Radiation Hardness of FAIR Magnet Materials & Components

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MATERIAL ANALYTIK

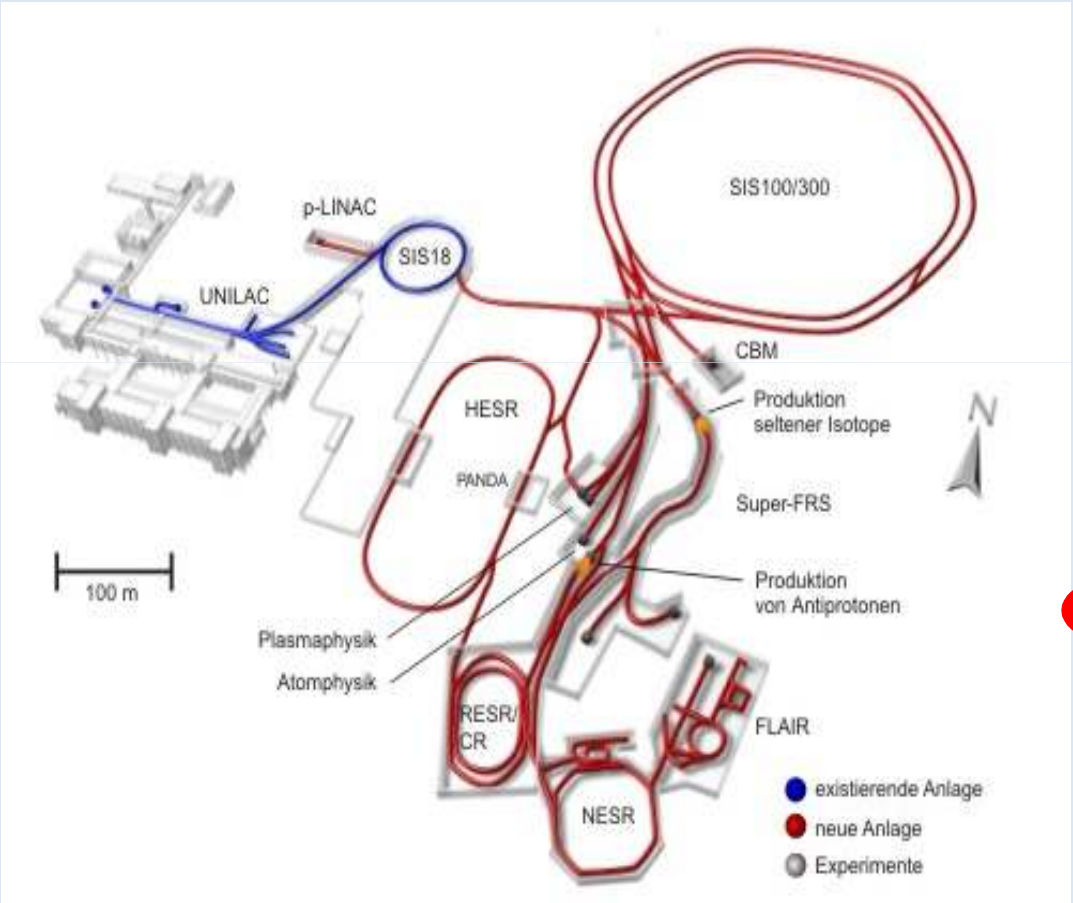
TECHNISCHE UNIVERSITÄT DARMSTADT

Radiation Hardness of FAIR Magnet Materials

- Motivation
- Irradiation Experiments
- Results
- Outlook

Tim Seidl

Facility for Antiproton and Ion Research



planned beams at FAIR

2.7 GeV/u U^{28+} ; 22 GeV/u U^{92+}

29 GeV protons

15 GeV antiproton beam

primary beam increase

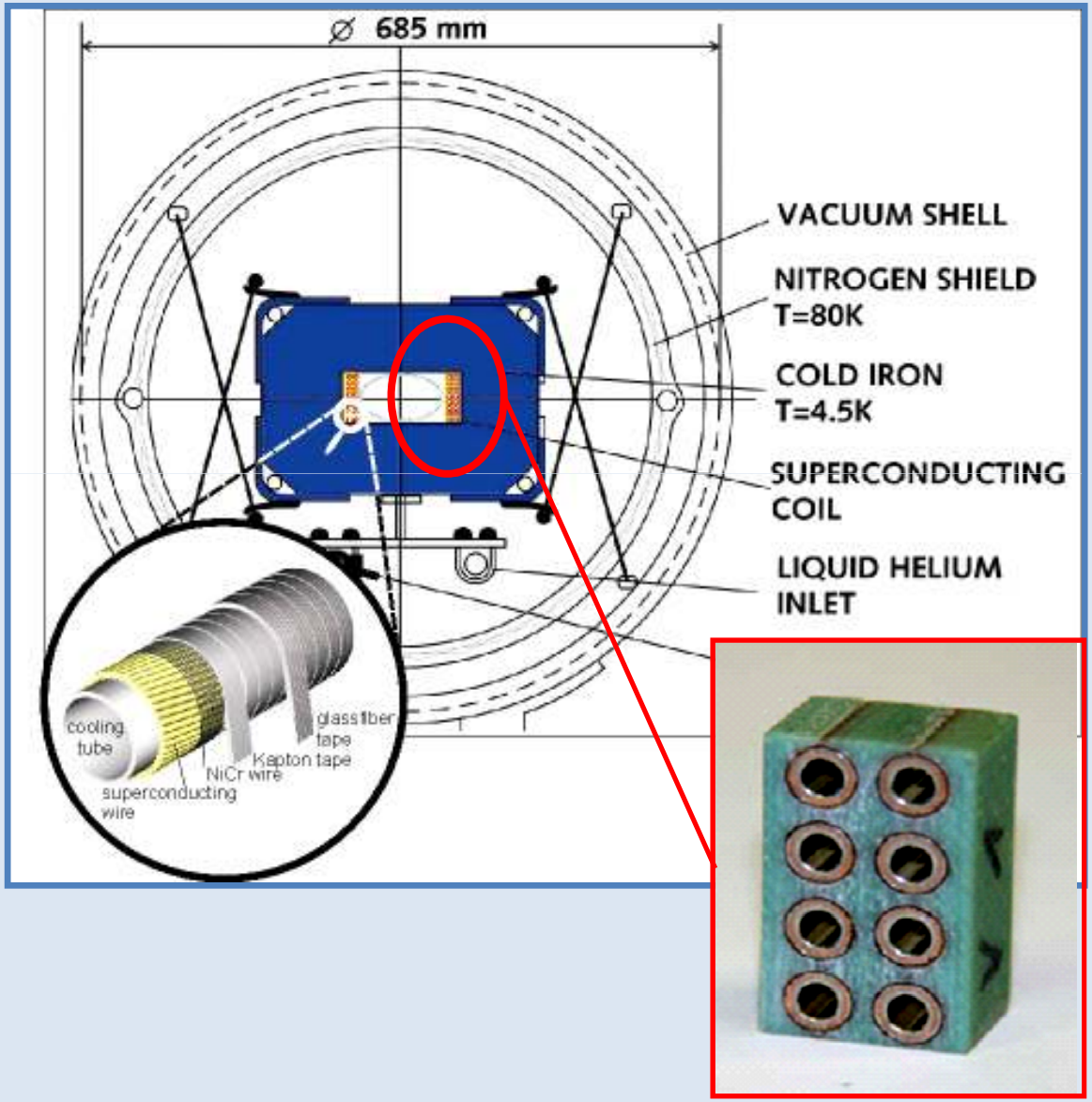
intensity: x100-1000;

energy: x25;

radioactive beams

intensity x10000

FAIR-Magnet Materials (SIS 100 Dipole)



radiation sensitive materials

- polymers
- fiber reinforced plastics (FRP)

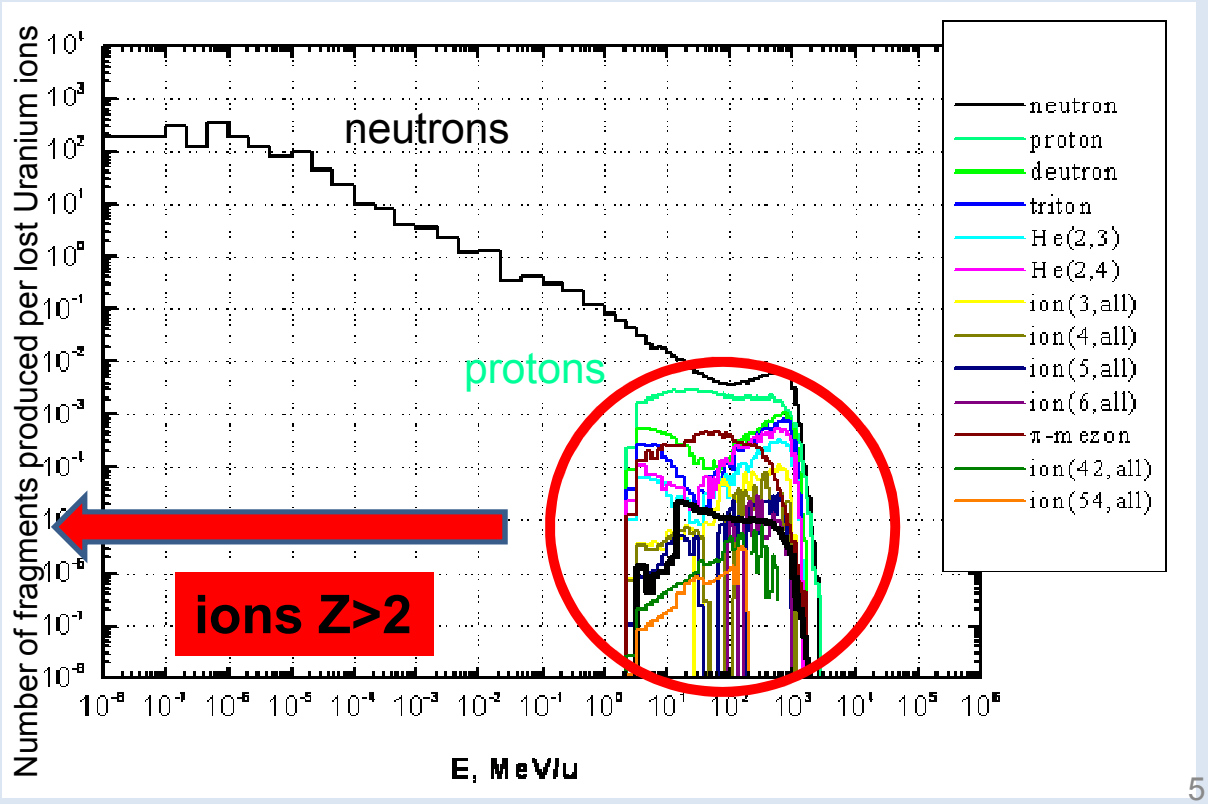
Extreme Environment

operating conditions

- pulsed mechanical & electrical forces
- low T: 4.5 K (superconducting magnets)
- high radiation environment

SHIELD-code

L.N. Latycheva (INR)



contribution up to 80% of total dose depending on:

- **angle of beam loss**
- **position of "target"**
- **$E_{kin,ion}$, density, ect...**

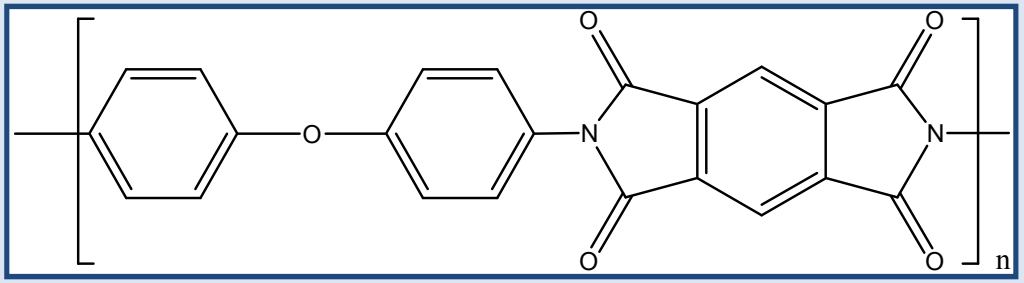
Selection of Samples and Material Properties

- **Polyimide** (Kapton HN, Apical AV)
  - -dielectric strength
  - -thermal properties (low Temperature)
- **Glasfiber Reinforced Plastics** (GFRP, G11CR-type)
  - -dielectric strength
  - -mechanical properties
- **„Voltage Breaker“**

- **Low T-Sensors**

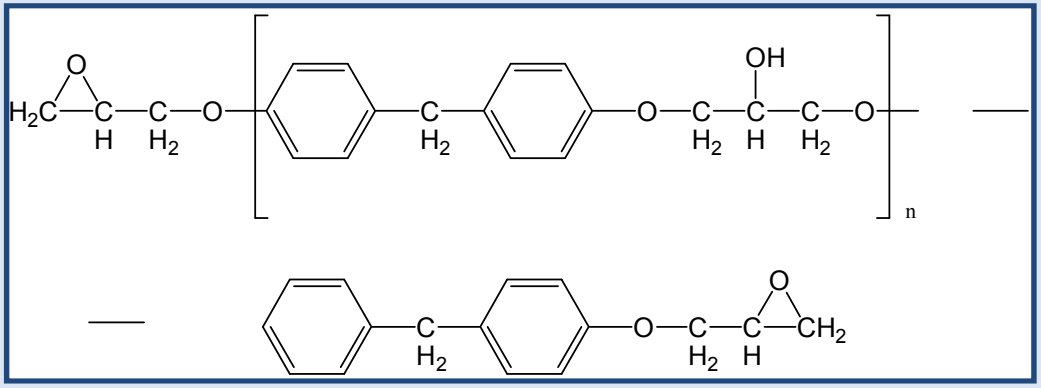
Organic FAIR-Magnet Materials

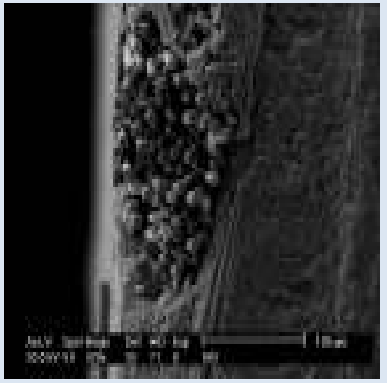
Polyimide:

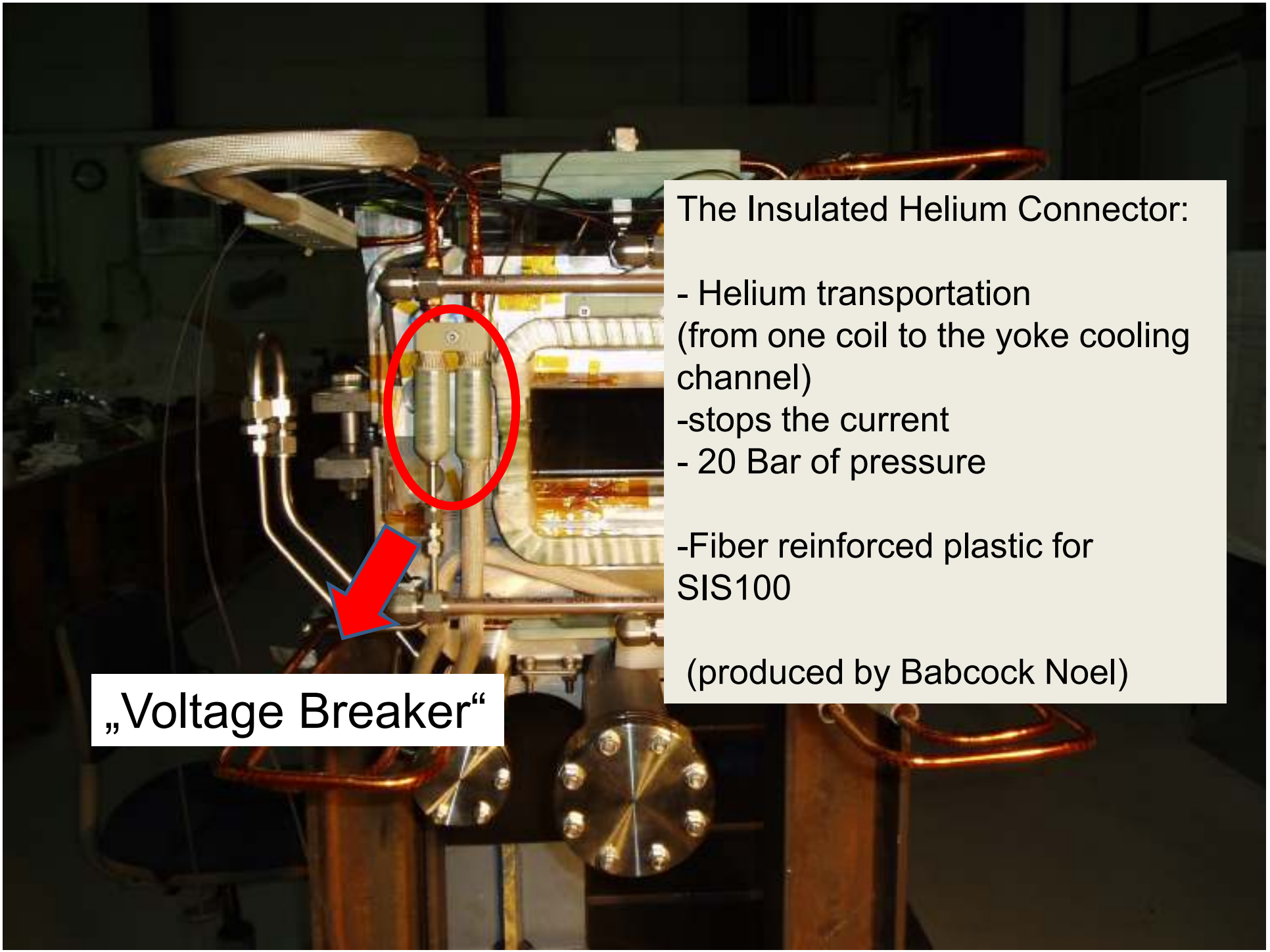


Apical AV (Kaneka Texas)
Kapton HN (Du Pont)

-G11CR type epoxy/fiber composite (Gatex GmbH)







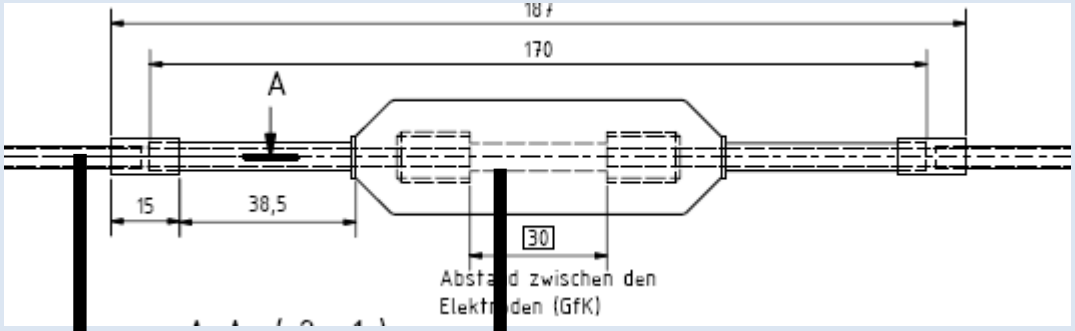
The Insulated Helium Connector:

- Helium transportation
(from one coil to the yoke cooling channel)
-stops the current
- 20 Bar of pressure

-Fiber reinforced plastic for SIS100

(produced by Babcock Noel)

„Voltage Breaker“



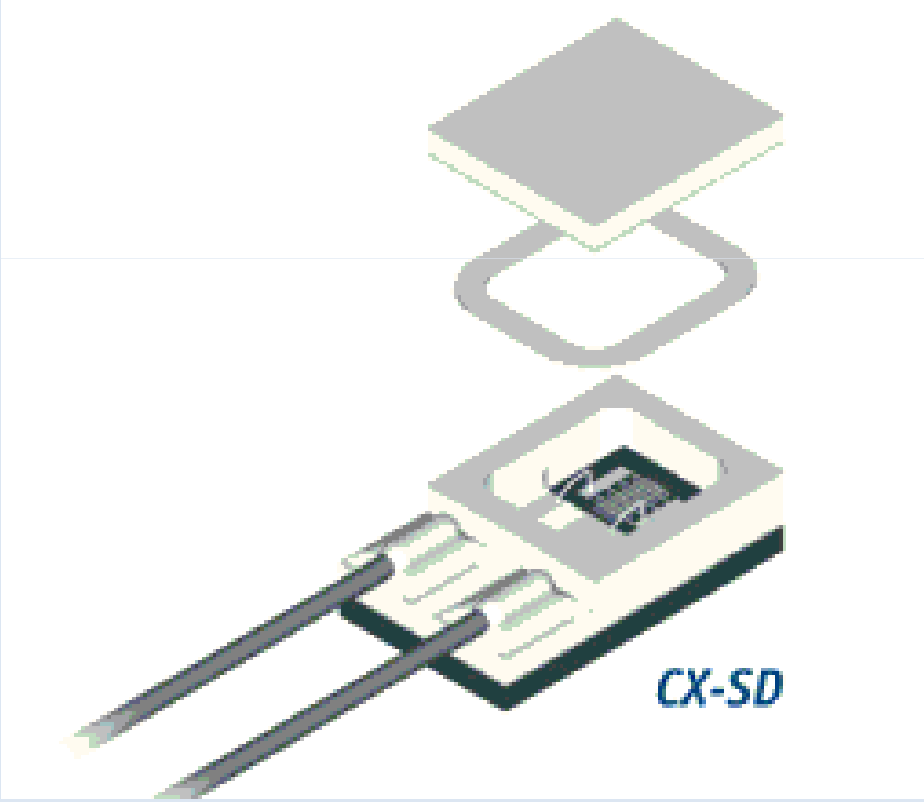
stainless steel tube

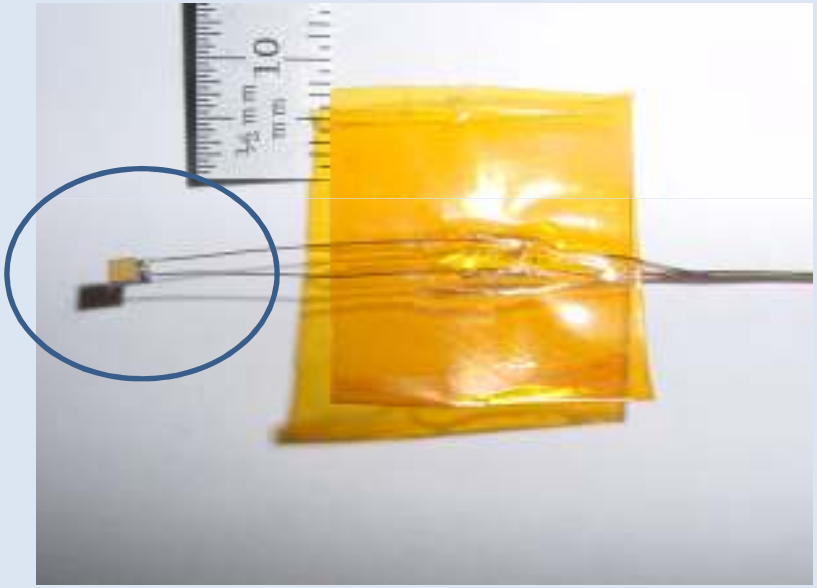
epoxy/fiber laminate (impregnated)

Specification: Leakage rate of 1e-9 mbar*l/s at a helium pressure of 30 bar.

Temperature Sensor for Low Temperature

(Cernox CX) from Lake Shore
"Metal Oxy-Nitride Resistance"





Types of Irradiation-Experiments:

UNILAC: C-U ions 11MeV/u

SIS 18: Xe ions ~ 280 MeV/u
fragmented 1 GeV/u Uranium beam

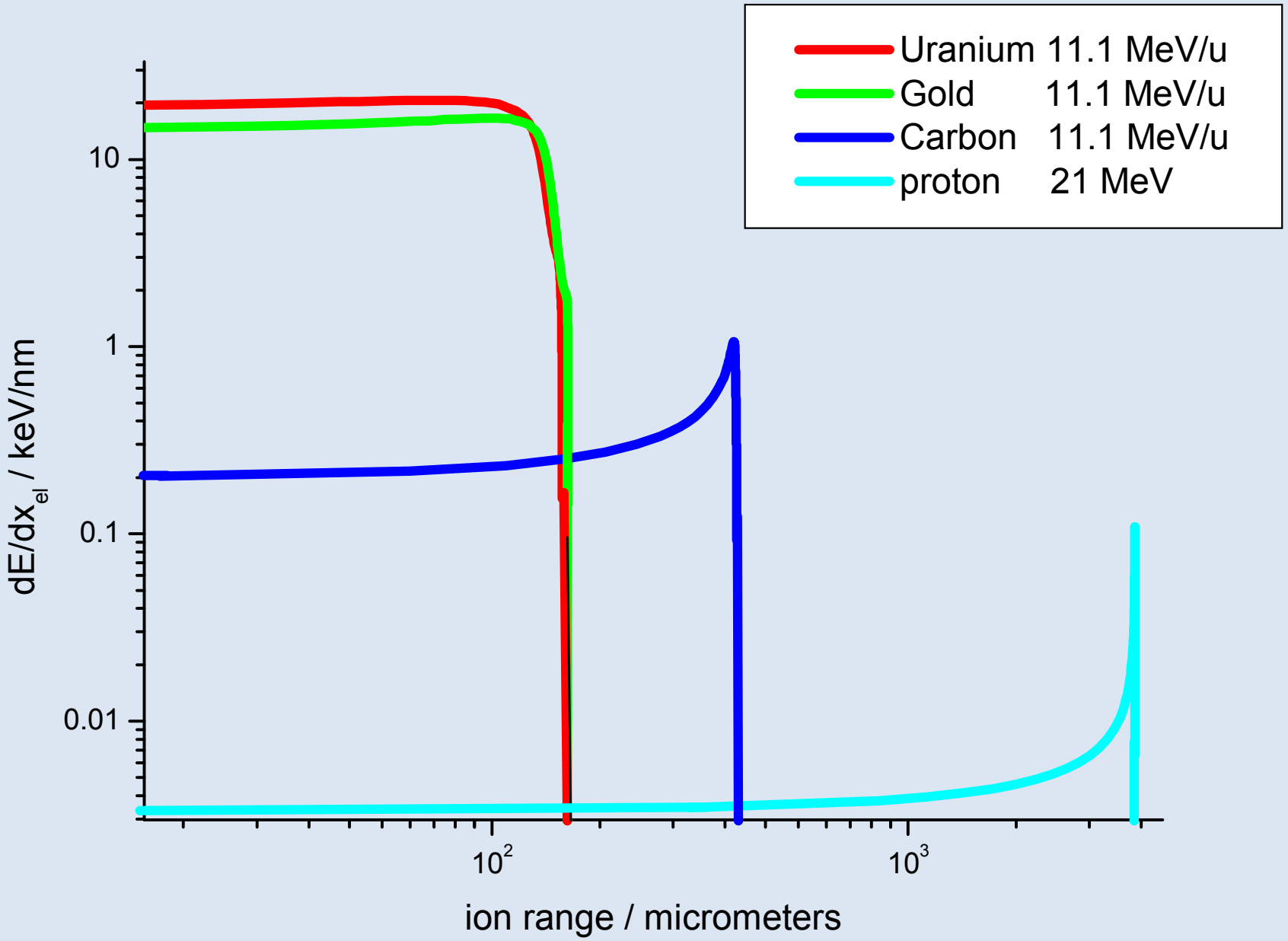
LINAC: protons, 21 MeV

Synchroton: protons 0.8 GeV

Fast neutrons ~ 800 MeV/u

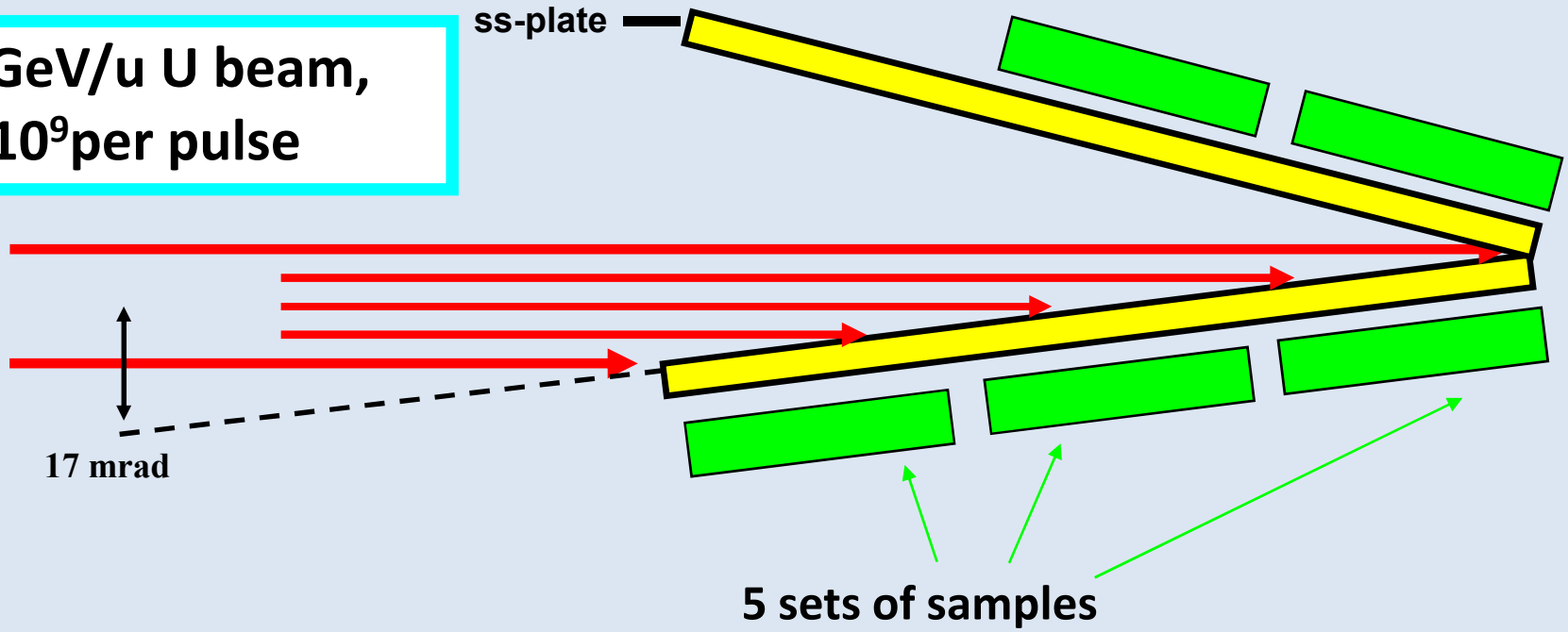
Gammas from Co^{60} -source

Types of Irradiation-Experiments: dE/dx_{el}

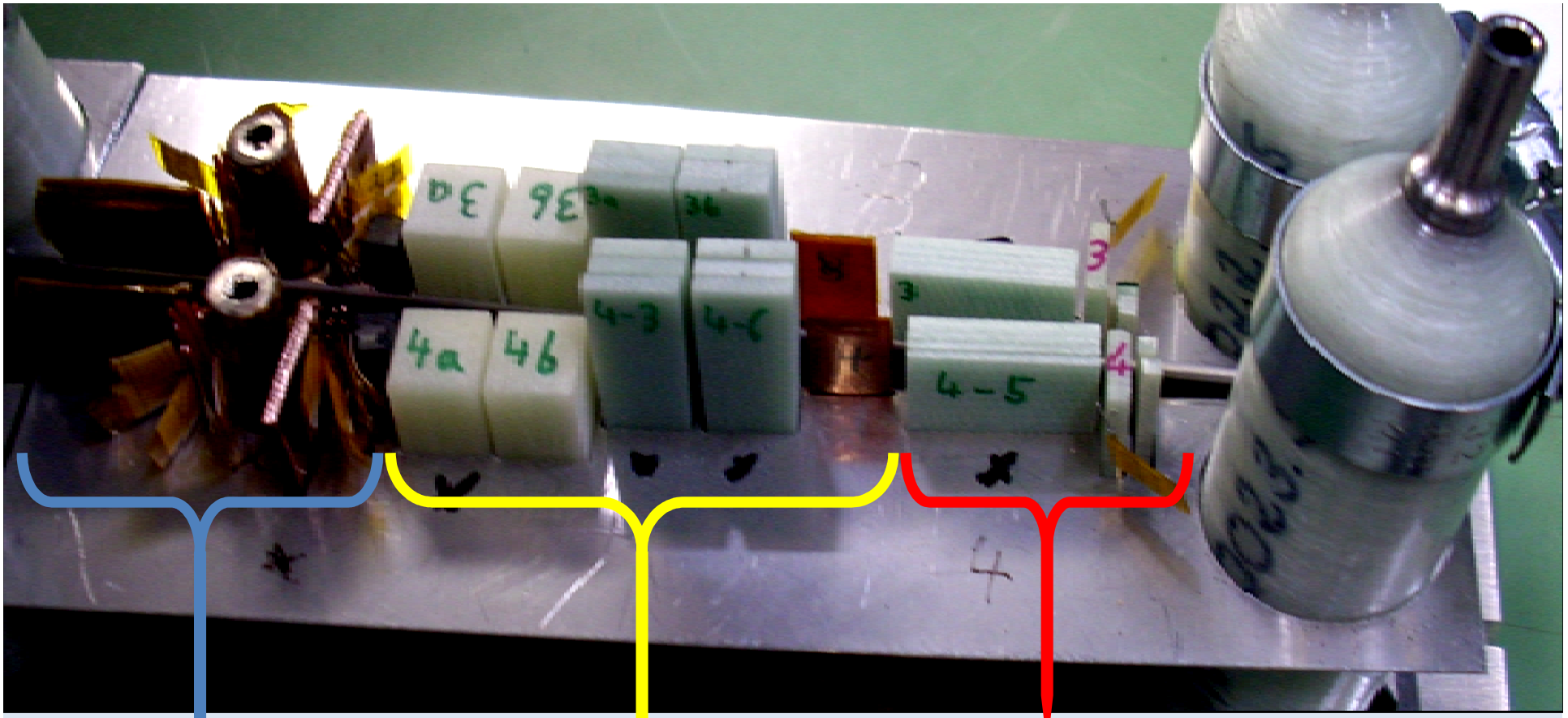


HHD-05-2008 Experiment („Cocktail Beam“-Exp.)

1 GeV/u U beam,
$1 \cdot 10^9$ per pulse

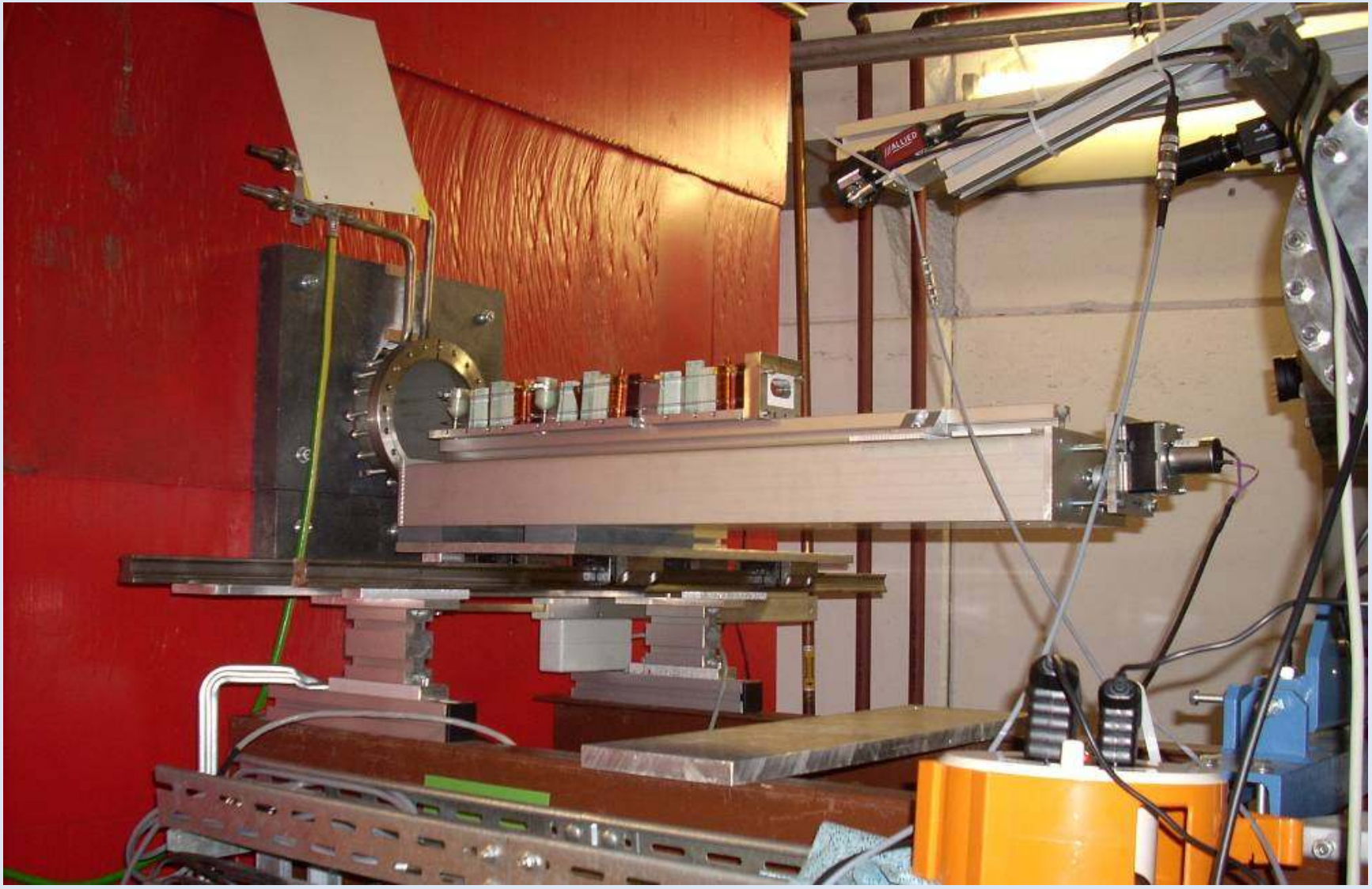


Total number of Uranium Particles: 2.23E+14



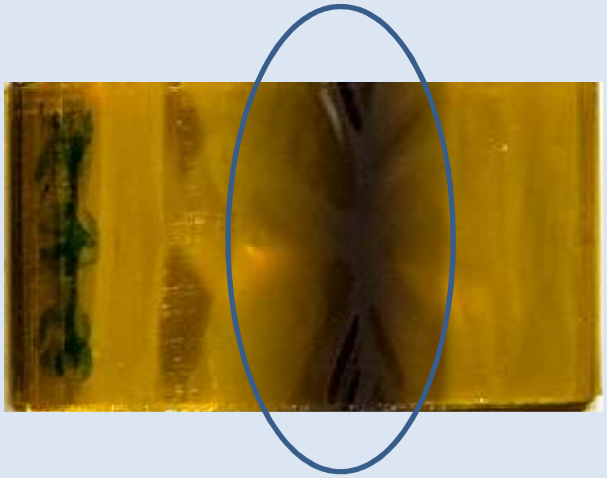
in total ~350 samples

HHD-05-2008 Experiment („Cocktail Beam“)



Types of Irradiation-Experiments:

Protons, 21 MeV, 2E16 p/cm^2, 82 MGy



„Cocktail beam“ ~6MGy

Ni, 11 MeV/u. 5E12 ions/cm^2, 25 MGy

Ta, 11 MeV/u. 5E12 ions/cm^2, 80MGy

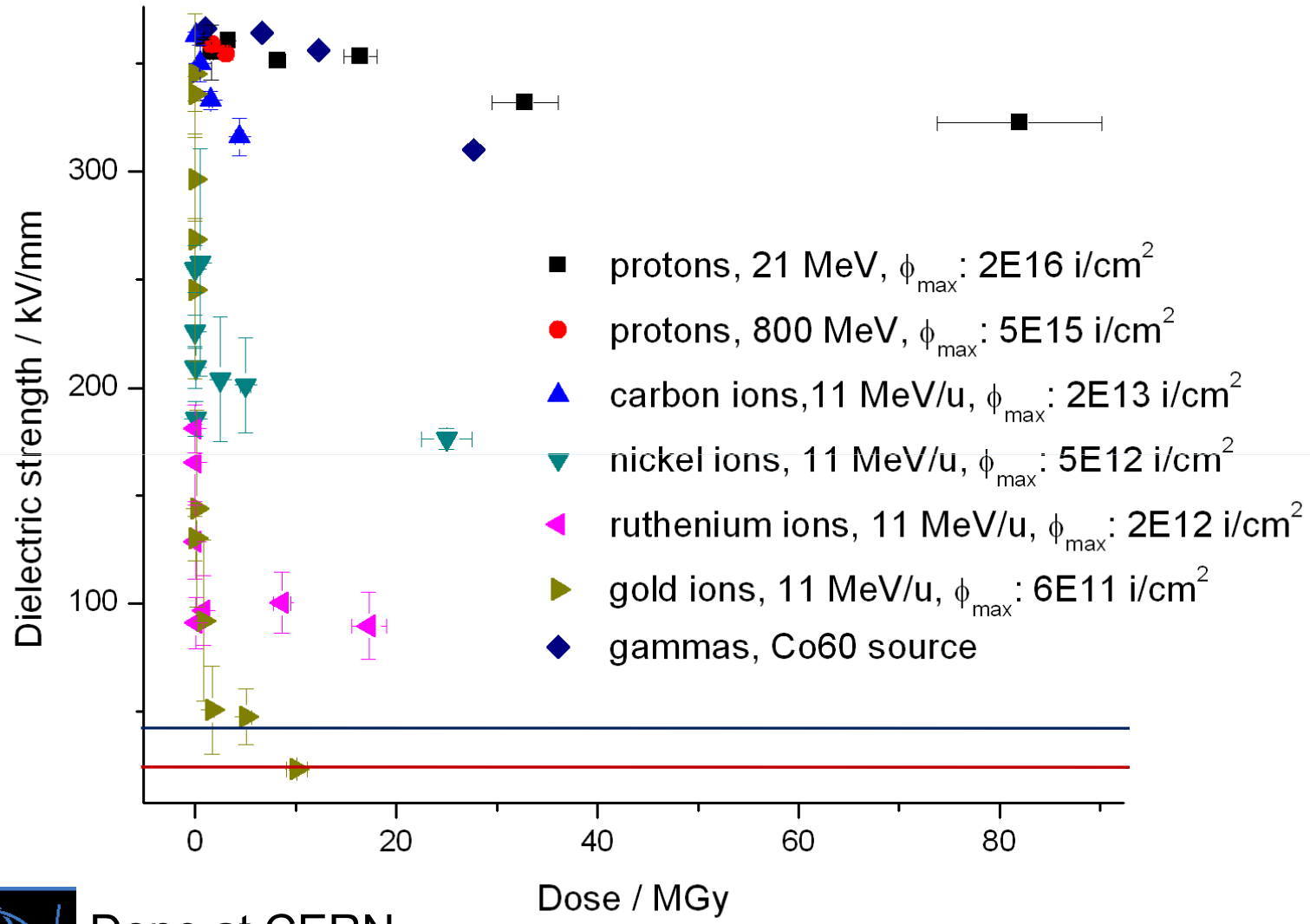
(SRIM calculations)

Defined Hardness Tests

Critical properties:

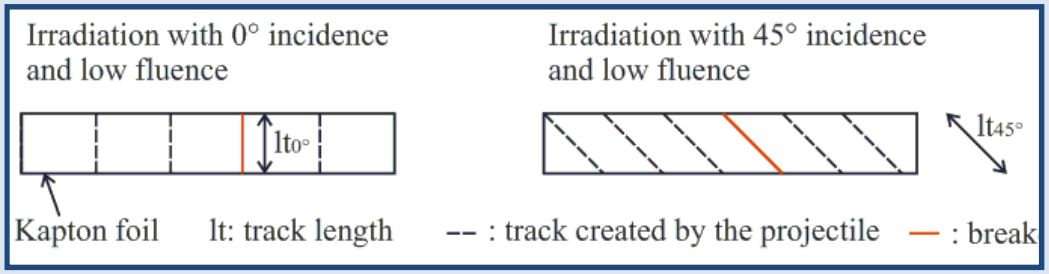
- Breakdown Voltage → Insulation Lifetime
- Thermal Properties → Quench Protection
- „Voltage Breaker“-Test → Helium Transfer
- T-sensors → Cryo-Reliability
- (Mechanical properties) → Coil stability

Breakdown Voltage of Polyimide

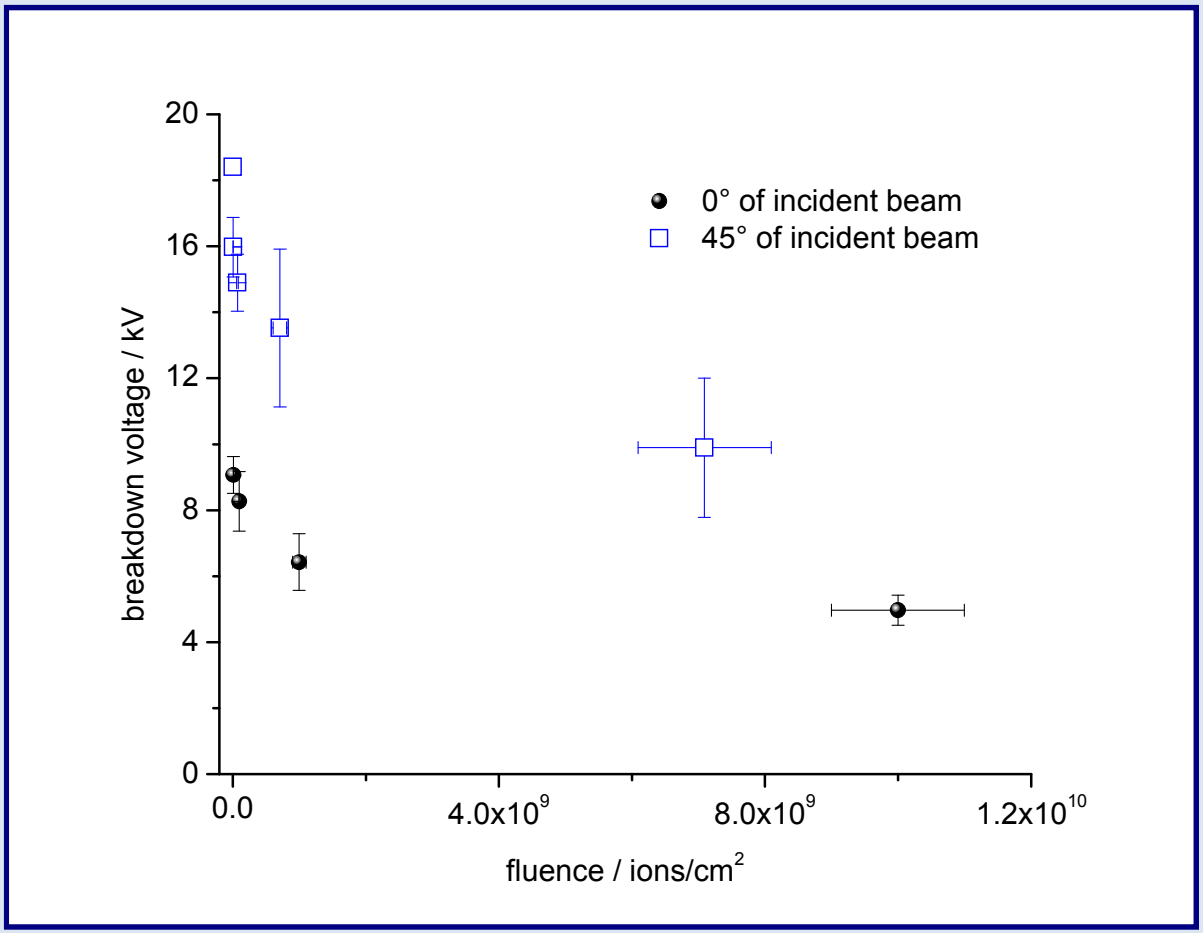


Done at CERN
with R. Lopez
and D. Tommasini

Breakdown Voltage of Polyimide (angular dependence)



Ru-ions 11 MeV/u
UNILAC (GSI)

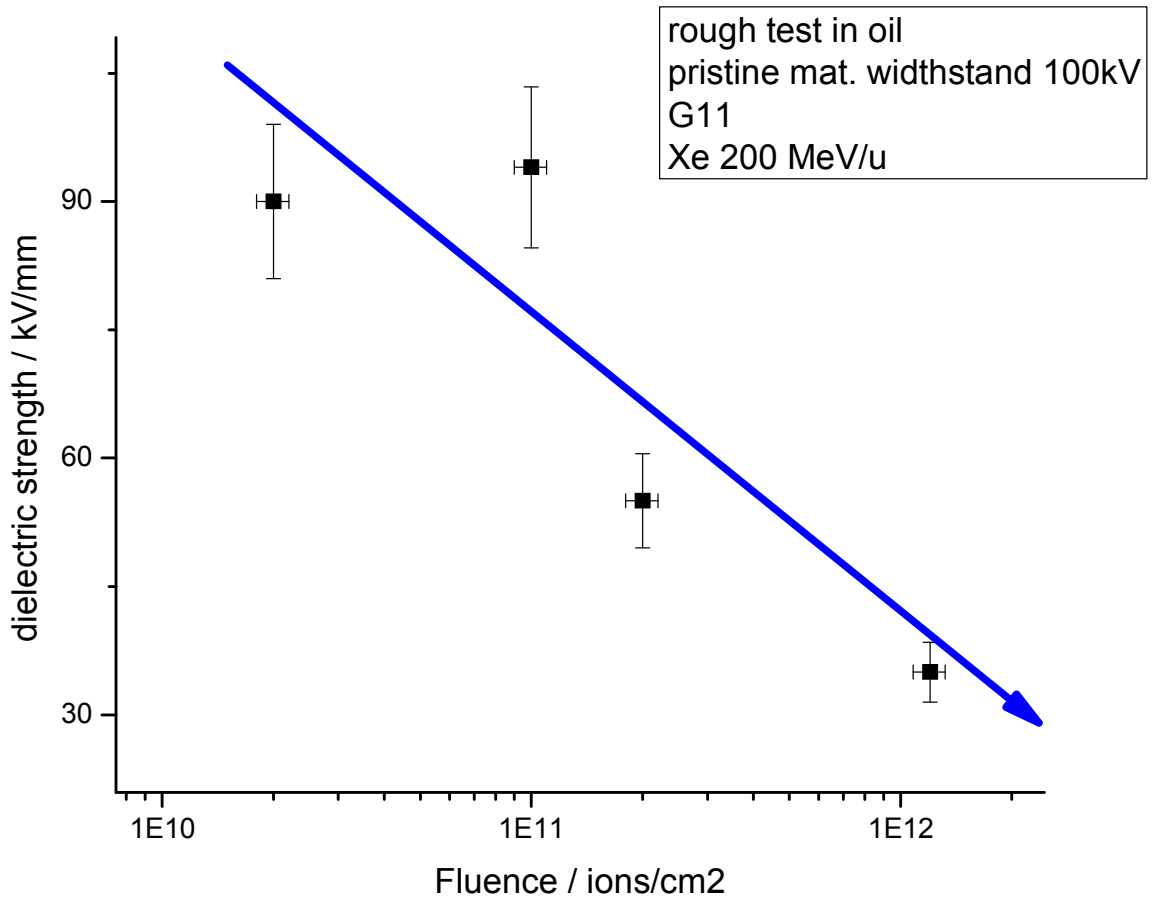


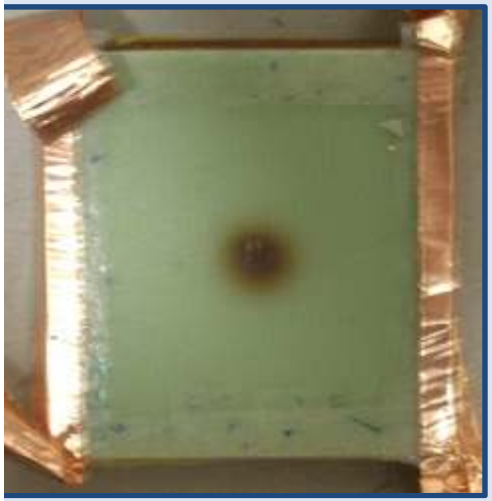
$DB_{45°} > DB_{0°}$

~sqrt 2

-DB of the track is measured

Breakdown Voltage of epoxy/fiber composite





High Voltage Group
Prof. Dr. Hinrichsen

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Dielectric strength: Summary

What does that mean for SIS100 magnets?

more calculations and statistics needed:
-failure probability calculation

-„exact“ beamloss calculations with angular distribution

-low T reference measurements

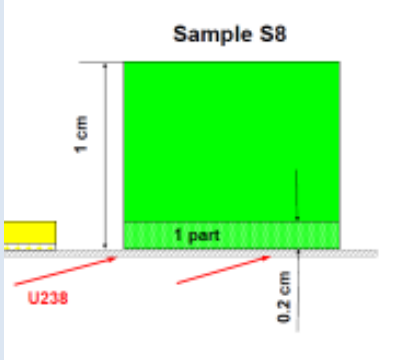
Insulation meets the specification up to high doses of gamma irradiation and „light“ ion beams.

2*75 µm + 2*50 µm of polyimide should withstand: ~90 kV

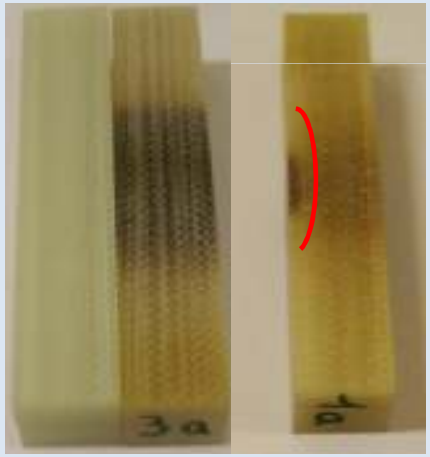
Expected are about 1.3 kV (3kV as defined security limit).

Maybe more crucial: Fatigue of the coil structure support

G11 sample from „cocktail beam“-experiment



50% of the dose contributes to fragments Z=41-60 having a mean energy of 400 MeV



Fatigue measurements at low T necessary!

- The wedges of endspacers (SIS300) see a maximum stress of 60 MPa
- When the magnet is ramped the stress can decrease by 26 MPa
- The number of cycles is expected to be in the range of 1.4 10^7 during 20 years of operation

Defined Hardness Tests

Critical properties:

- Breakdown Voltage → Insulation Lifetime
- Thermal Properties → Quench Protection
- Voltage Breaker → Helium Transfer
- T-Sensors → Cryo-Reliability

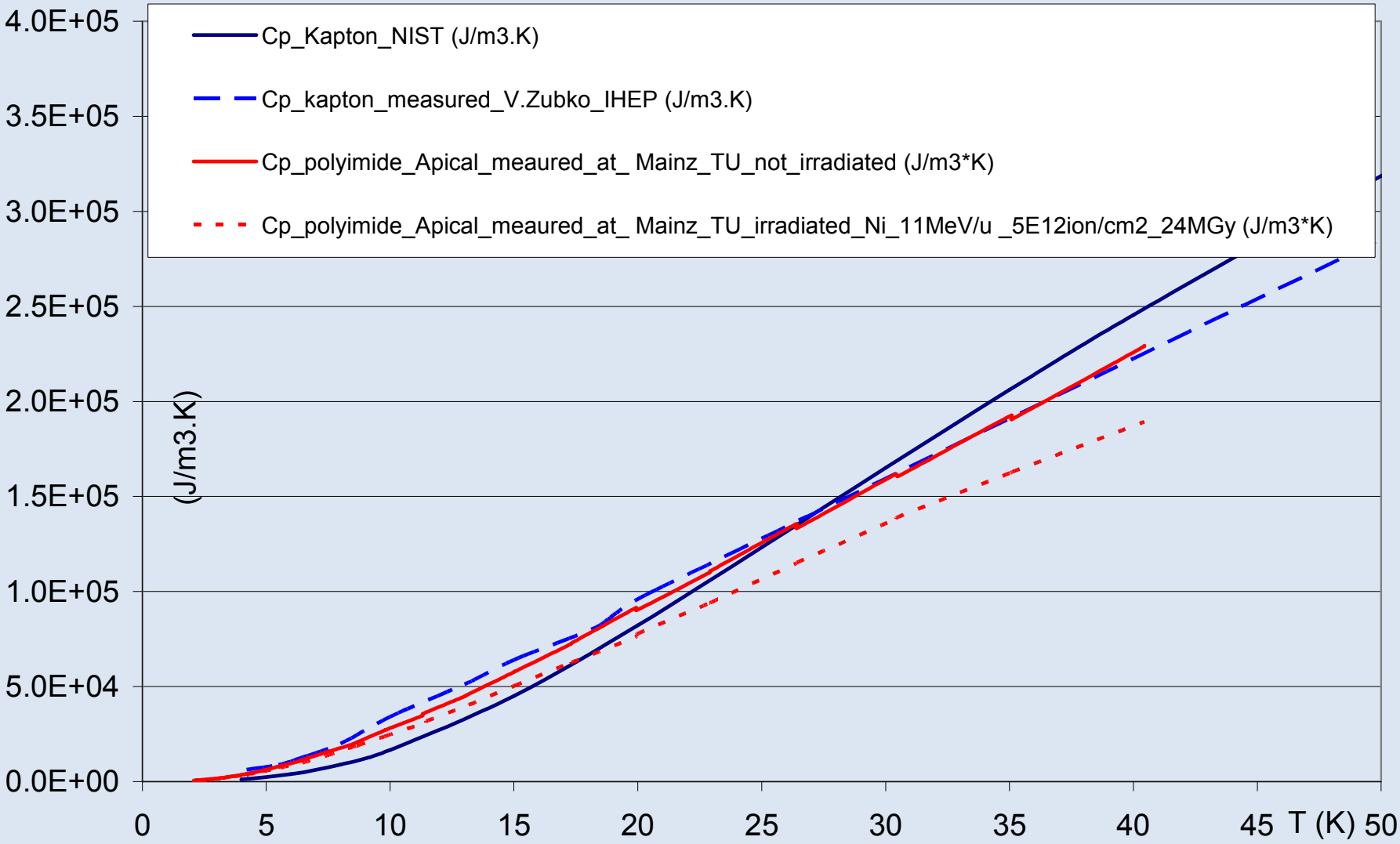
Thermal Properties at low Temperature

Specific Heat

Thermal Conductivity

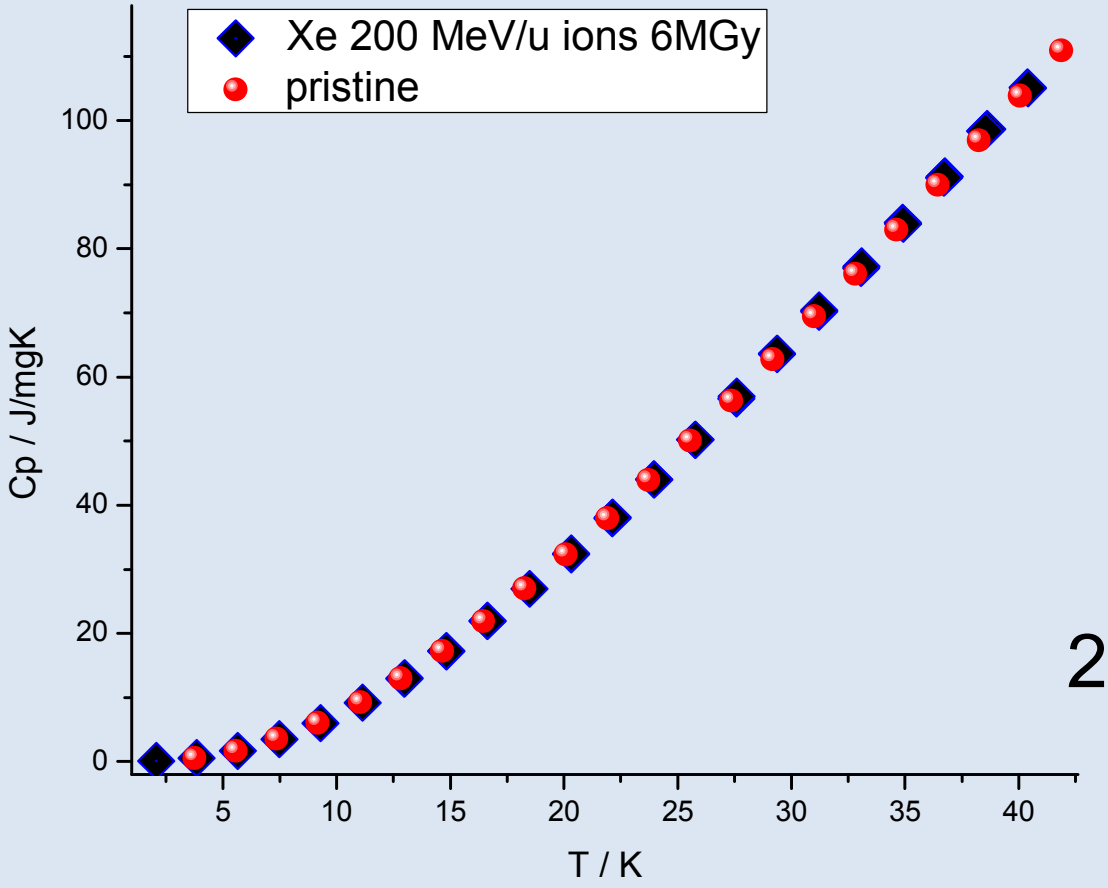
needed values for quench calculations

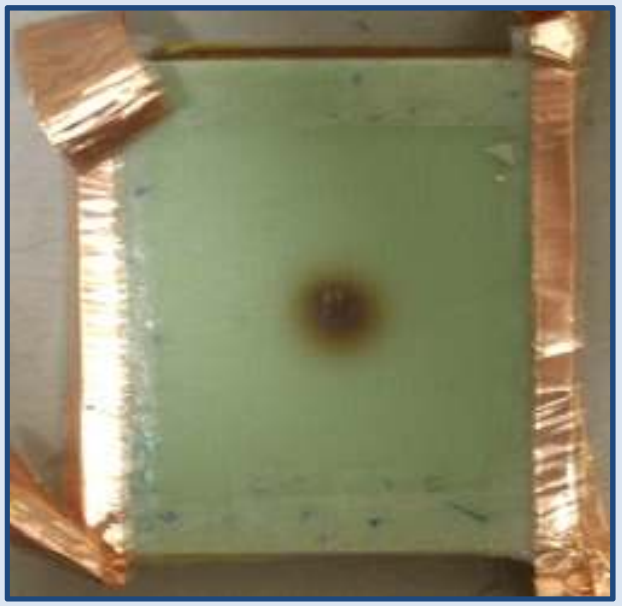
Specific Heat at low Temperature of polyimide



Apical AV 25MGy Ni 11MeV/u, 50 micrometer foil

Specific Heat at low Temperature of Epoxy/Fiber Composite





~6MGy
200 MeV/u Xe-beam

No significant change!!!

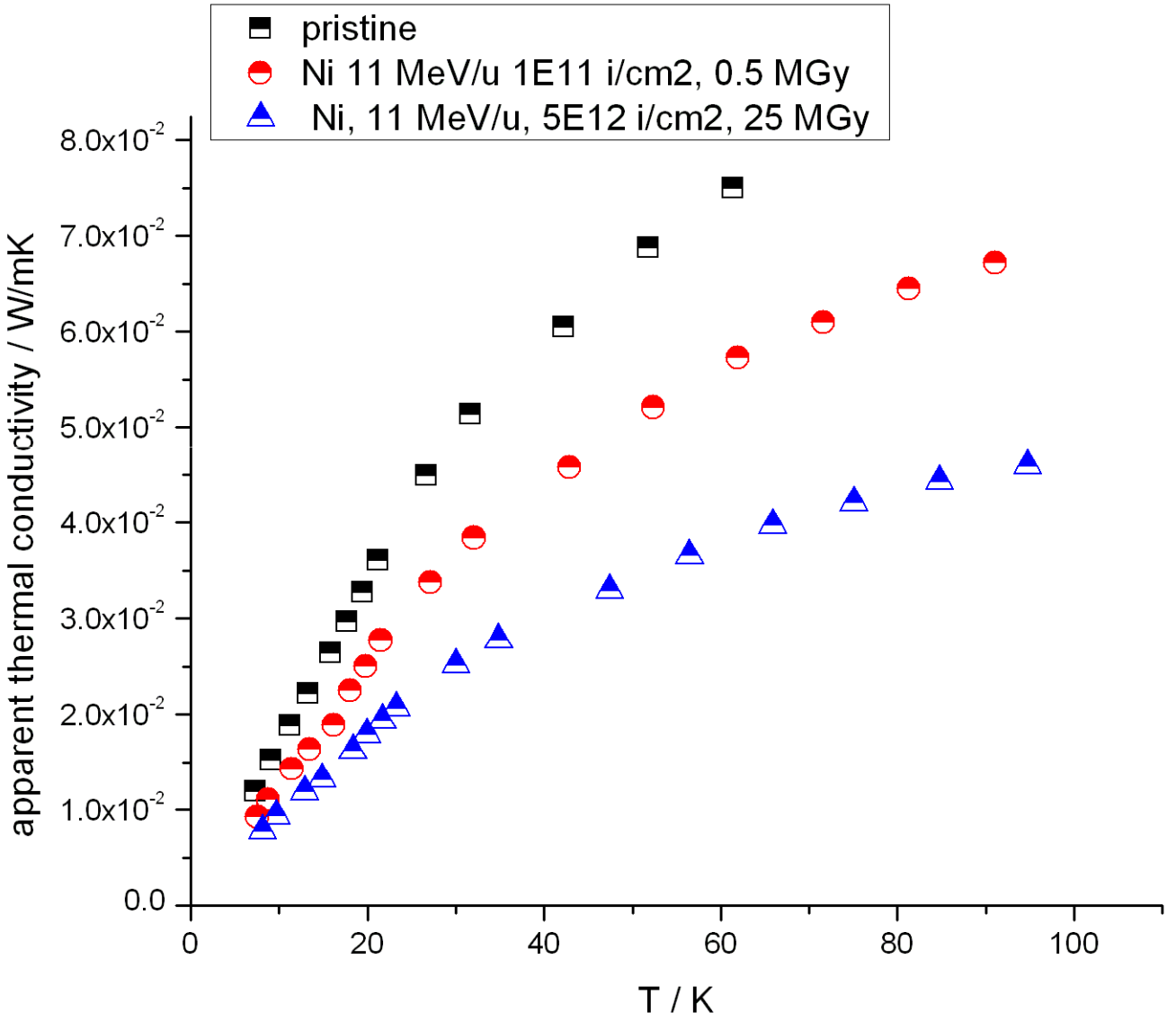
Ion Induced Changes of Specific Heat at low Temperature

Summary:

A small beam induced decrease of low T specific heat (polyimide)

no significant change in ion irradiated epoxy/fiber composite in the observated dose range.

Thermal conductivity at low Temperature (polyimide)



Thermal Conductivity at low Temperature

thermal conductivity of irradiated polyimide decreases about 50% after 25 MGy of Ni-ions having 11 MeV/u.

Defined Hardness Tests

Critical properties:

- Breakdown Voltage → Insulation Lifetime
- Thermal Properties → Quench Protection
- Voltage Breaker → Helium Transfer
- T-Sensors → Cryo-Reliability

„Voltage Breaker“ Test

Direct irradiation with Ar-Ions (400MeV/u)
up to $0.9*10^{14}$ ions/cm^2 (8.9 MGy)

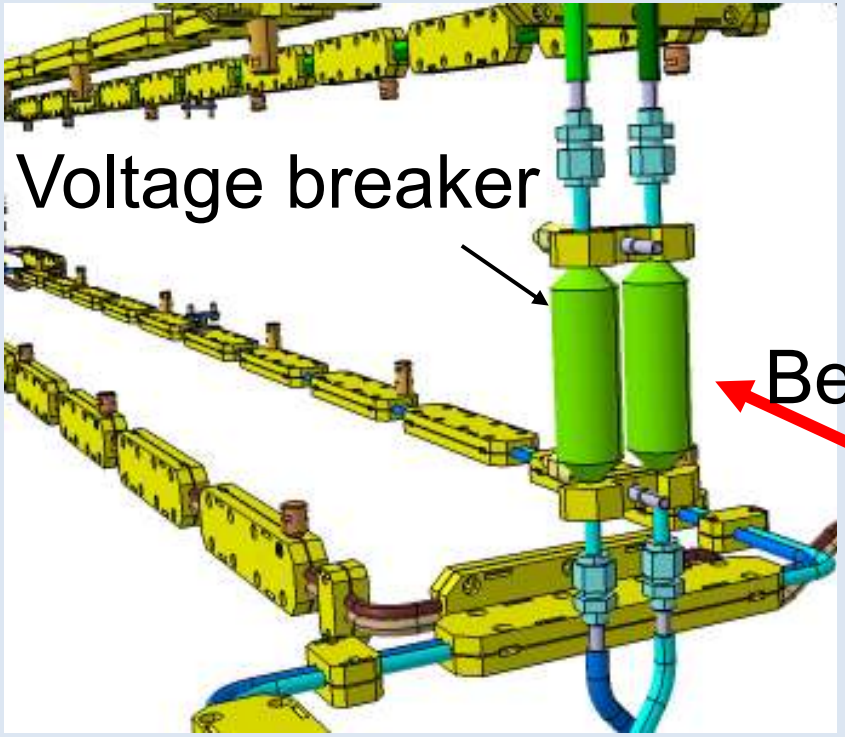
After one thermal cycle to 77K the
leakage rate of the voltage breaker
increases from 1e-11 mbar*l/s to
5e-5 mbar*l/s (at a helium pressure of 25 Bar)

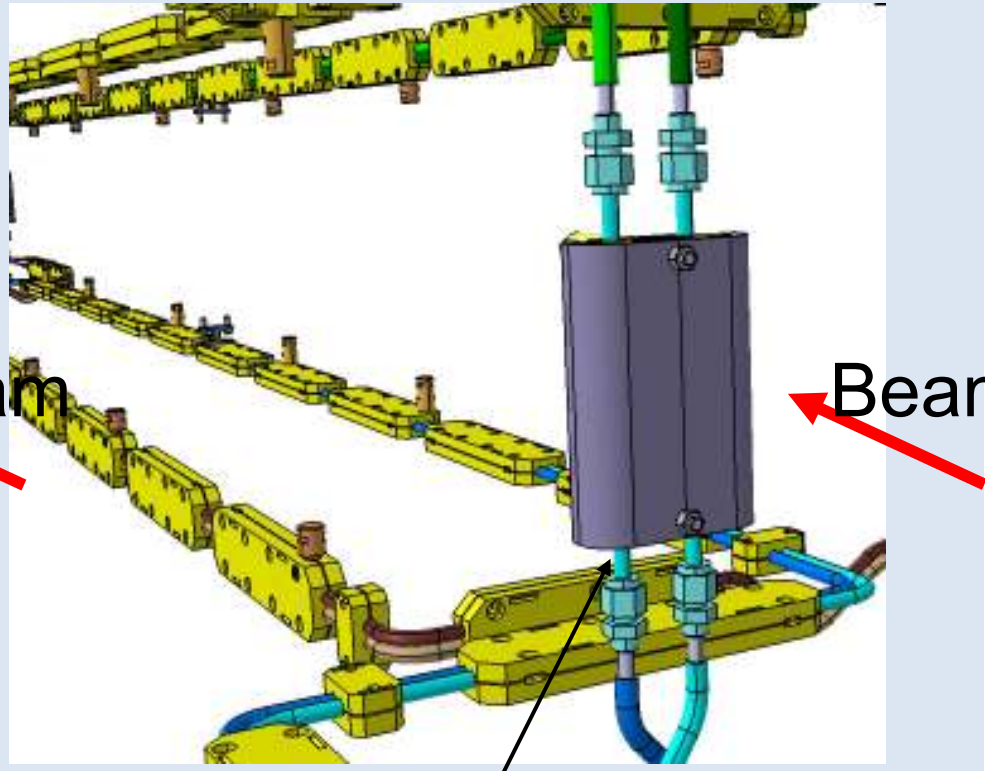
9 MGy of Ar beam is too much
for the voltage breaker:

Shielding will be foreseen

Shielding of the voltage breaker

Before the shield installation After the shield installation





Shield: 6 mm of stainless steel

Defined Hardness Tests

Critical properties:

- Breakdown Voltage → Insulation Lifetime
- Thermal Properties → Quench Protection
- Voltage Breaker → Helium Transfer
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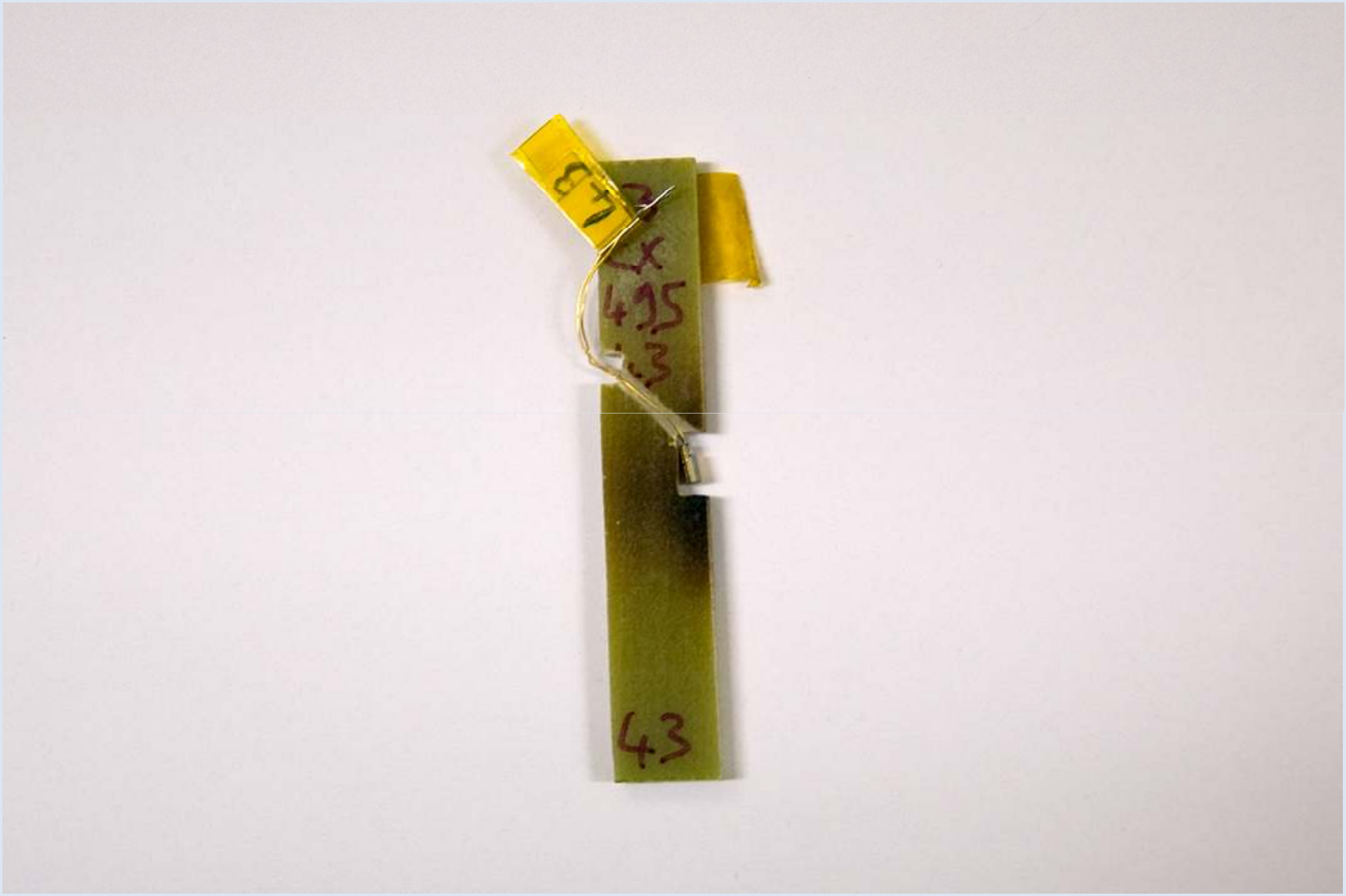
T sensors: First results on HHD-05-2008 Experiment



Calculated max. dose of „cocktail beam“ ~6MGy

T sensors: First results on HHD-05-2008 Experiment

No systematic ion induced changes of Cernox sensors in the observated dose range.

~6 MGy of max. Dose („cocktail-beam“)

Outlook

-measurements of activated samples (~350)
- -mechanical tests
- -dielectric strength tests
- (ITEP beamtime 2008 160 MGy p+)
- („Cocktail Experiment“)

-Measurements of other magnet materials components:

-Formvar & Enamel insulated wires

-„ITER“-epoxy/fiber composite

Acknowledgment

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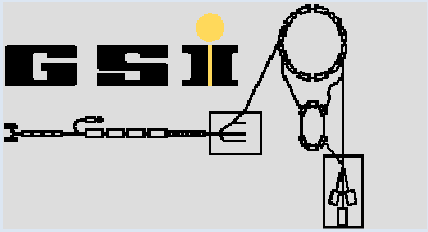

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Eric Floch (FAIR-MG)
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Thanks

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