Advances in High-Power Targets

PAC 07

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BROOKHAVEN
NATIONAL LABORATORY

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The Drive for Intense (MW Class) Sources

In Operation:

LANSCE: 0.8 MW -- 0.8 GeV Protons
PSI: 1.2MW -- 0.6 GeV Protons
CERN SPS: 0.5MW -- 400 GeV Protons

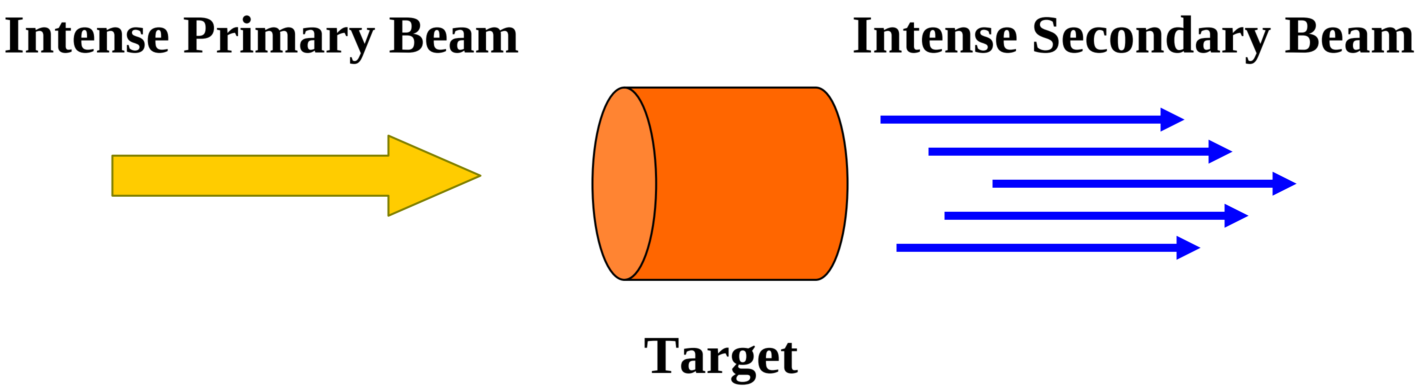
Under Construction:

SNS: 1.4 MW – 1 GeV Protons
JPARC: 0.75MW -- 50 GeV Protons

Under Consideration:

BNL AGS: 2MW -- 30 GeV Protons
ISIS: 1MW -- 0.8 GeV Protons
FNAL Main Injector: 2MW -- 120 GeV Protons
JPARC: 4MW -- 50 GeV Protons
SNS: 2MW -- 1 GeV Protons
SPL: 4MW -- 3.5 GeV Protons

The Challenge: Convert to Secondaries



Secondary Beams for New Phyisics

- Neutrons (e.g. for neutron sources)
- π's (e.g. for Super ν Beams)
- μ's (e.g. for Muon Colliders, Neutrino Factories)
- Kaons (e.g. for rare physics processes)
- γ's (e.g. for positron production)
- Ion Beams (e.g. RIA, EURISOL, β-Beams)

Facilities with High-Power Target Interest

AGS	ESS
EURISOL	IFMIF
ISIS	JPARC
LANCE	Muon Collider
Neutrino Factory	NUMI
ILC	RIA
SINQ	SNS

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

Choices of Target Material

- Solid
  - Fixed
  - Moving
  - Particle Beds
- Liquid
- Hybrid
  - Particle Beds in Liquids
  - Pneumatically driven Particles

Desirable Attributes for High-Power Targets

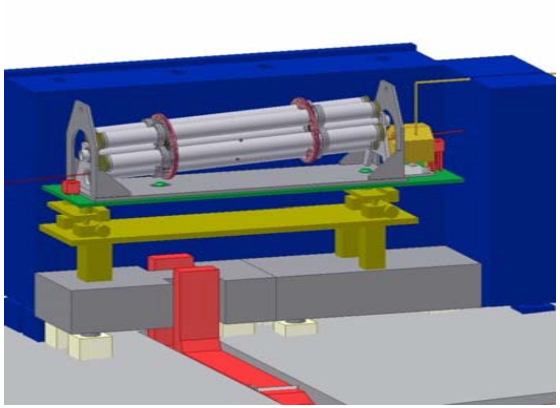
- High heat capacity, C_V (to reduce thermal load)
- Low thermal expansion, α_T (especially for pulsed beams)
- Low bulk modulus, Y (to reduce stress)
- High yield strength, (for solids to resist fracturing)
- Good diffusivity (to quickly move the heat away)
- Resistance to irradiation damage (to retain the beneficial properties)

Stress = $Y \, \alpha_T \, U / C_V$

Where U is energy deposition

(> 100 J/g is Considered Aggressive)

Static Solid Target Examples



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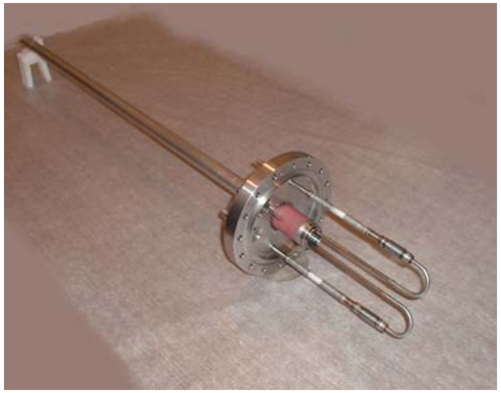

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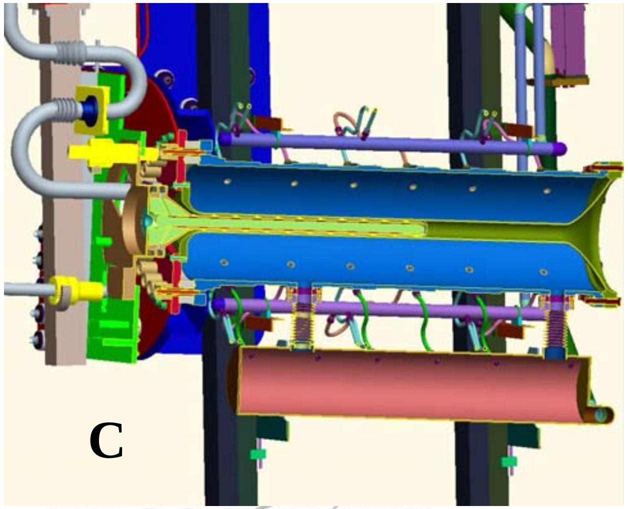

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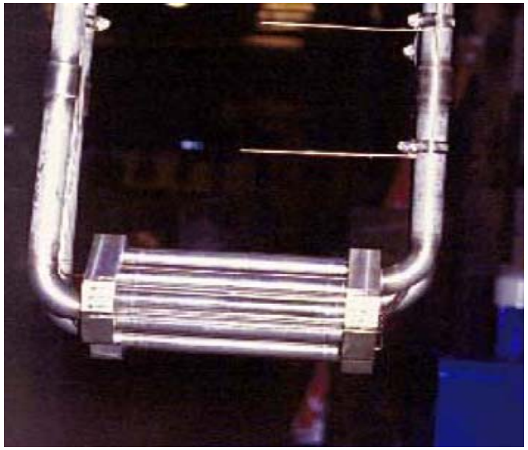


D

A. CERN CNGS
Carbon 750 J/g
He Gas Cooled

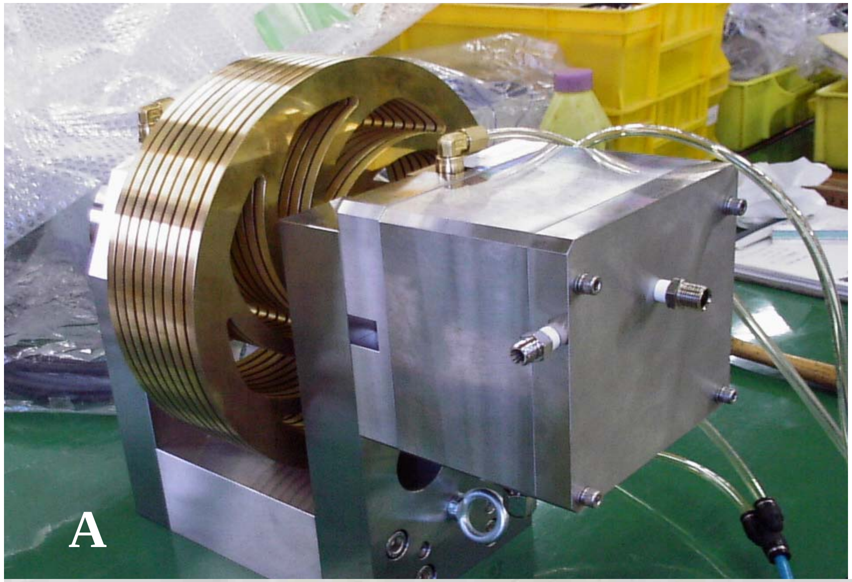
B. FNAL NUMI
Carbon 350 J/g
Water Cooled

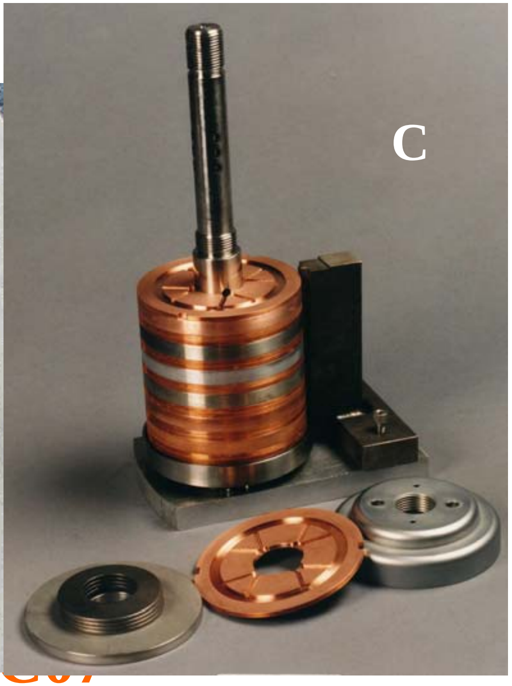
C. JPARC T2K
Carbon 170 J/g
He Gas Cooled

D. Los Alamos NS
Tungsten 100 J/g

Moving Solid Target Examples

A. **KEK Kaon Target-Ni Pulsed 600 J/g Water Cooled**
B. **PSI Target-M- Carbon CW 30 J/g Radiation Cooled**
C. **FNAL Pbar Target-Various materials Pulsed 800 J/g Air Cooled**



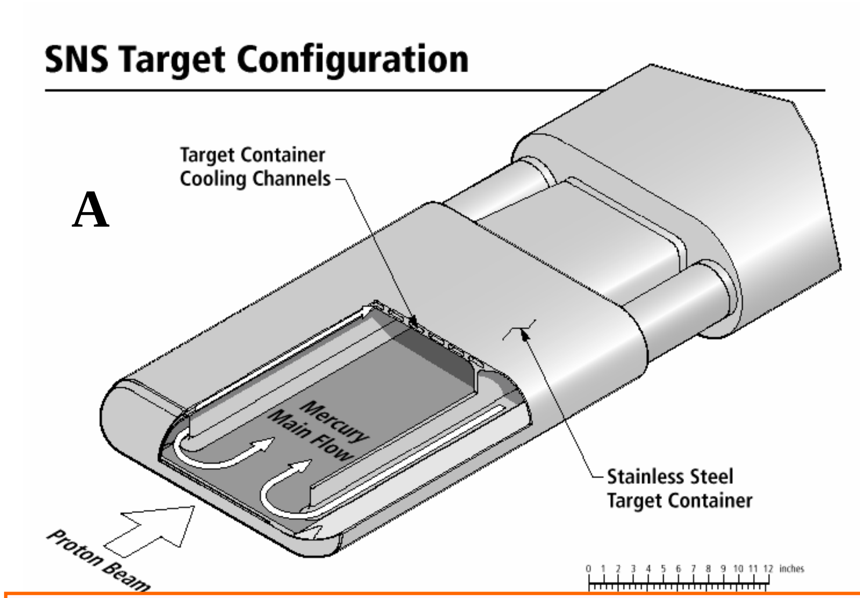


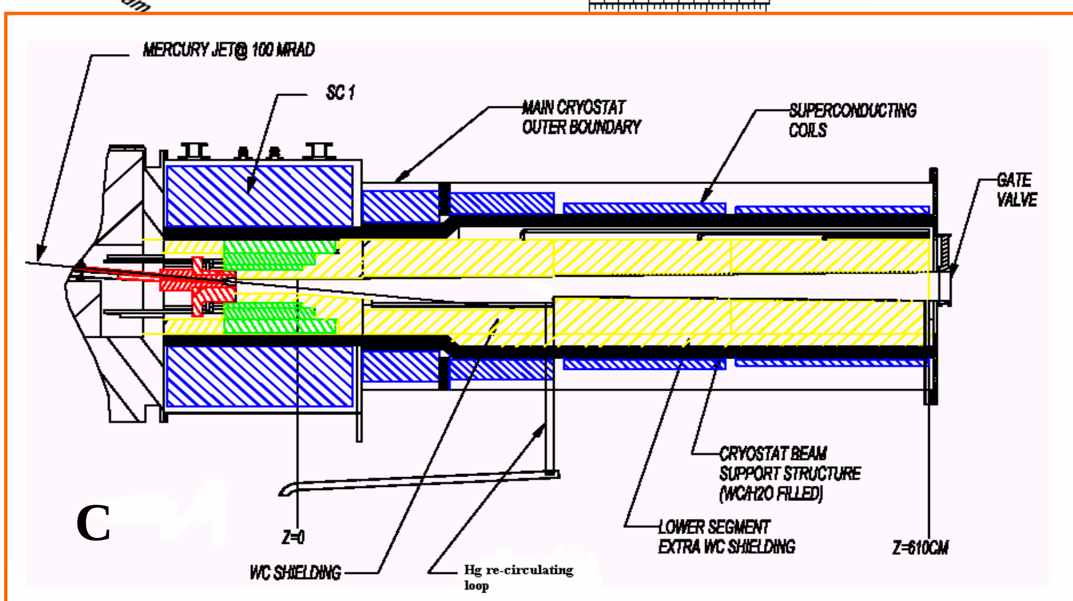
Liquid Target Examples

A. **ORNL SNS Pulsed 1J/g**

B. **PSI MEGAPIE CW 125W/g**

C. **U.S. Neutrino Factory Pulsed 160J/g**





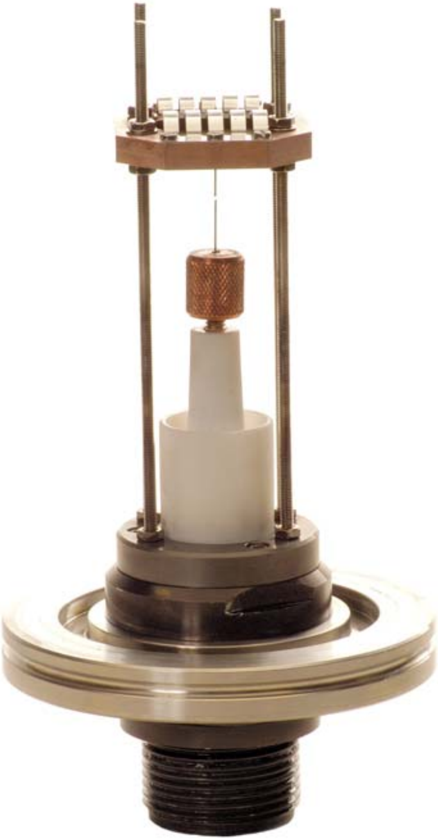
High-Power Targetry R&D

Key Target Issues for high-power targets

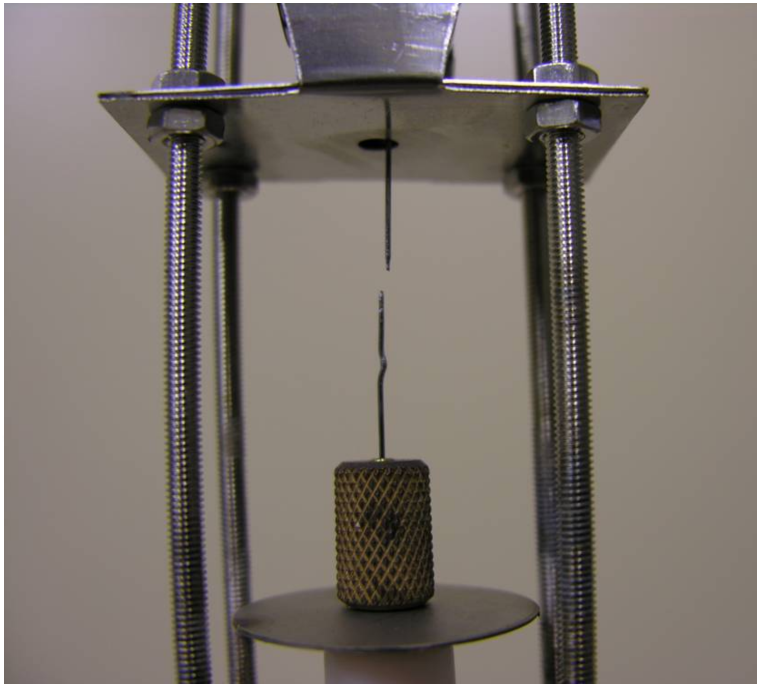
- What are the power limits for solid targets?
- Search for suitable target materials (solid and liquid) for primary beams > 1MW
- Optimal configurations for solid and liquid targets
- Effects of radiation on material properties
    - Target materials
    - Target infrastructure
- Material limits due to fatigue
- Design of reliable remote control systems

Fatigue Testing

R. Bennett, et al   Rutherford Appelton Lab



Experimental Setup



Fatigue Failure

The test concept:
Pulse the wire "target" with equivalent energy and pulse structure.

Tantalum wire broke after 3 x 10^6 pulses.

Tungsten wire has survived >
19 x 10^6 pulses

1Year at 50 Hz is
~ 10^9 pulses

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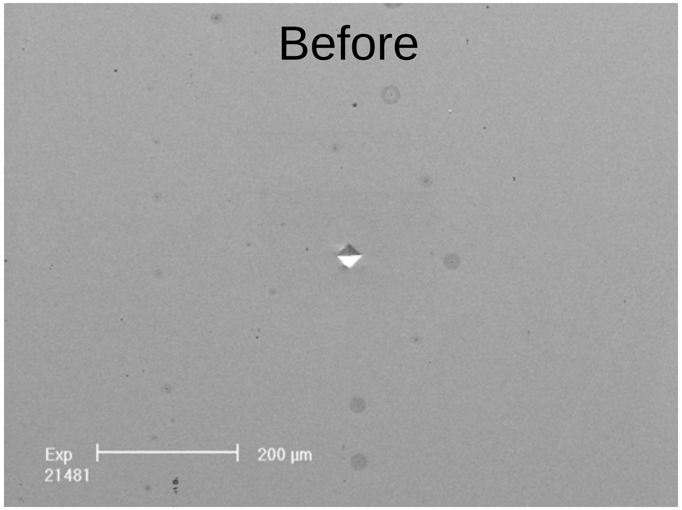
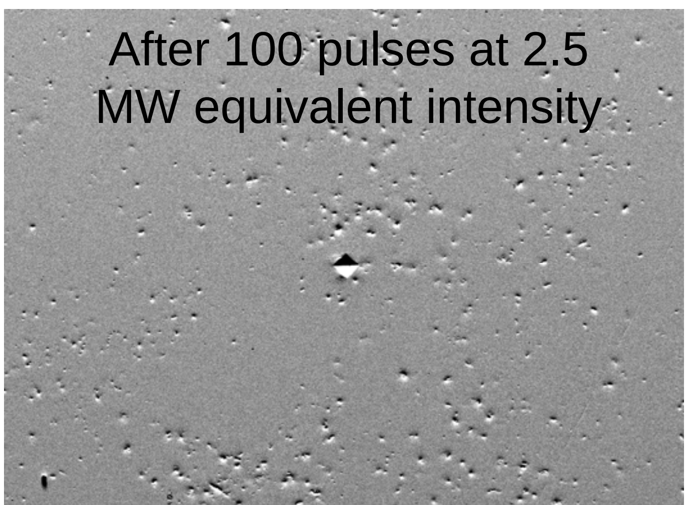
SNS Target : The Pitting Issue





Effect has been identified as resulting from cavitation development within the Hg followed by violent collapsing of the the bubbles near the Stainless Steel surface.

SNS Team has been pursuing several options:

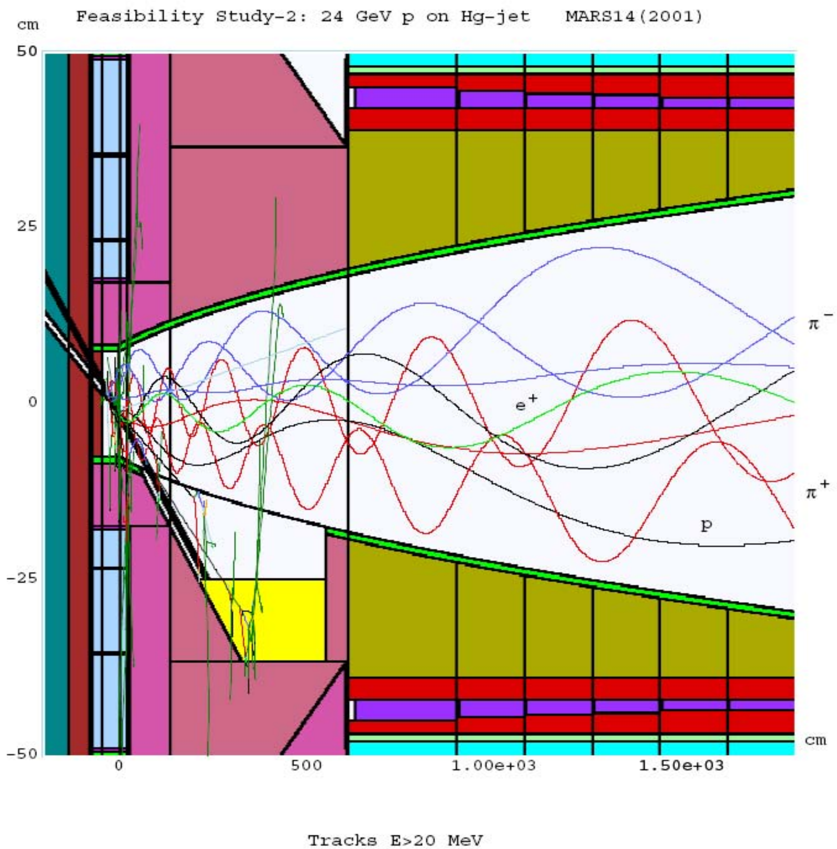
- **Gas layer near container surface**
- **Kolsterizing the SS surface**
- **Bubble injection**

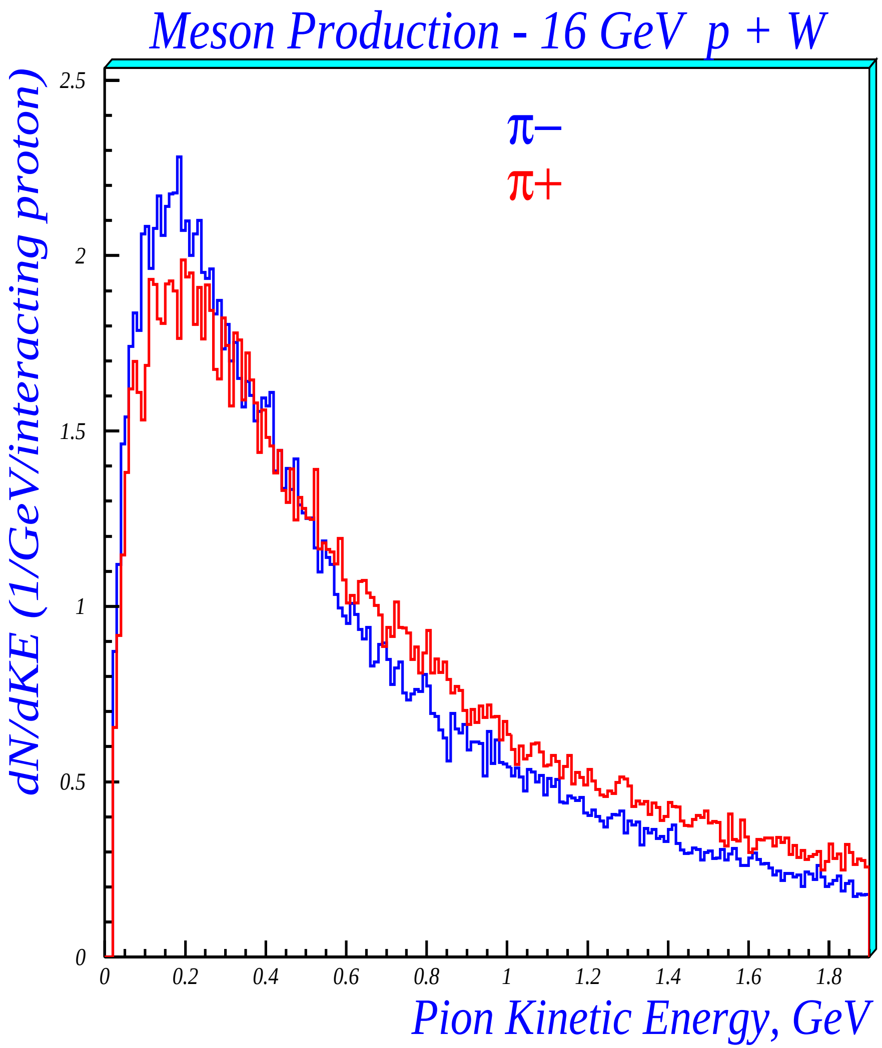
Further R&D is ongoing

The Neutrino Factory Target Concept

Maximize Pion/Muon Production

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





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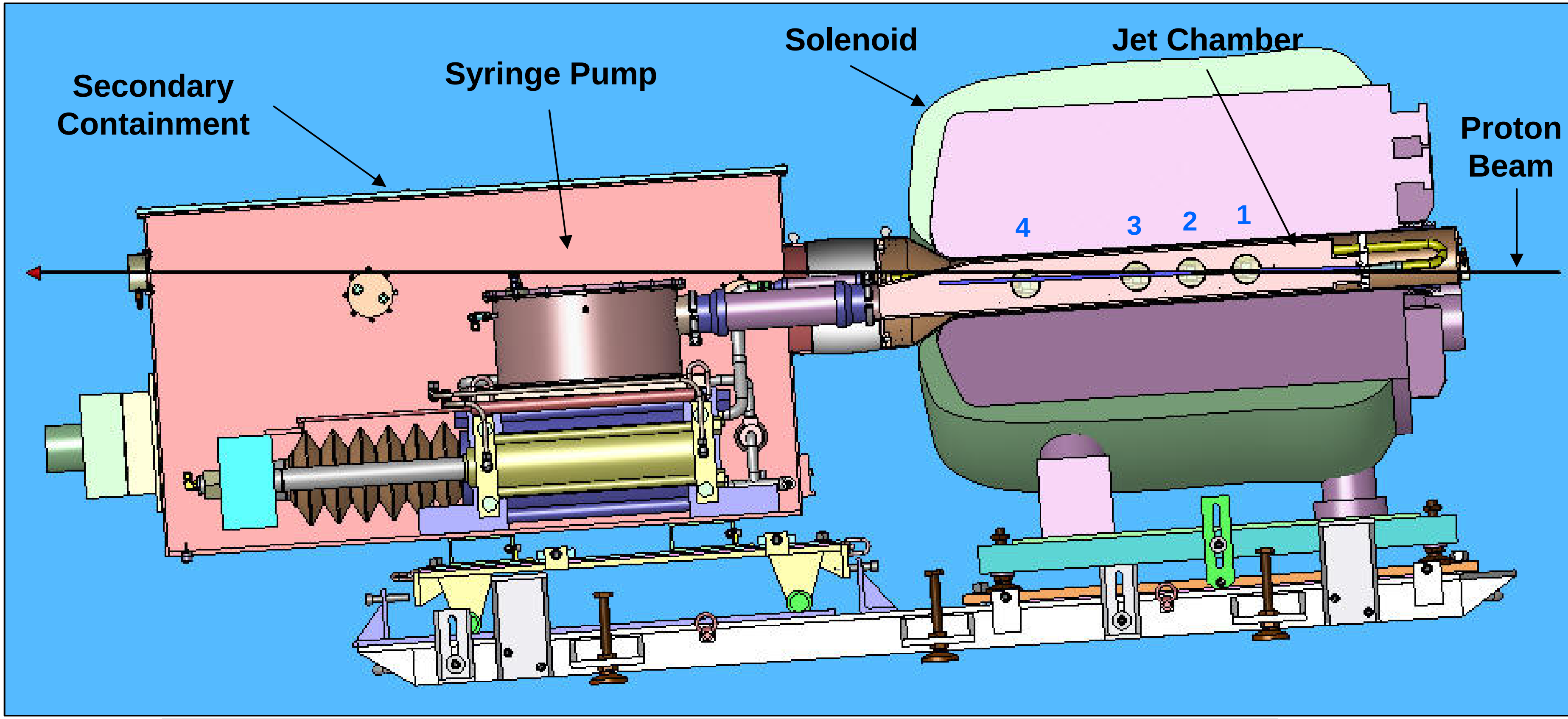
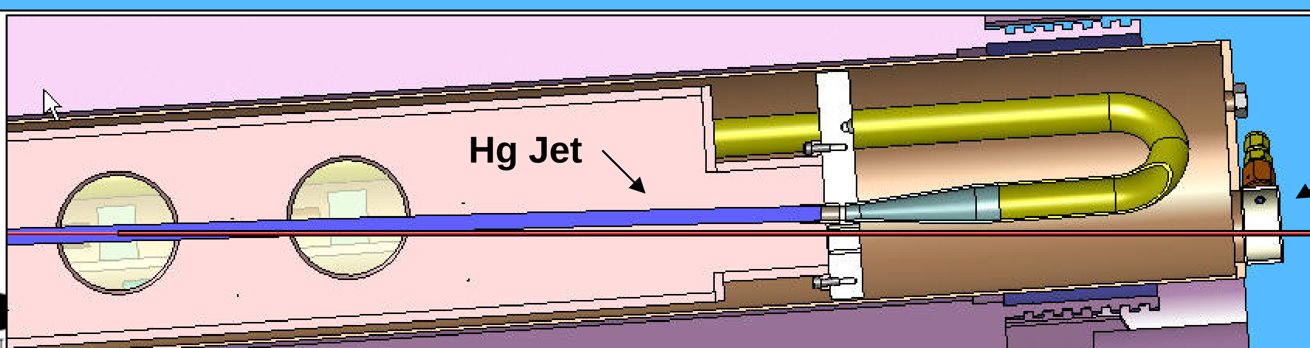
MERIT Experiment at CERN





Beam Window

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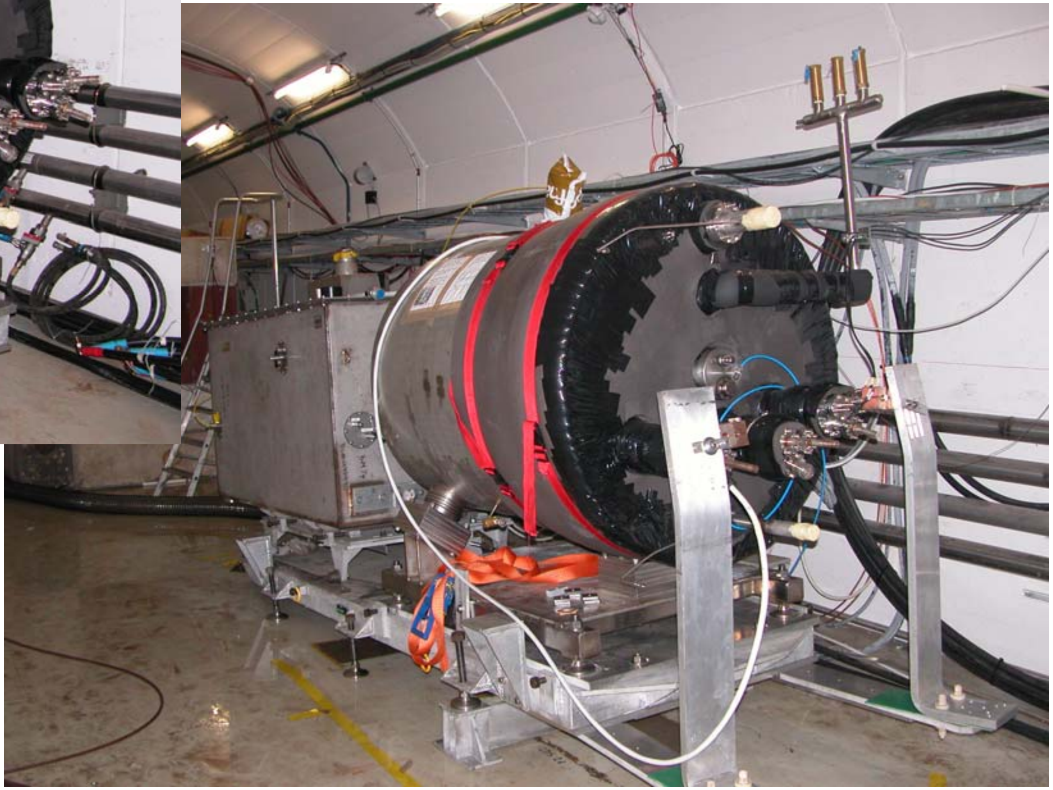
Installed in the CERN TT2a Line

Before Mating

After Mating and Tilting



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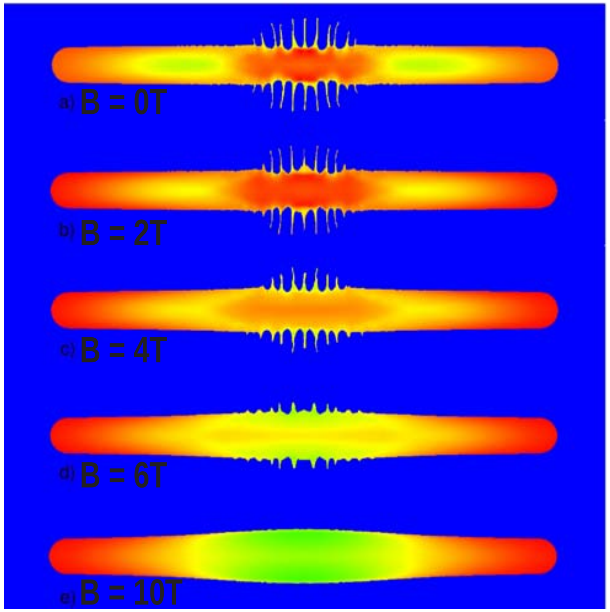
MERIT Scientific Goals

Milestone towards demonstration of a 4MW target concept

Study MHD effects of pion capture scheme with Hg-jet and 15T solenoid

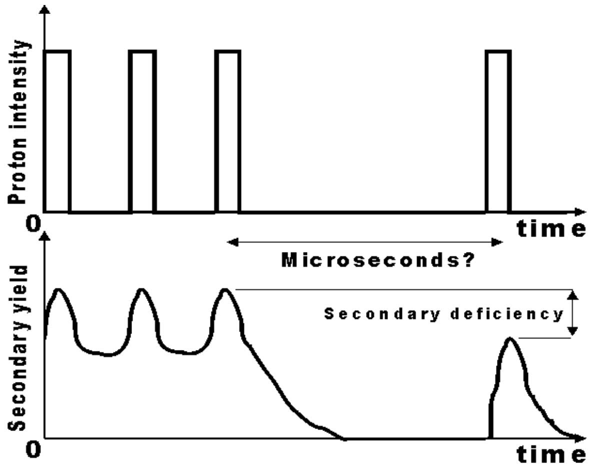


Jet dispersal at t=100μs with magnetic field varying from 0 to 10 Tesla

Study jet disruption and cavitation by varying the PS spill structure

MERIT: 180 J/g

- **30TP@24GeV protons**
- **1cm diam. 20m/s Hg-jet**
- **1.2×1.2 mm^2 beam size rms**



Pump-Probe with Particle Detectors

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Material Properties R&D

Irradiation studies are being undertaken at many facilities:

- BNL BLIP
- Los Alamos Lance
- RAL ISIS
- CERN ISOLDE
- PSI
- Triumf

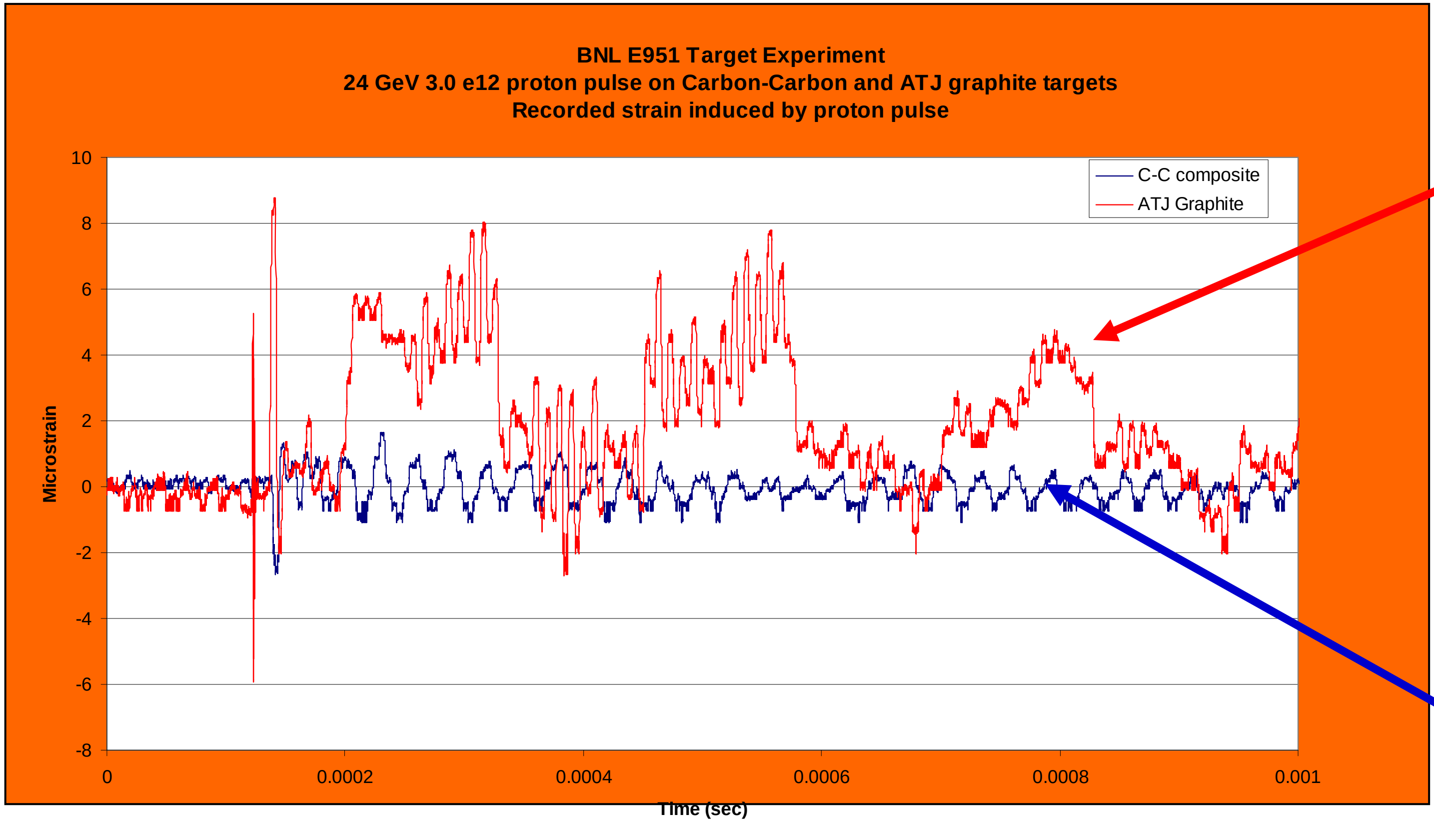
New facilities are being proposed:

- IFMIF

Strain Gauge Measurements

BNL E951: 24 GeV, 3 x 10^{12} protons/pulse

Stress = $Y\ \alpha_T\ U\ /\ C_V$

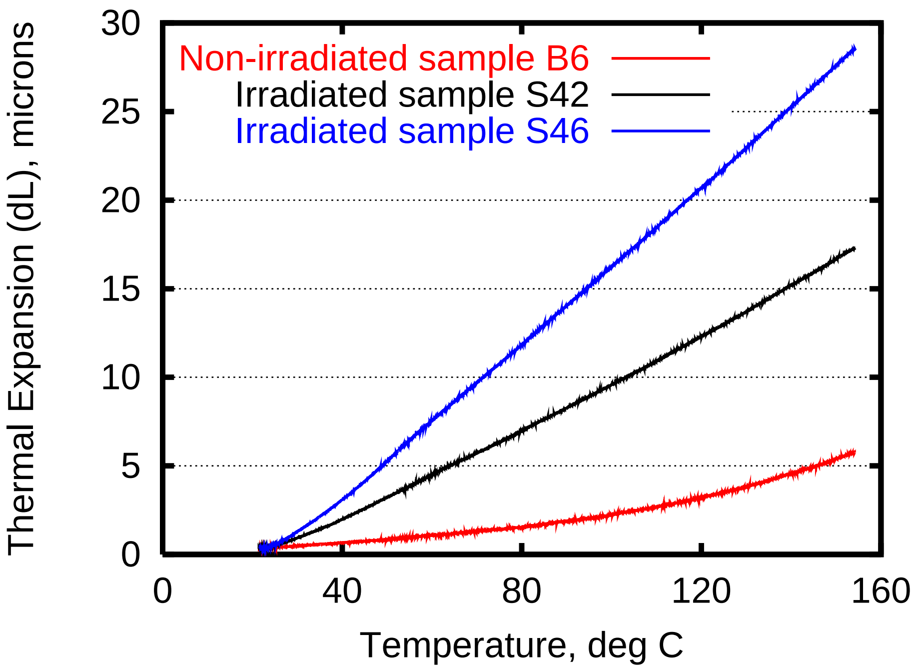


ATJ Graphite

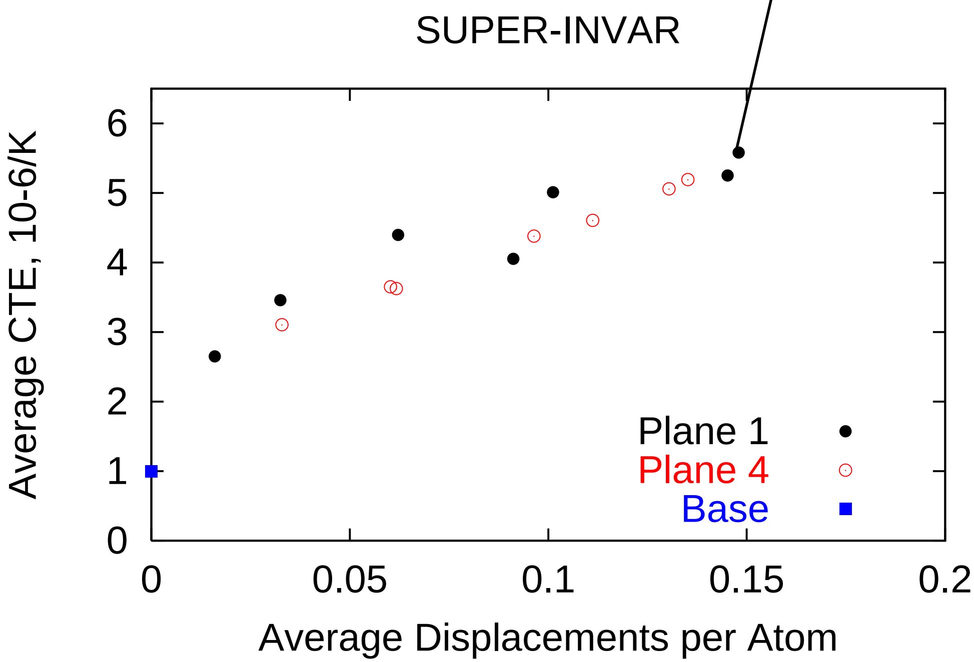
Carbon-Carbon Composite

Super-Invar CTE measurements

BNL BLIP



Peak Proton fluence
1.3 x 10^{20} protons/cm^2



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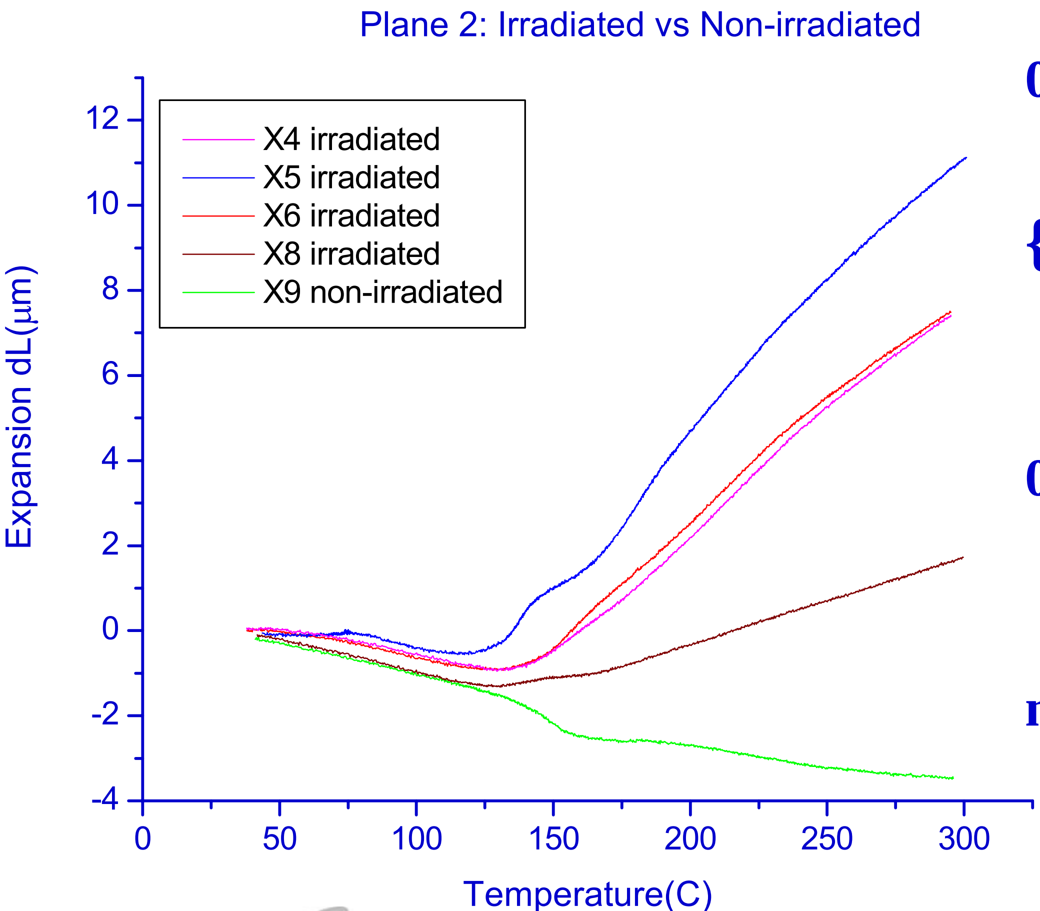
Carbon-Carbon Composite



Average Proton Fluence

(10^{20} protons/cm^2)

0.76

{ 0.52 and 0.36

0.13

none

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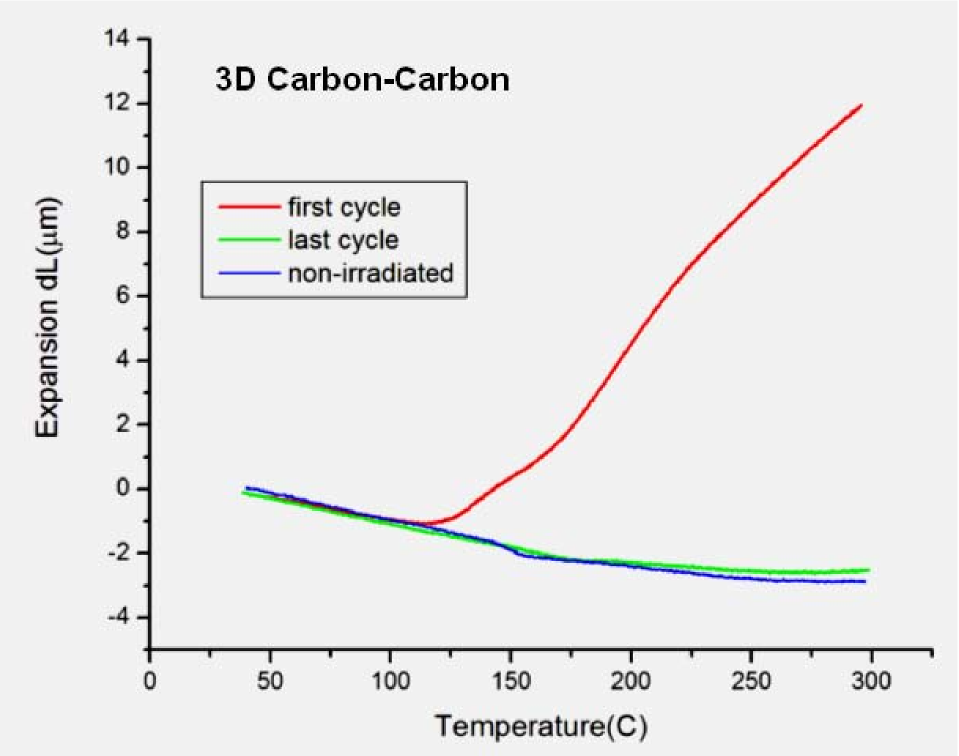
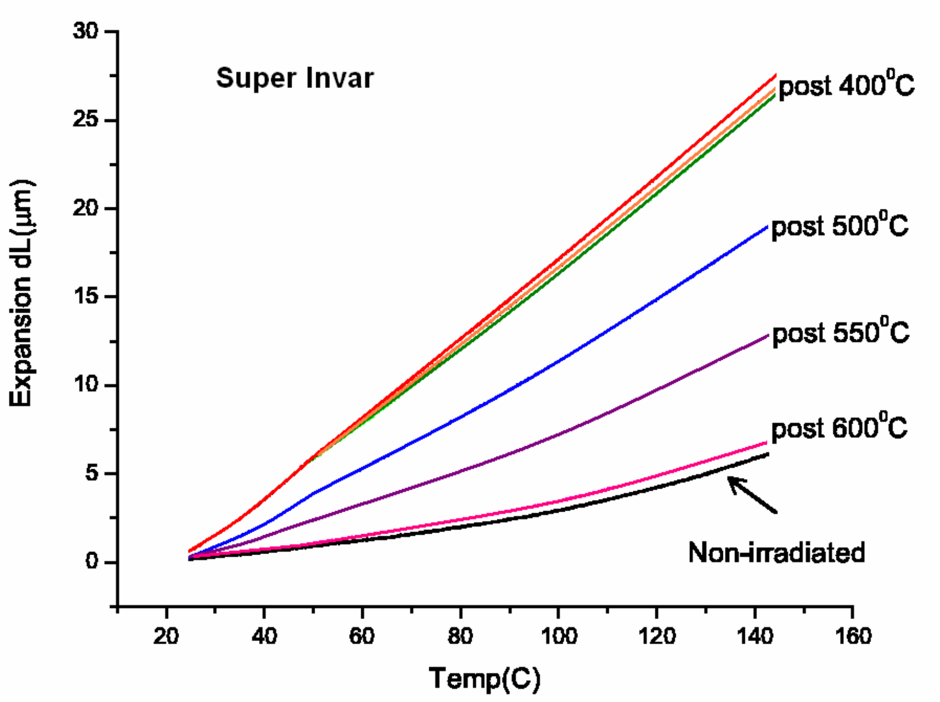
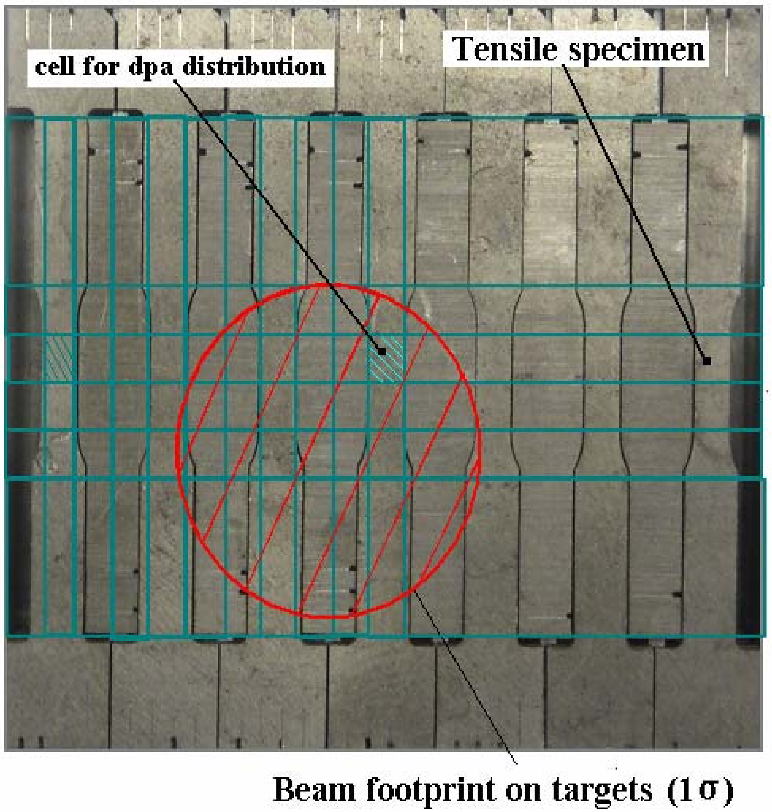
Recovery of low α_T



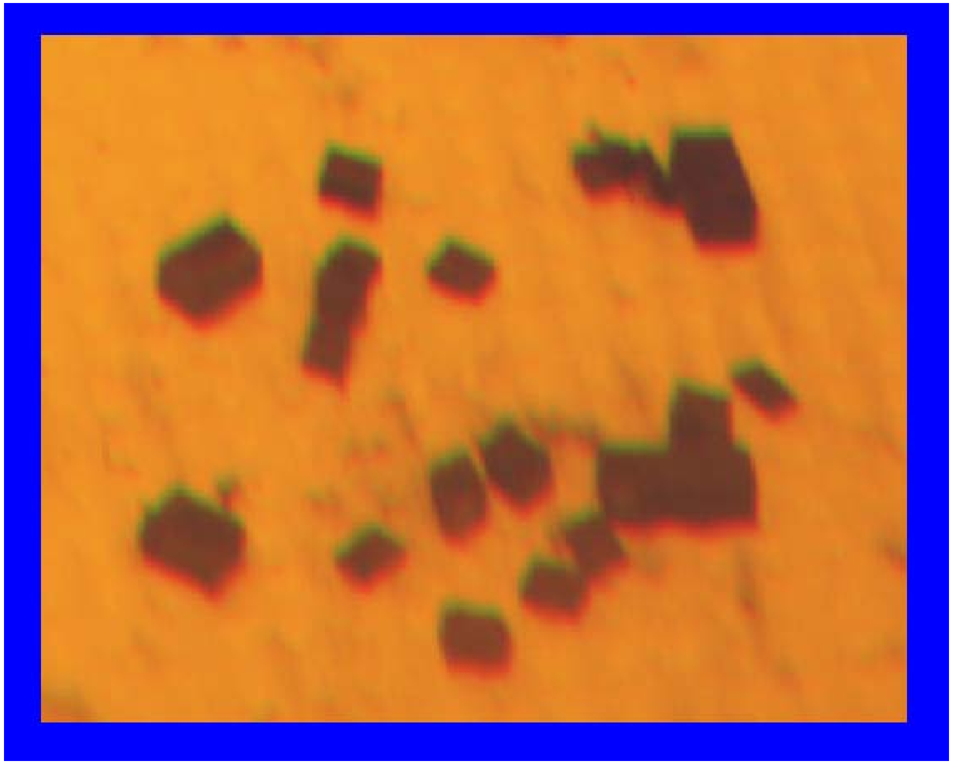


Carbon-Carbon anneals at ~200⁰C **Super-Invar anneals at ~600⁰C**

Degradation of Carbon-Carbon

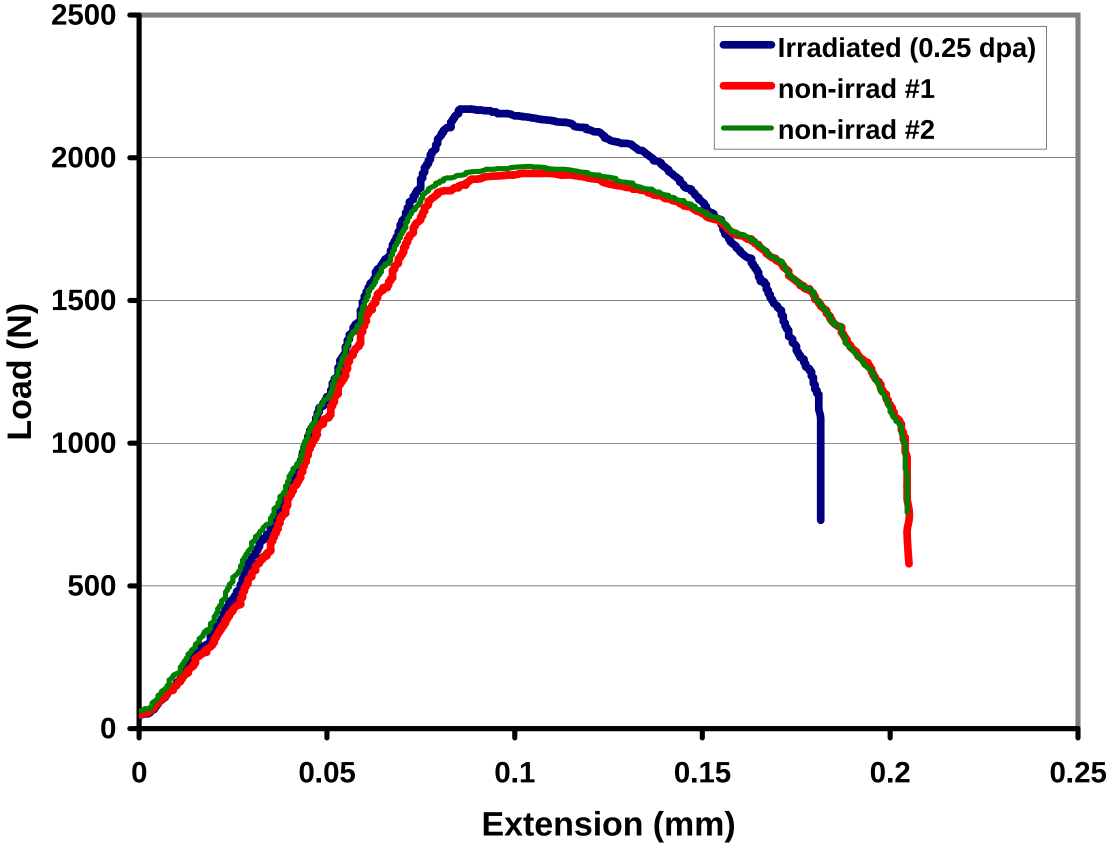


Carbon-Carbon Composite before irradiation



Carbon-Carbon Composite after exposure to fluence of 10^{21} protons/cm^2

Super-Invar Tensile Testing



Tensile testing shows that Super-Invar strengthens while remaining ductile (at the 0.25 dpa level)

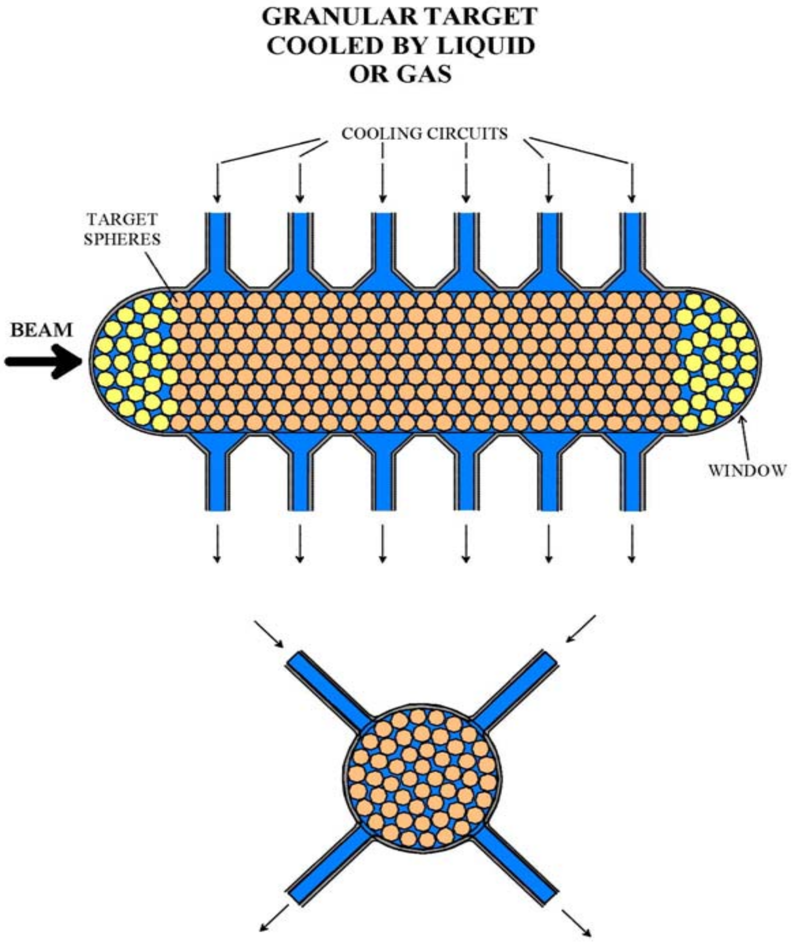
A New Approach I

Fluid Cooled Particle Bed

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

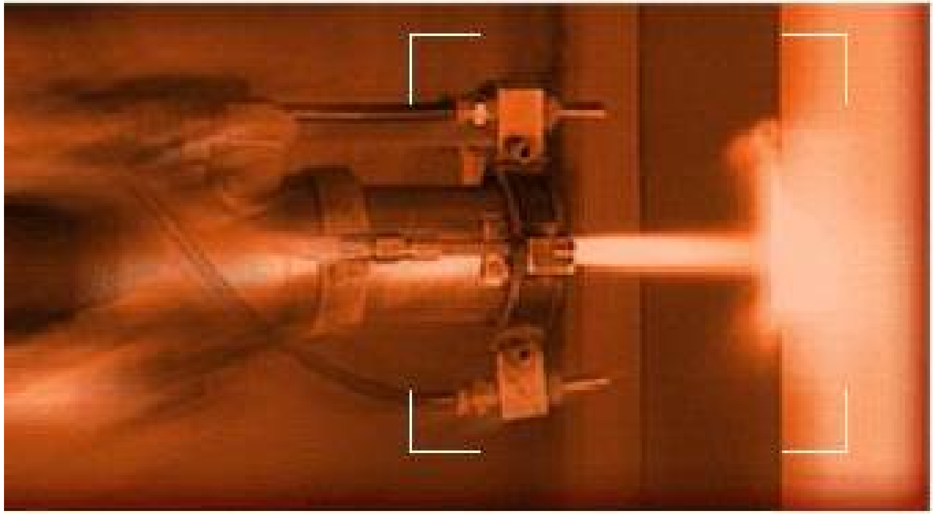
Peter Sievers, CERN

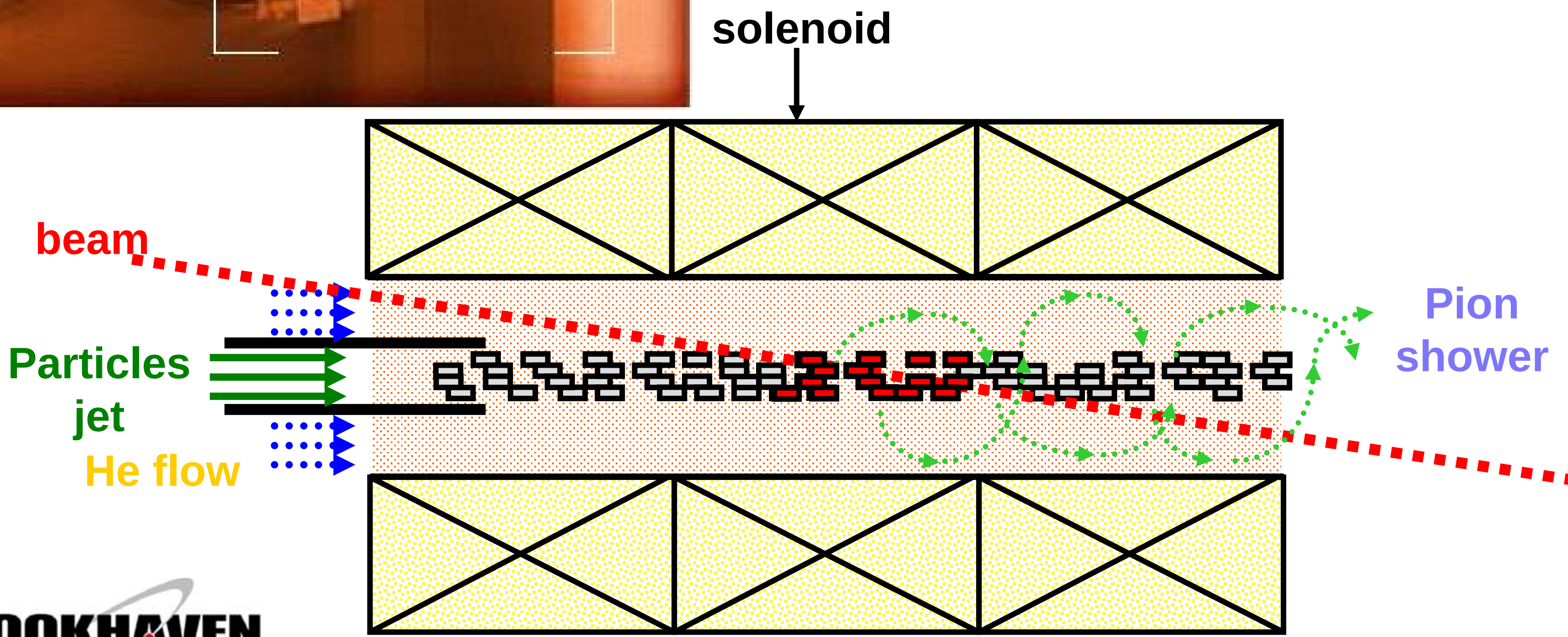


New Approach II

O. Carletta, C. Densham RAL

A pneumatically driven slury





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Summary

The R&D Program for the development of high-power targets is diverse and includes exciting new ideas—but:

- **Solutions for >1MW primary beam targets are still unproven**
- **Target test facilities are lacking – more in beam experiments like MERIT are needed**
- **Search for suitable target materials is an important ongoing effort with wide reaching impact**
- **More irradiation experiments are needed**