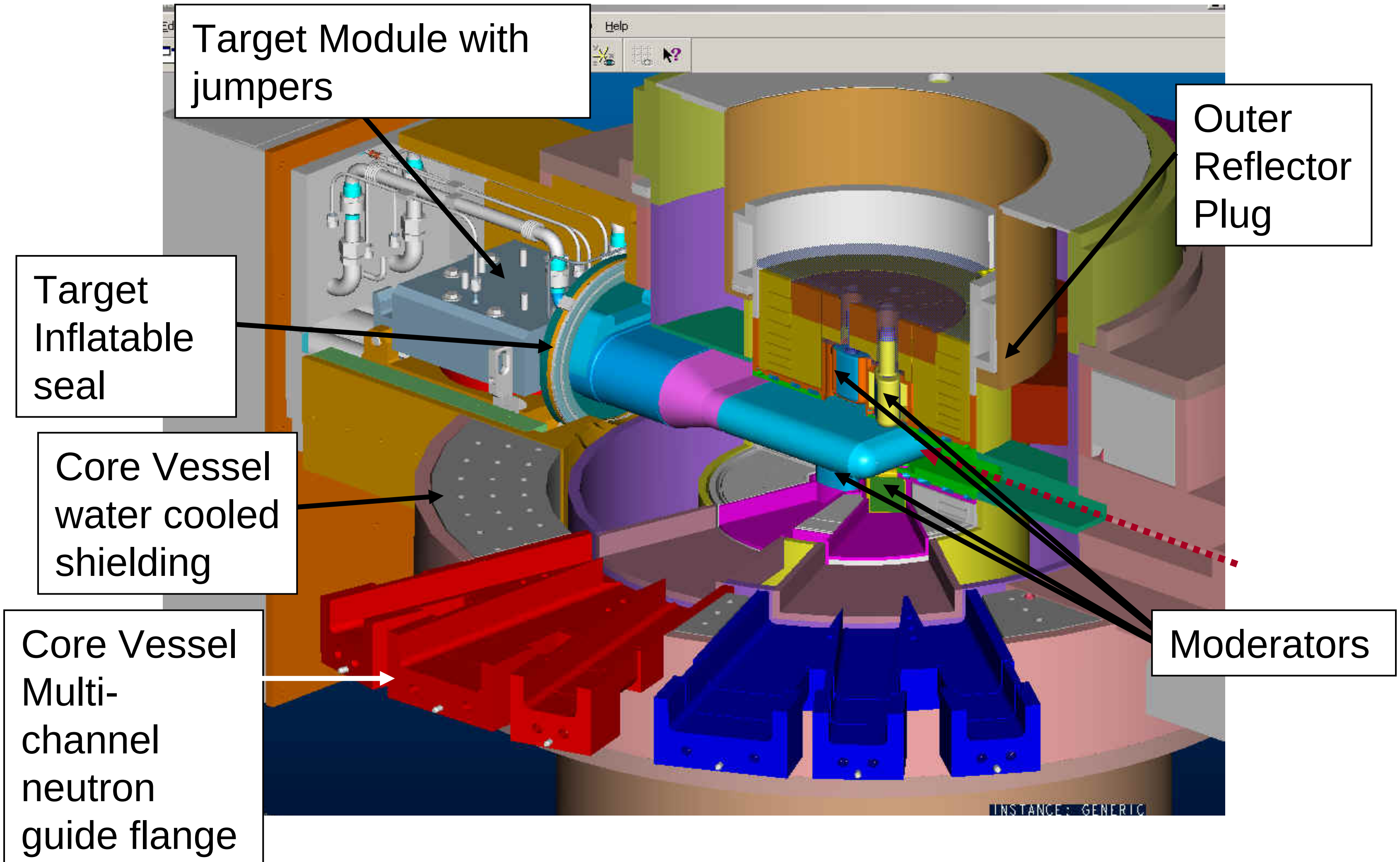
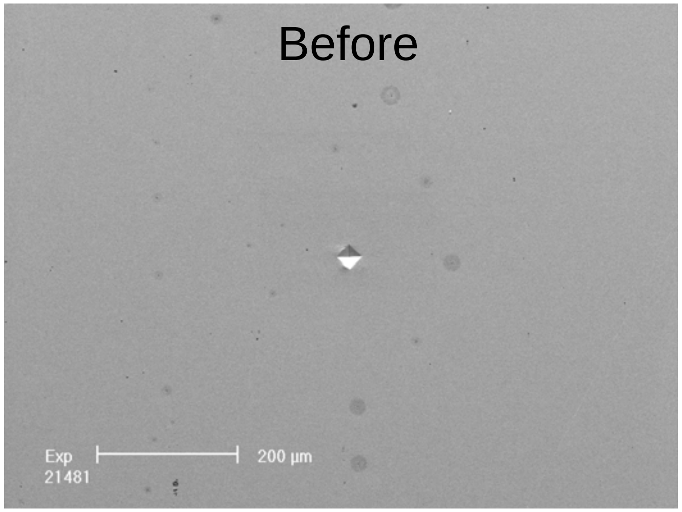
The SNS Mercury Target

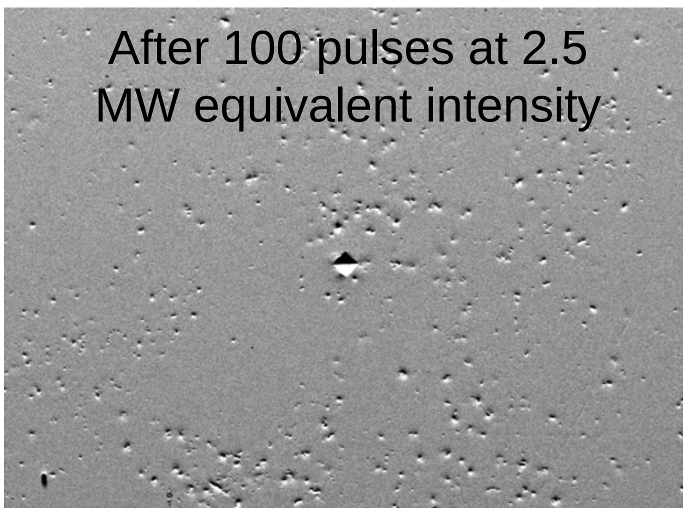


Target Region Within Core Vessel



The Target Pitting Issue





Feature	Normalized Erosion*
Gas layer near surface	0.06
Bubble Injection	0.25
Kolsterized surface	0.0008
1/2 Reference Power	0.09

* Erosion relative to reference (2.5 MW) case

ESS team has been pursuing the Bubble injection solution.
SNS team has focused on Kolsterizing (nitriding) of the surface solution.
SNS team feels that the Kolsterized surface mitigates the pitting to a level to make it marginally acceptable.
Further R&D is being pursued.

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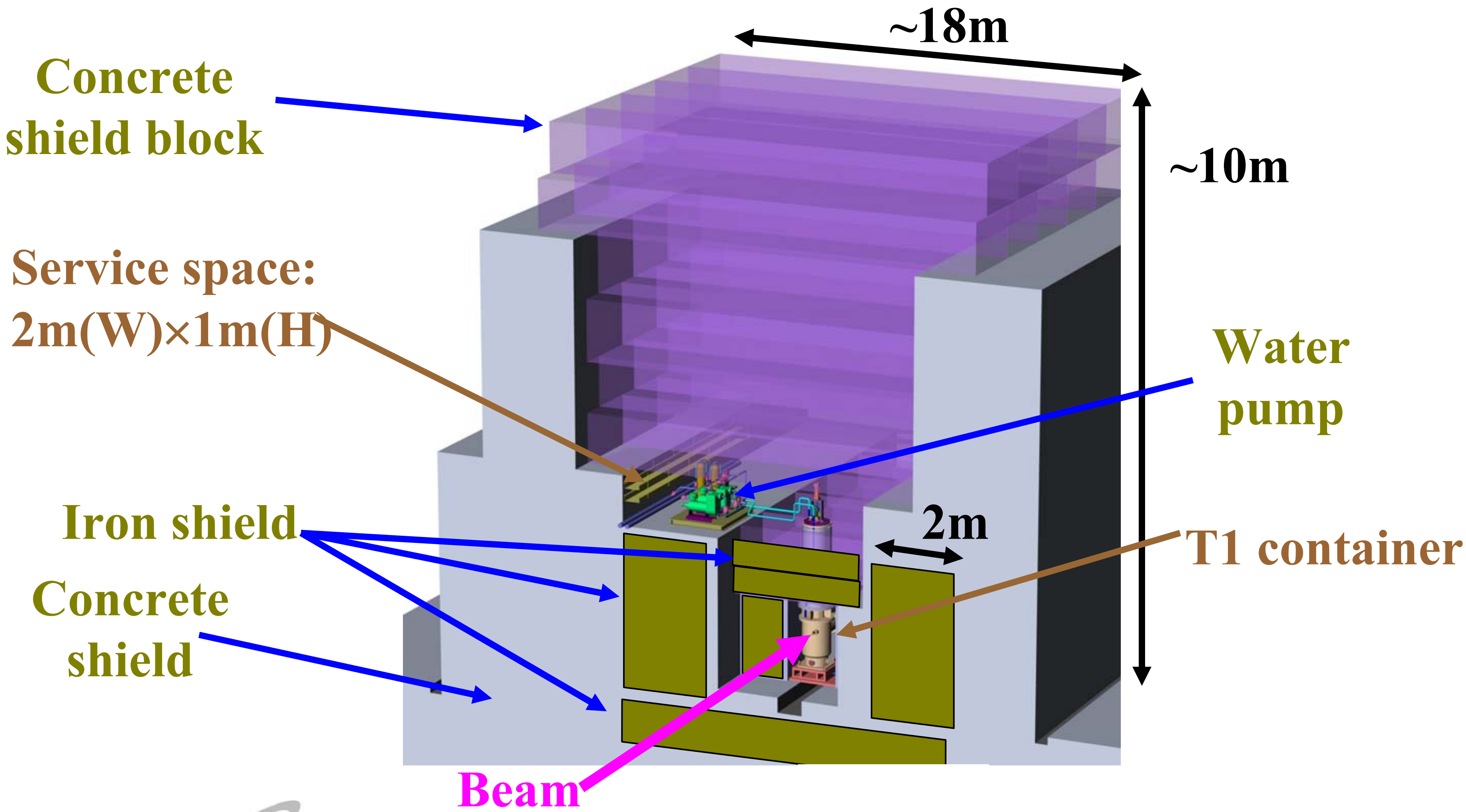
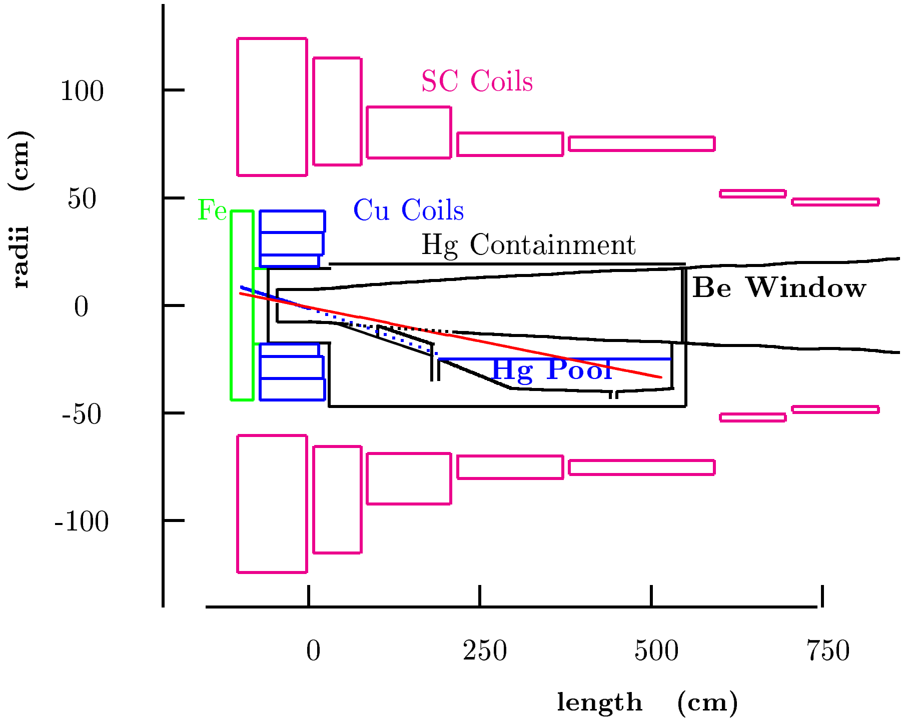
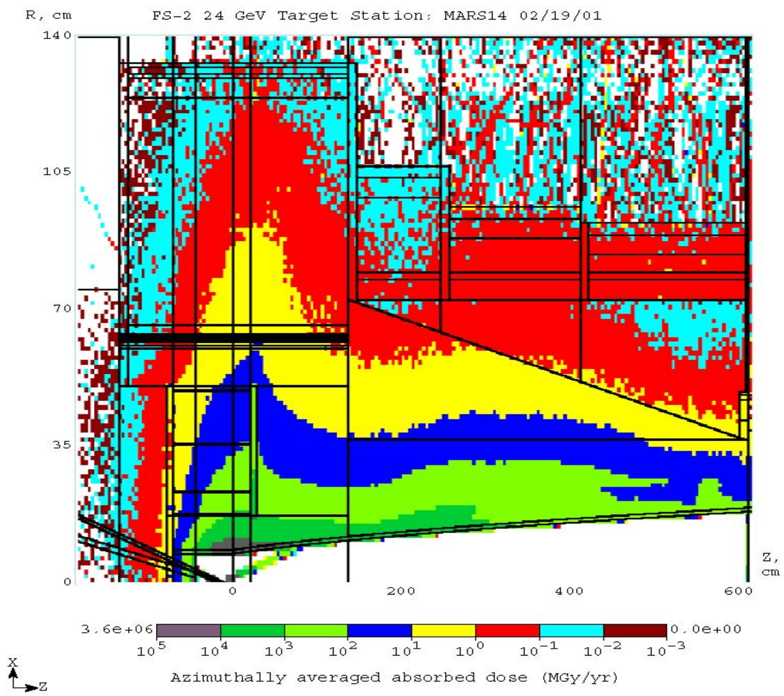
Radiation Management
The JPARC Kaon Target



The Neutrino Factory Target





Component Lifetime

Component	Radius (cm)	Dose/yr (Grays/2 x 10^7 s)	Max allowed Dose (Grays)	1 MW Life (years)	4 MW life (years)
Inner shielding	7.5	5×10^{10}	10^{12}	20	5
Hg containment	18	10^9	10^{11}	50	12
Hollow conductor coil	18	10^9	10^{11}	100	25
Superconducting coil	65	6×10^6	10^8	16	4

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High-peak Power Issues

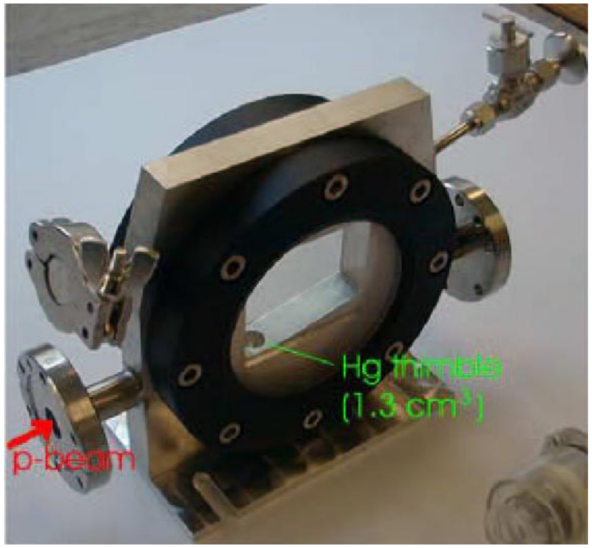
When the energy deposition time frame is on the order off or less than the energy deposition dimensions divided by the speed of sound then pressure waves generation can be an important issue.

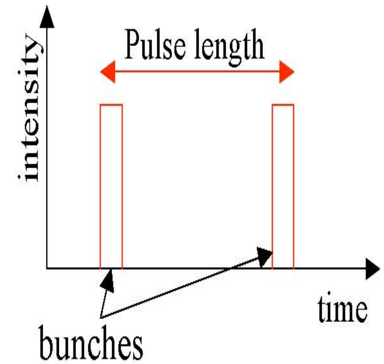
Time frame = beam spot size/speed of sound

Illustration

Time frame = 1cm / 5×10^3 m/s = 2 μs

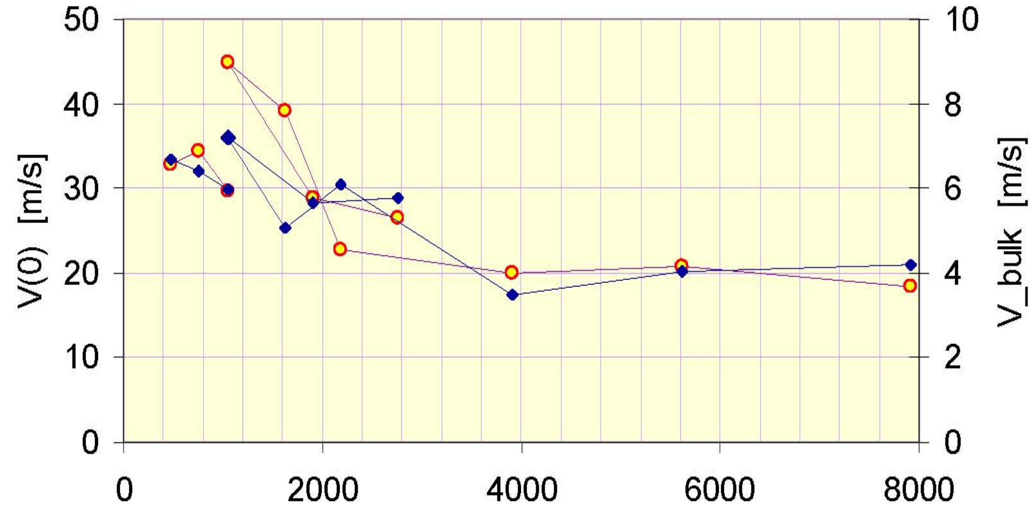
CERN ISOLDE Hg Target Tests





Pulse length

Proton beam 5.5 TP per Bunch.



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Pressure Wave Amplitude

$$\text{Stress} = Y \alpha_T U / C_V$$

Where Y = Material modulus

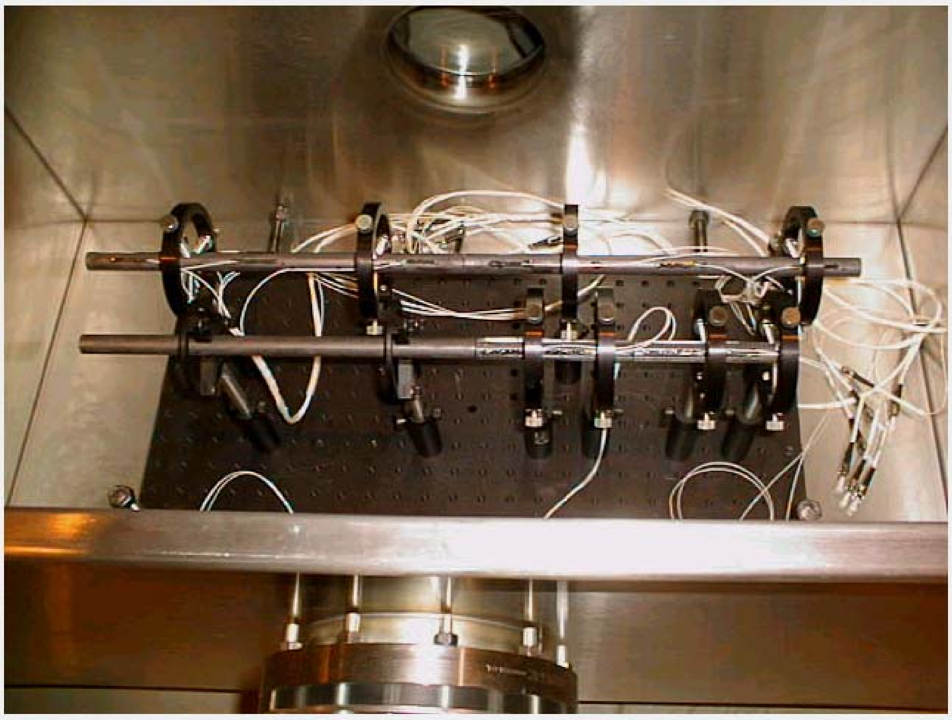
α_T = Coefficient of Thermal Expansion

U = Energy deposition

C_V = Material heat capacity

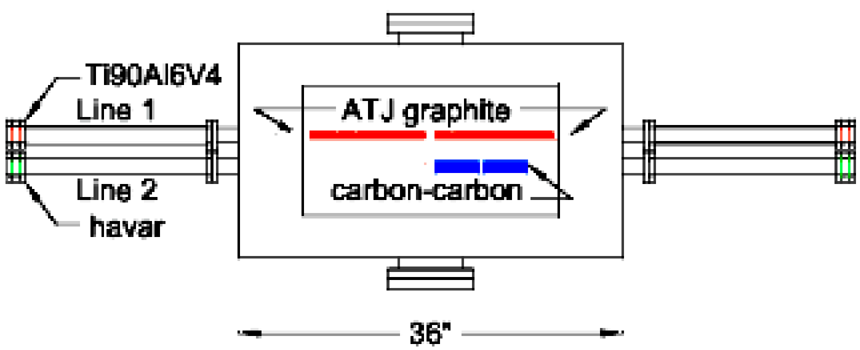
When the pressure wave amplitude exceeds material tensile strength then target rupture can occur. This limit is material dependant.

E951: Graphite & Carbon-Carbon Targets



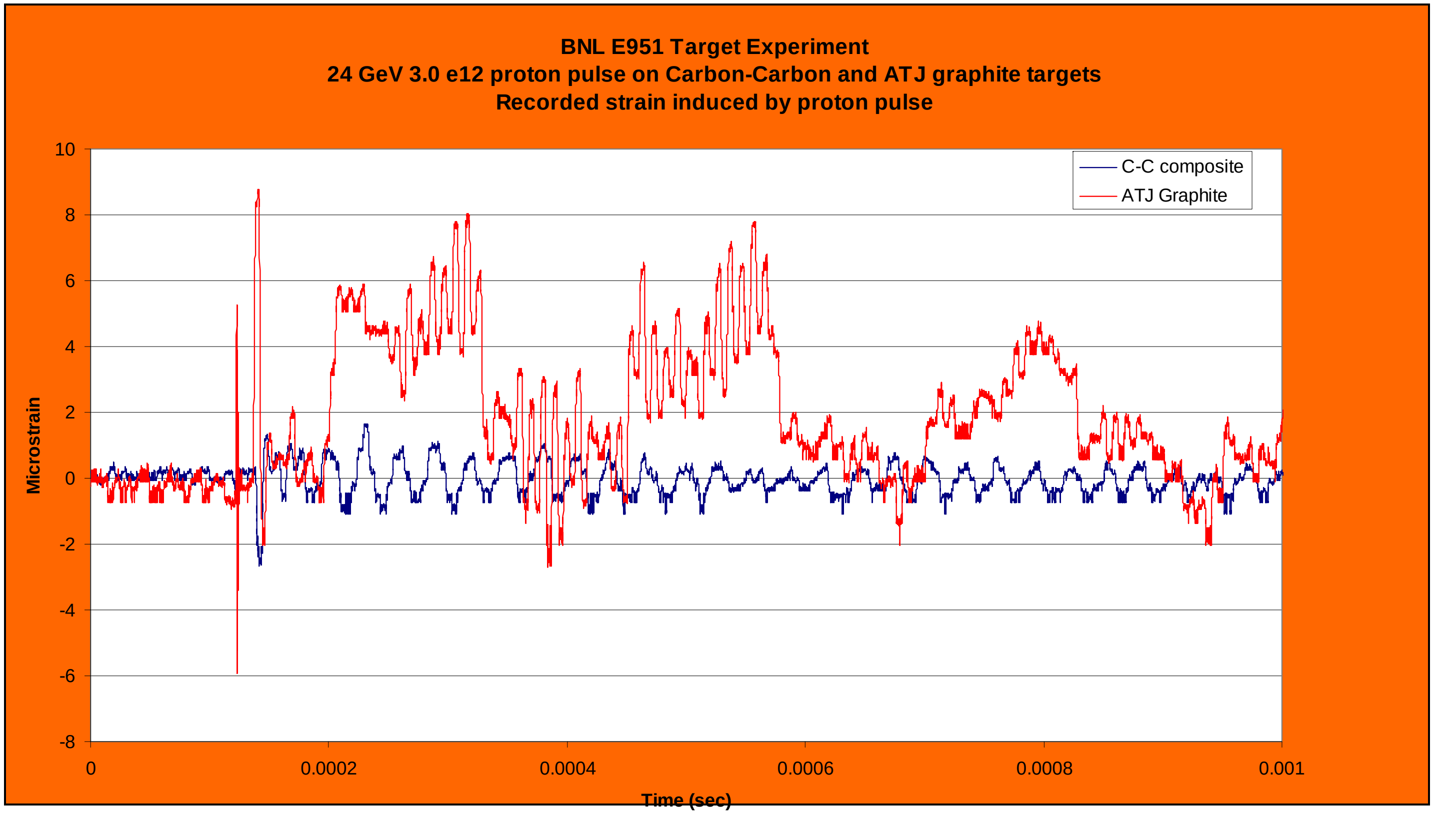
Key Material Properties

	ATJ	CC X/U
Y, GPa	10	54/5.3
α_T , $10^{-6}/^0K$	2.5	~0
Tensile Strength, MPa	15	182/44



E951: Strain Gauge Measurements

24 GeV, 3 x 10^{12} protons/pulse



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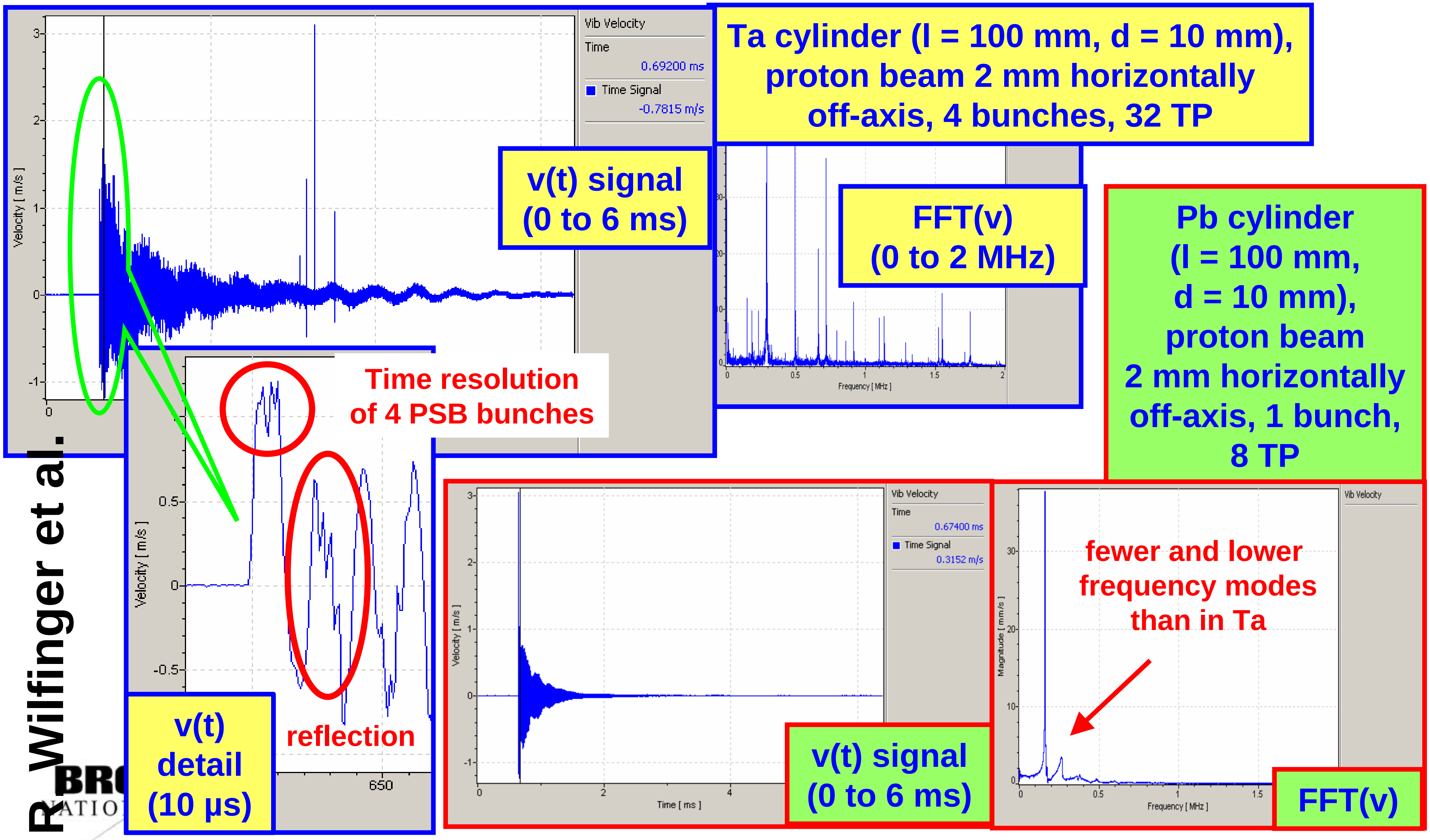
Laser-vibrometer studies of surface-movement at CERN

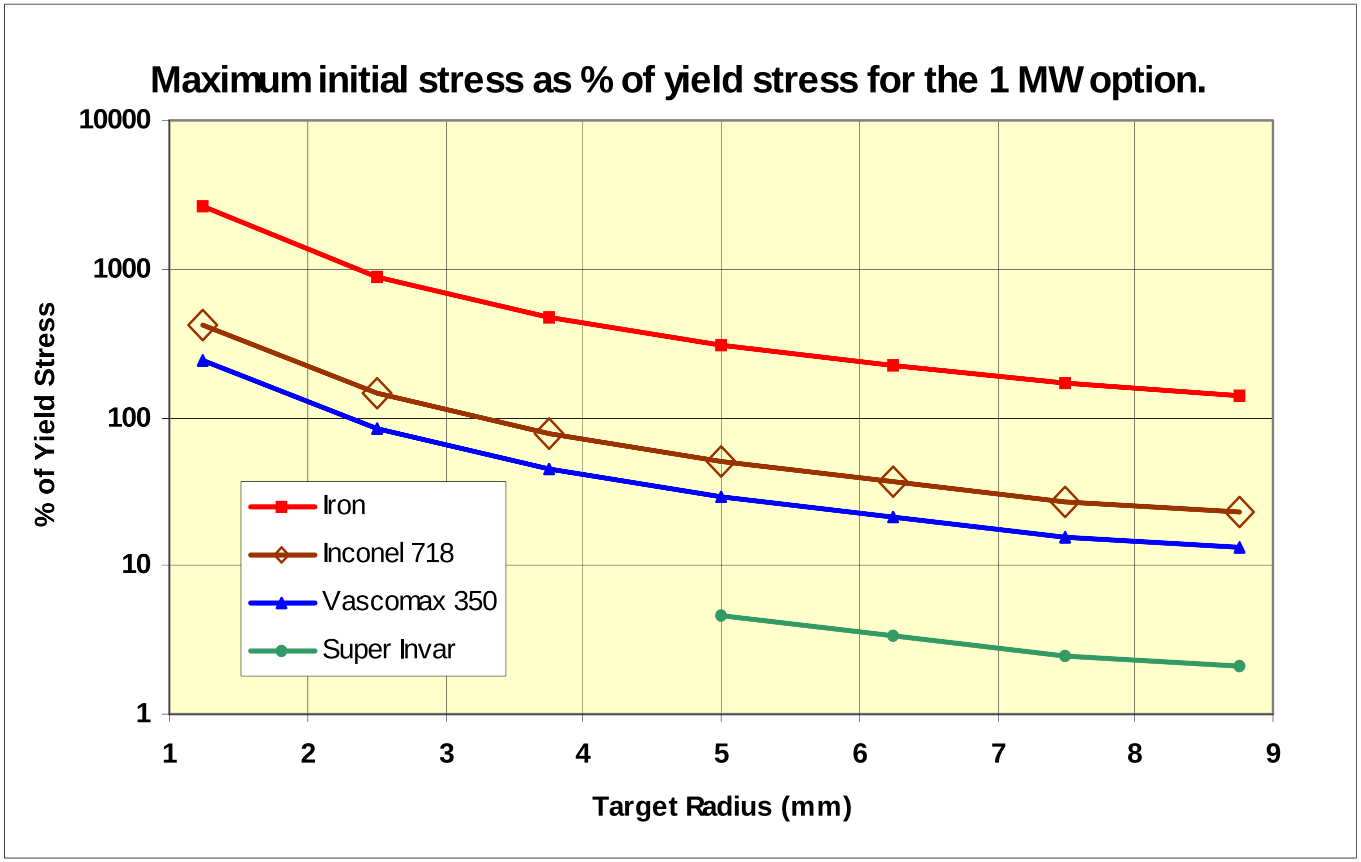


Target Material Examples

Peter Thieberger, BNL

Consider the case of a 16 TP , 3ns , 24 GeV proton pulses

Beam Induced Stress
Material Yield Strength



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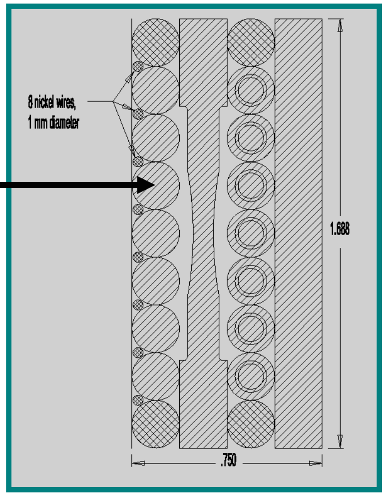
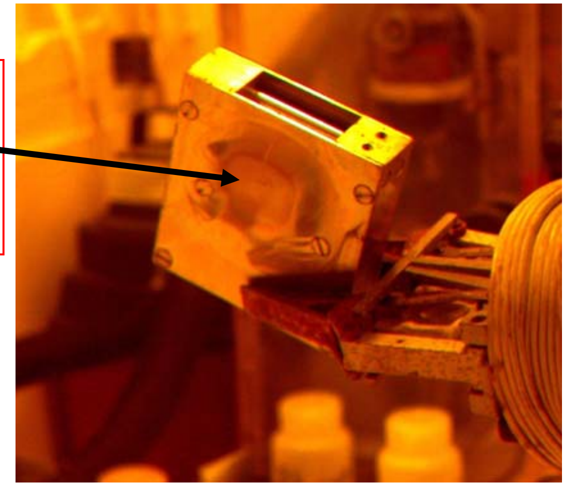
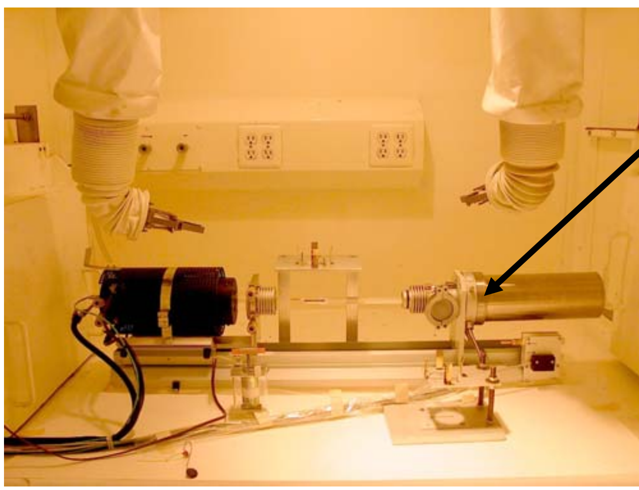
Super-invar Irradiation at BNL

The cylindrical samples of super-invar.



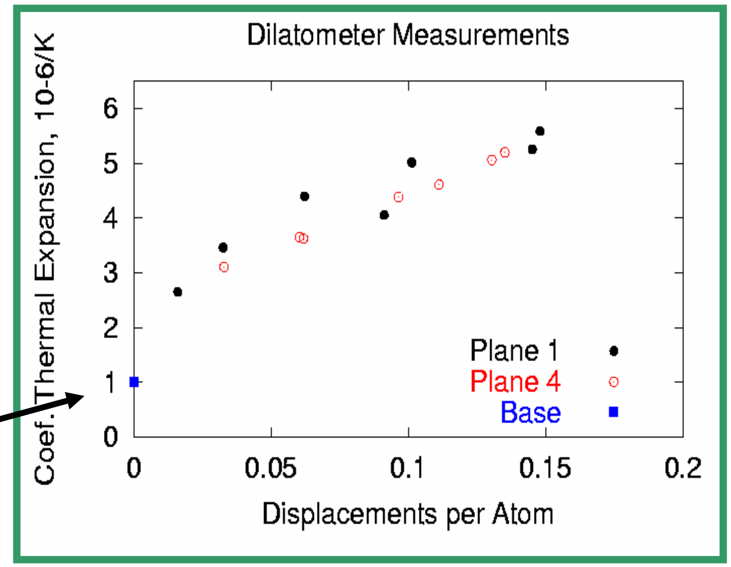
The target basket after irradiation





Dilatometer in Hot cell

Results of coefficient of thermal expansion measurements



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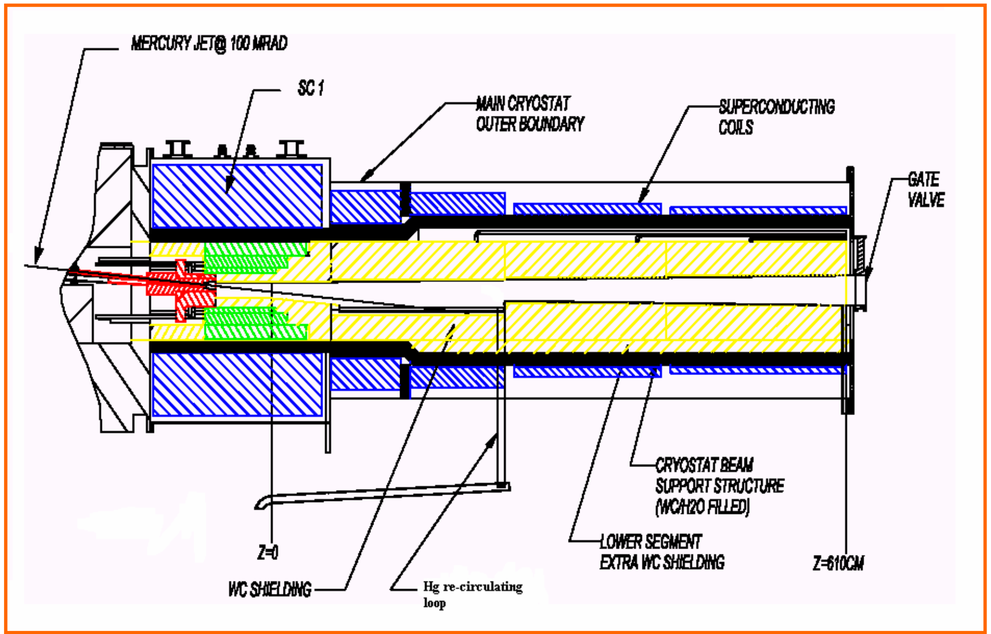
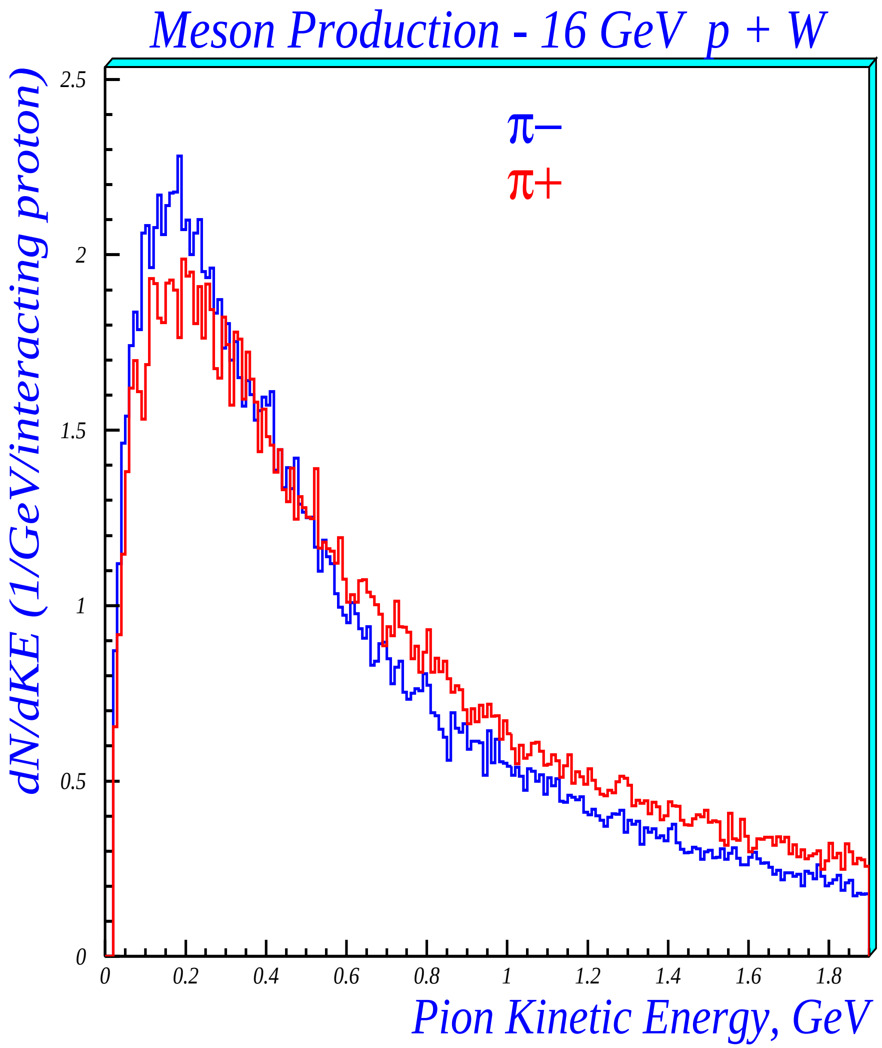
Achieving Intense Muon Beams

Maximize Pion/Muon Production

- Soft-pion Production
- High Z materials
- High Magnetic Field





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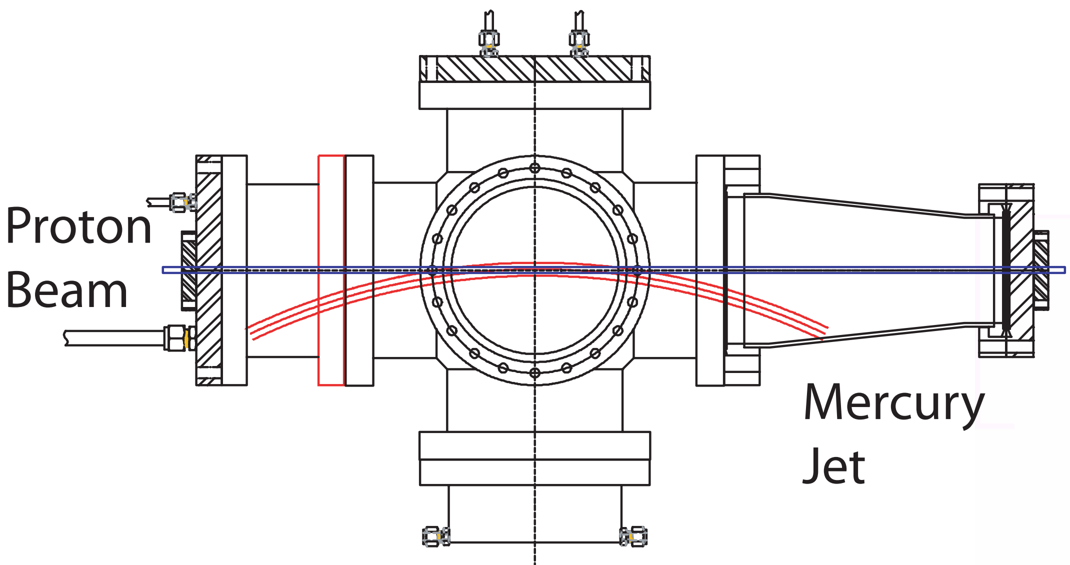
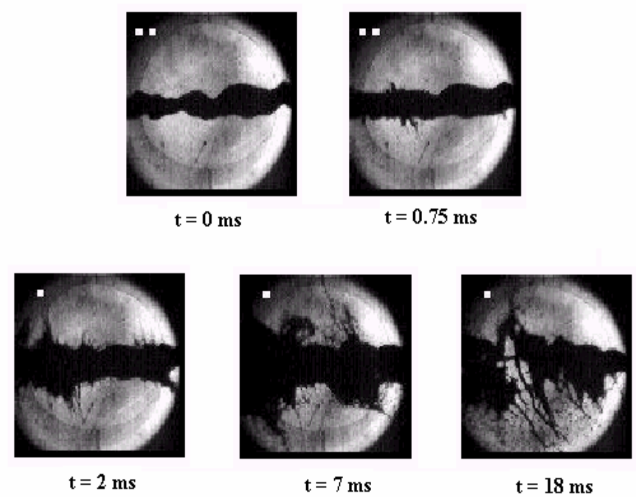
E951 Hg Jet Tests



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



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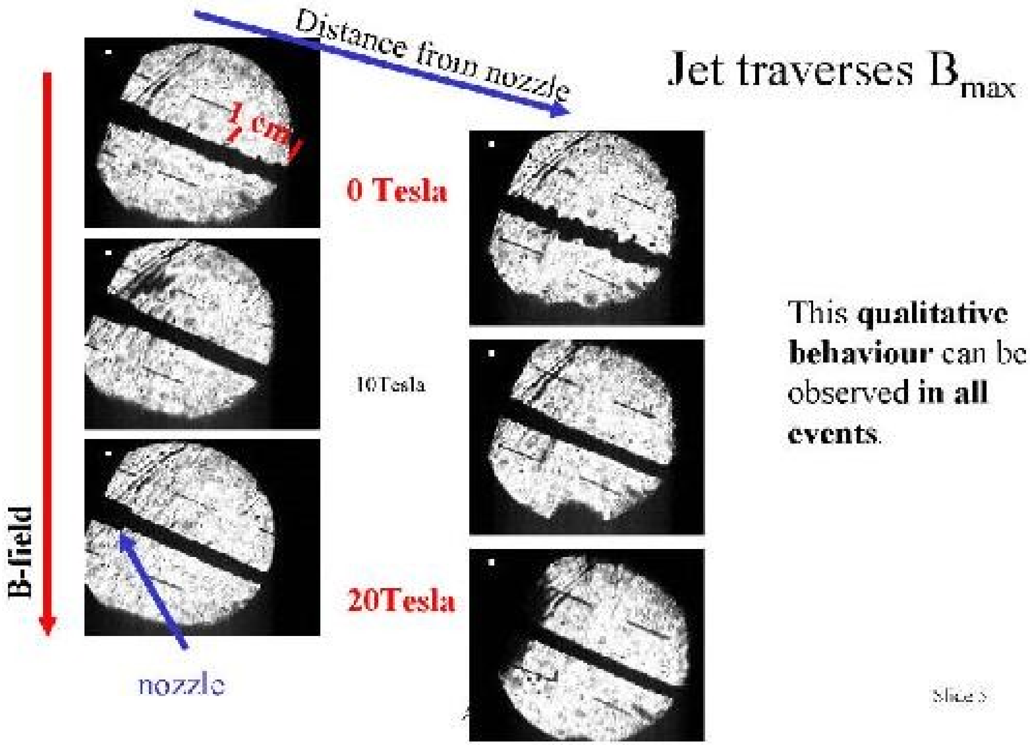
CERN/Grenoble Hg Jet Tests



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

A. Fabich, J. Lettry
Nufact'02

Key Initial Hg Jet Results

- Hg jet dispersal proportional to beam intensity (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
- The Hg jet is stabilized by the 20 T magnetic field

Bringing it all Together

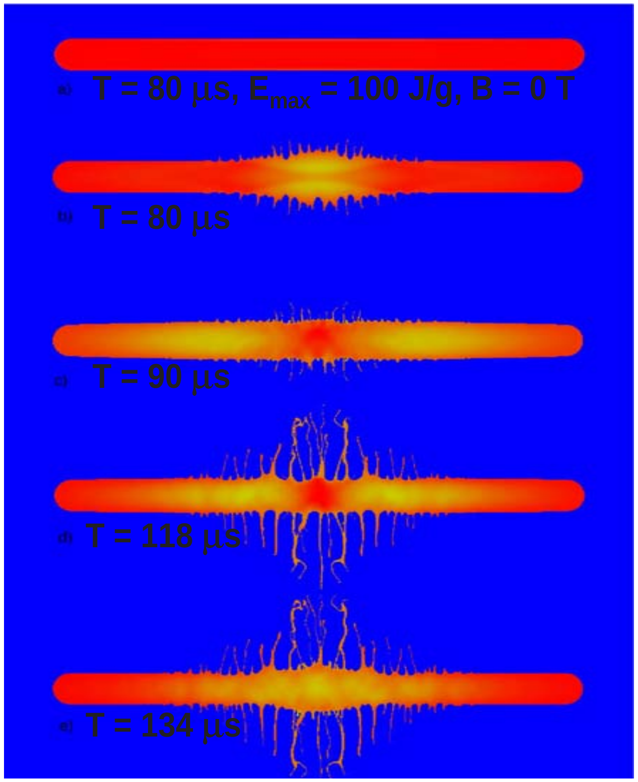
We wish to perform a proof-of-principle test which will include:

- 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

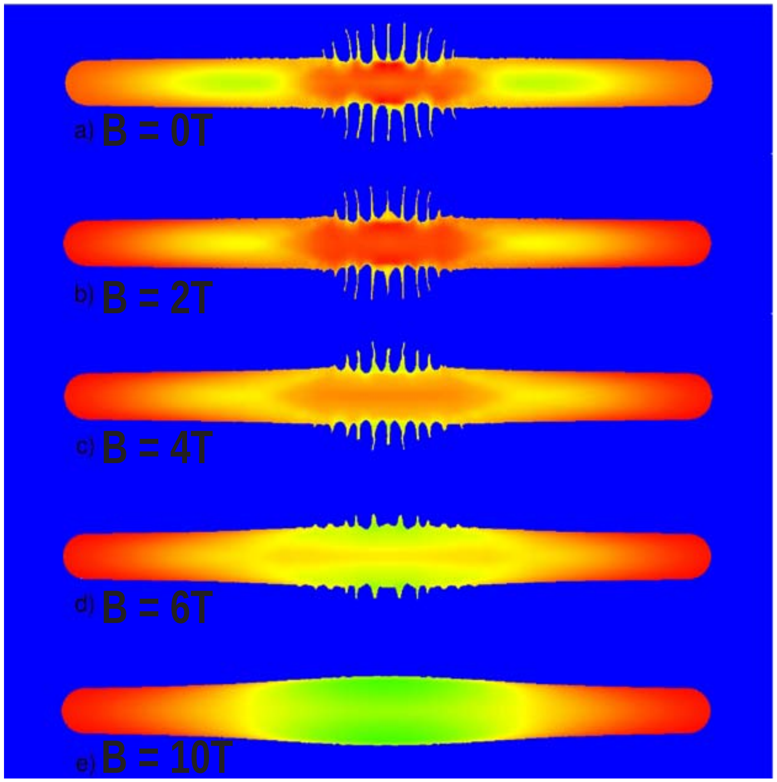
Experimental goals include:

- 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

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

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A High-power Target Test at CERN

CERN-INTC-2003-033
INTC-I-049
26 April 2004

A Proposal 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], Tony A. Gabriel[3], John R. Haines[3], Helmut Haseroth[2],
Yoshinari Hayato[4], Steven J. Kahn[5], Jacques Lettry[2], Changguo Lu[6], Hans Ludewig[5],
Harold G. Kirk[5], Kirk T. McDonald[6], Robert B. Palmer[5], Yarema Prykarpatskyy[5],
Nicholas Simos[5], Roman V. Samulyak[5], Peter H. Thieberger[5], Koji Yoshimura[4]

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

Participating Institutions

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

Proposal submitted April 26, 2004

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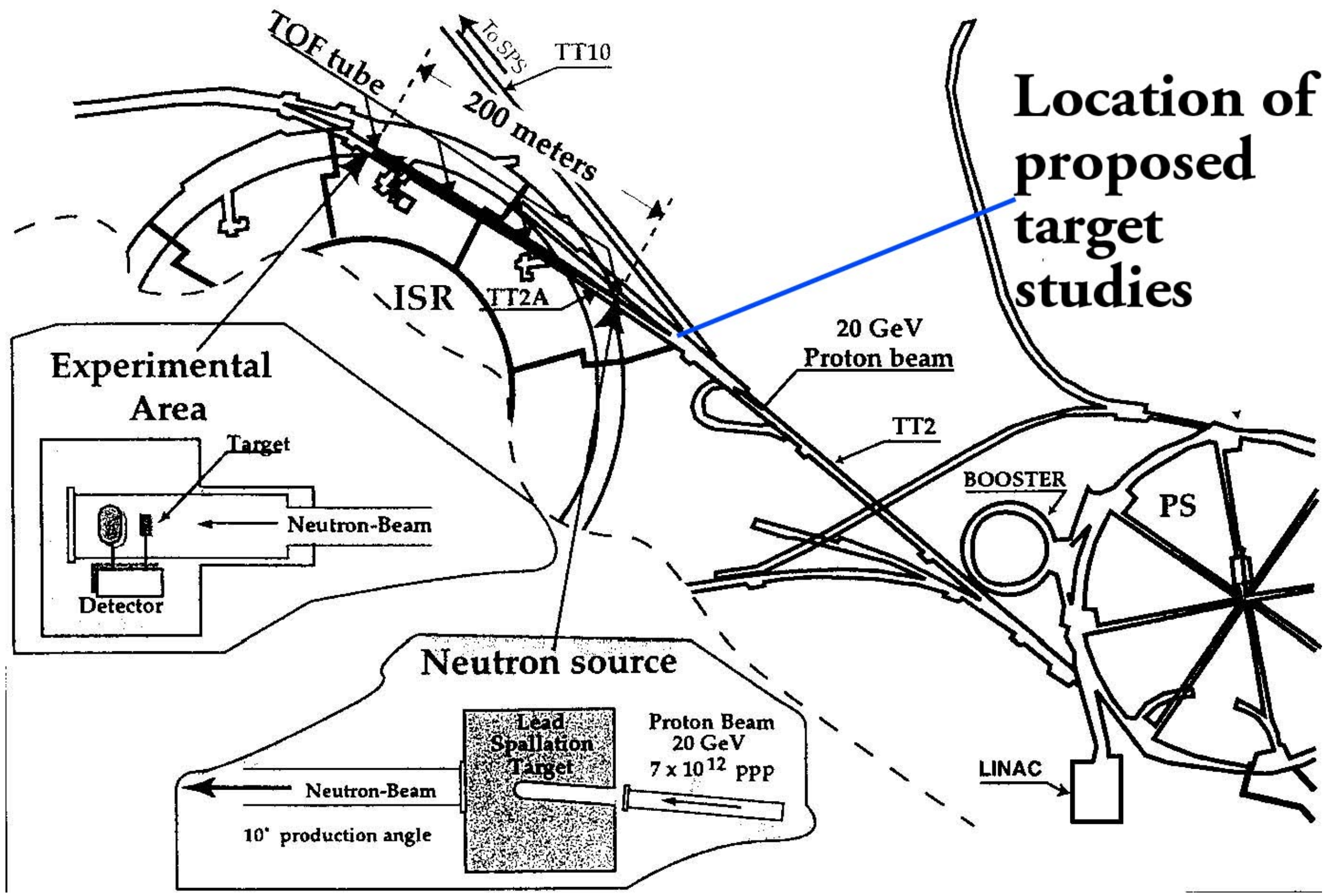
Proposed Target Test Site at CERN



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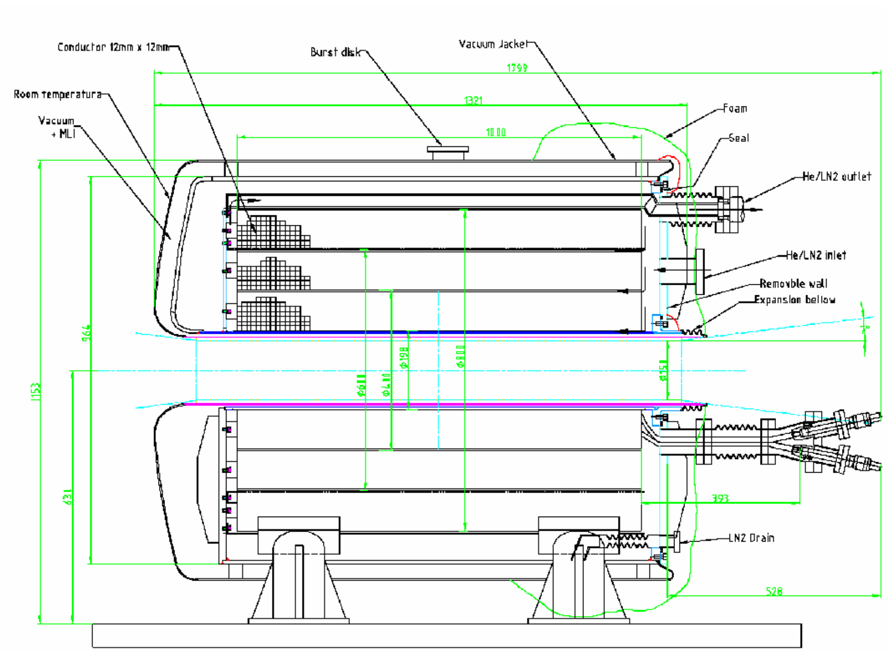
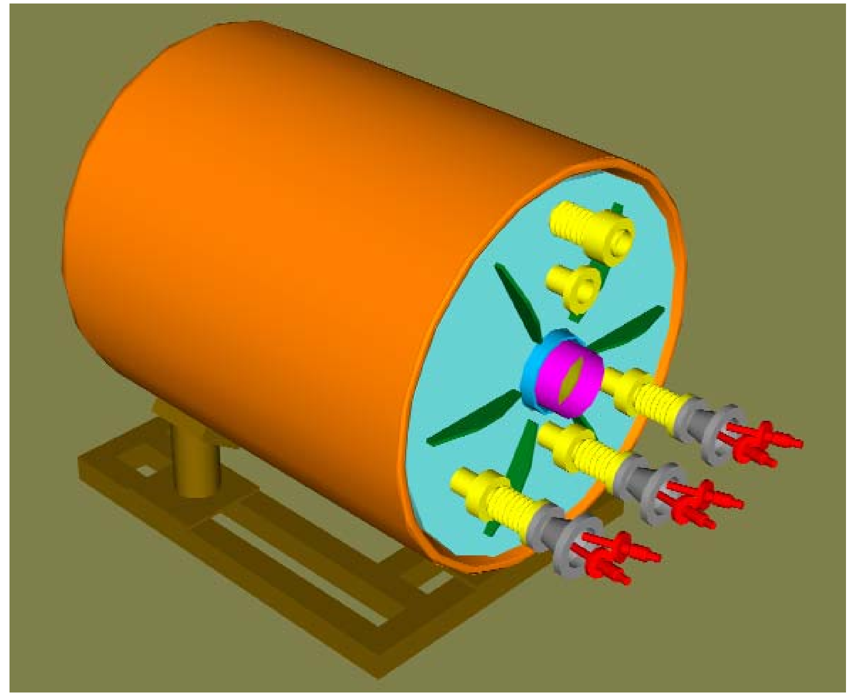
High Field Pulsed Solenoid





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

Peter Titus, MIT

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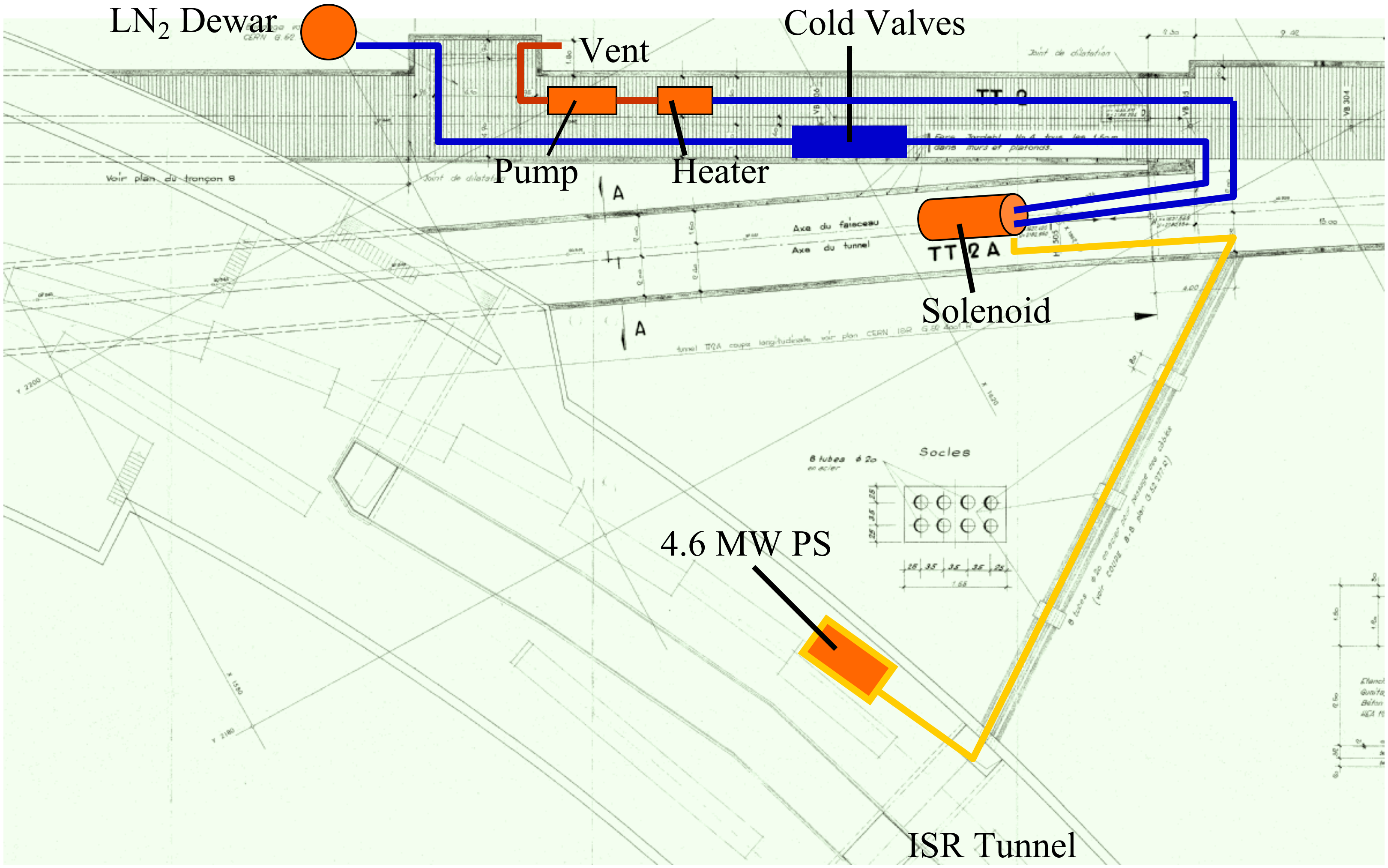
Layout of the Experiment



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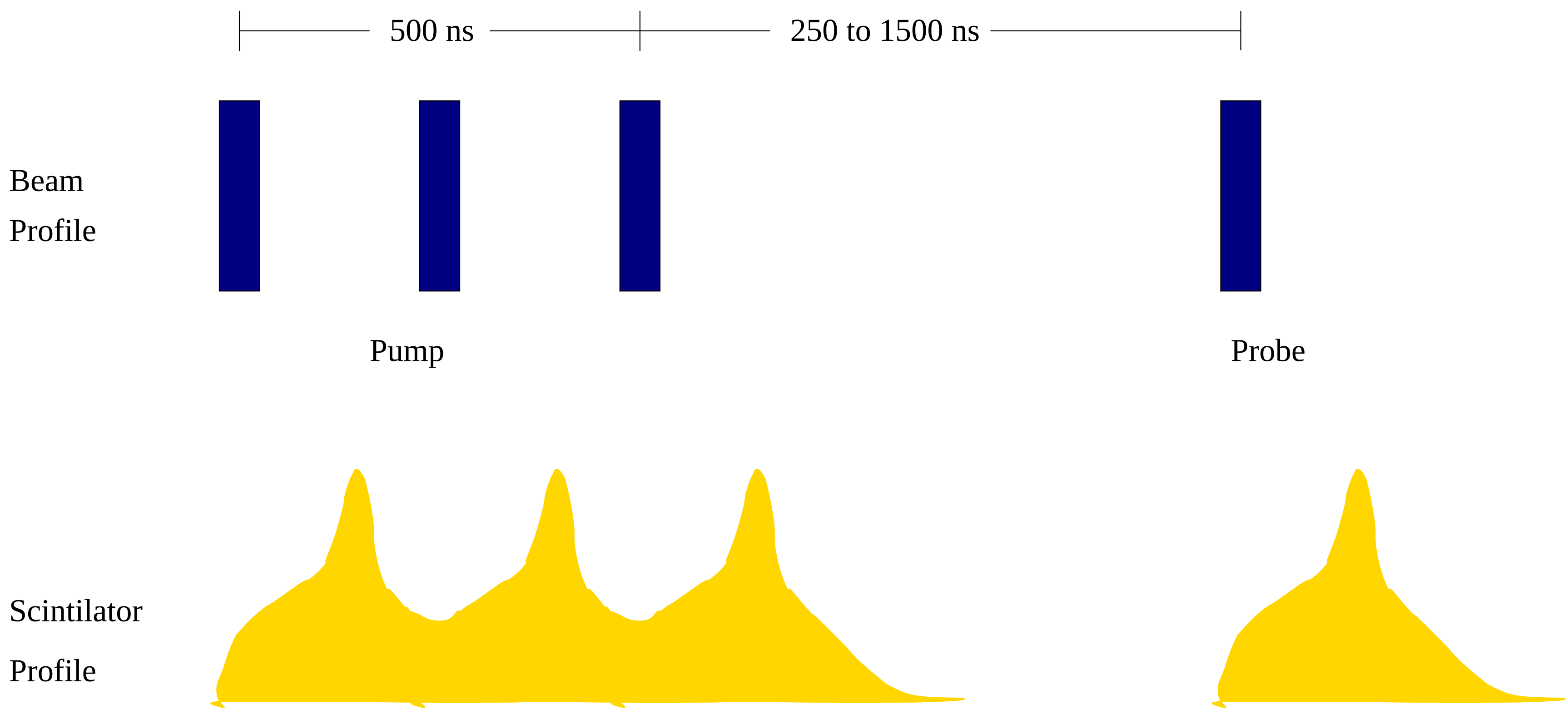
PS Extracted Beam Profile



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Conclusions

- New physics opportunities are establishing the case for the development of new high-power proton drivers.
- High-power targets are necessary for the exploitation of these new machines.
- Target systems have been developed for the initial 1MW class machines, but are as yet unproven.
- No convincing solution exists as yet for the envisioned 4 MW class machines.
- A world wide R&D effort is under way to develop new high-power targets and BNL is part of that effort.