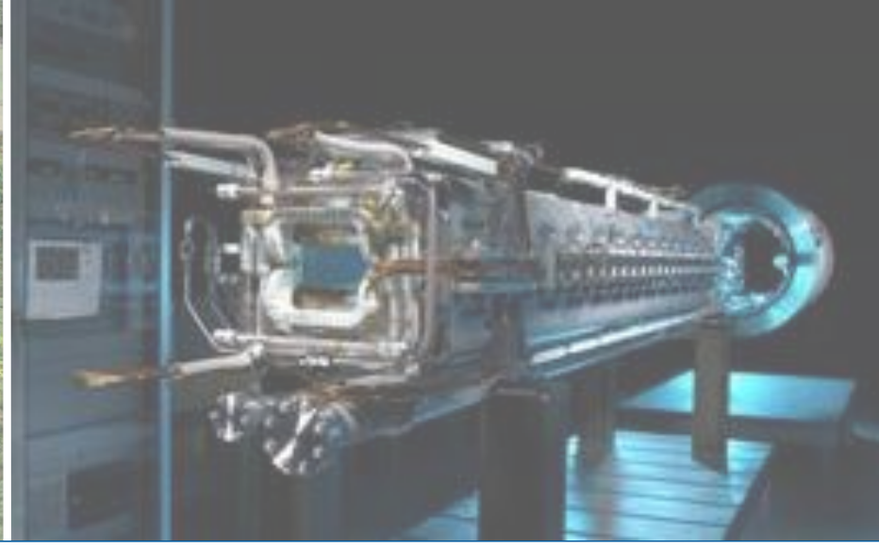


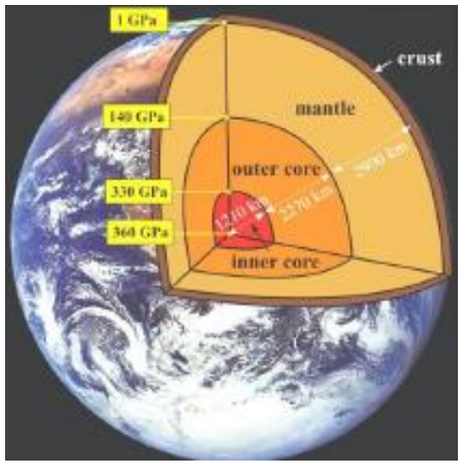
Space Reserach and Radiobiology at FAIR

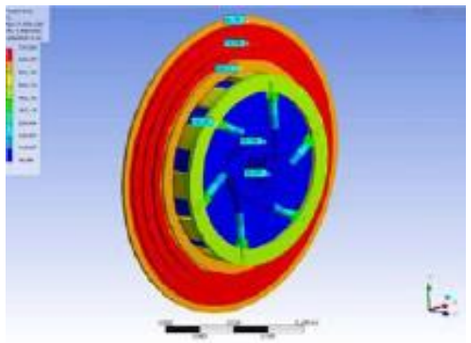
Radek Pleskac (BIOMAT Project at APPA)

Finland France Germany India Poland Romania Russia Slovenia Spain Sweden UK

Space Research and Radiobiology at FAIR

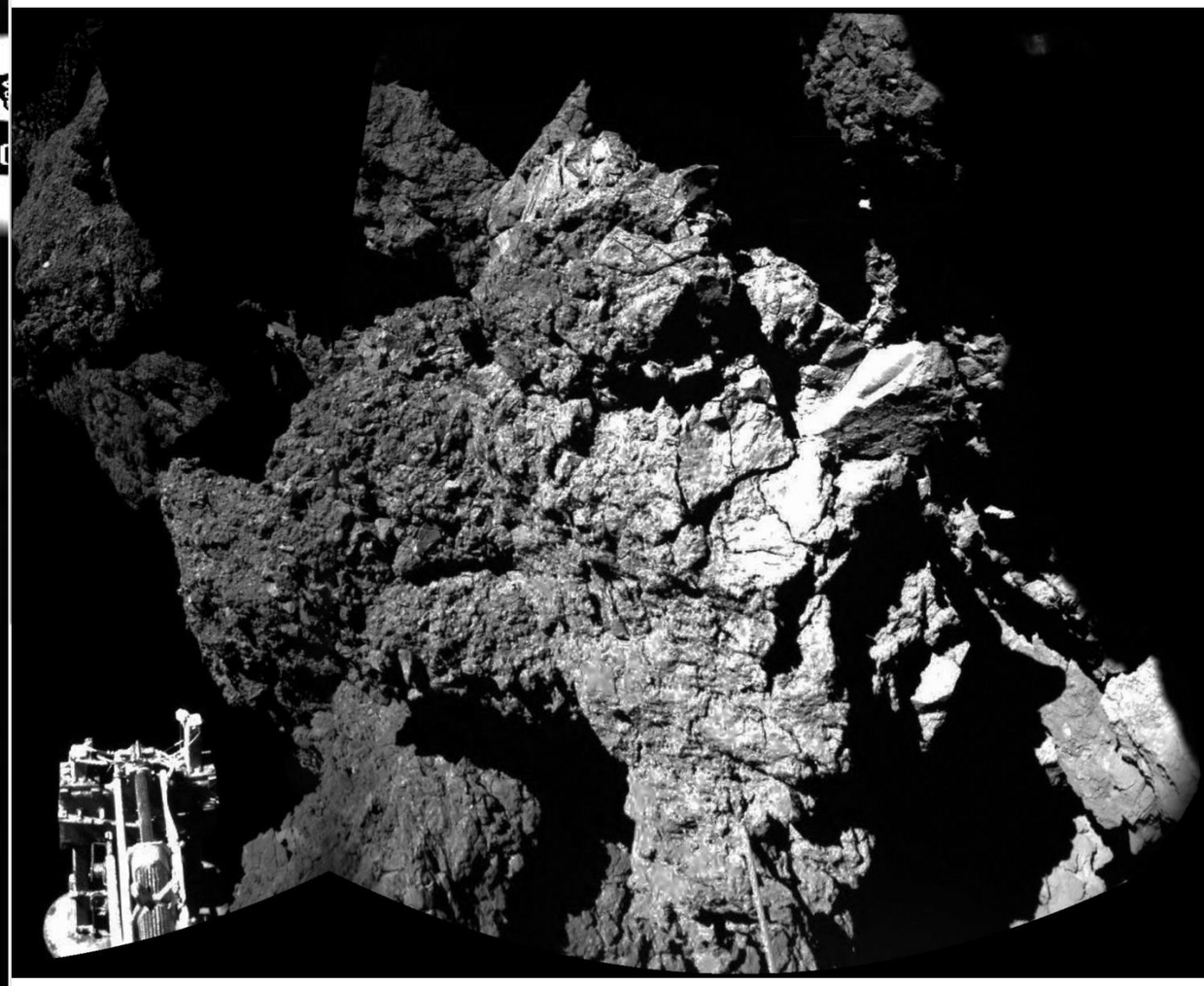
- Introduction
- Space Research
  - Motivation
  - Radiation in Space
  - Experiments at GSI
  - Some Examples: SOHO, ACE, AMS, ALTEA, cave A)
- Radiobiology and Therapy
  - Nuclear Fragmentation
  - Microbeam
  - Heart Arrhythmia
- BIOMAT at FAIR
  - Future Experimental Facility
  - Proton Theranostics
  - Material Science
- Summary





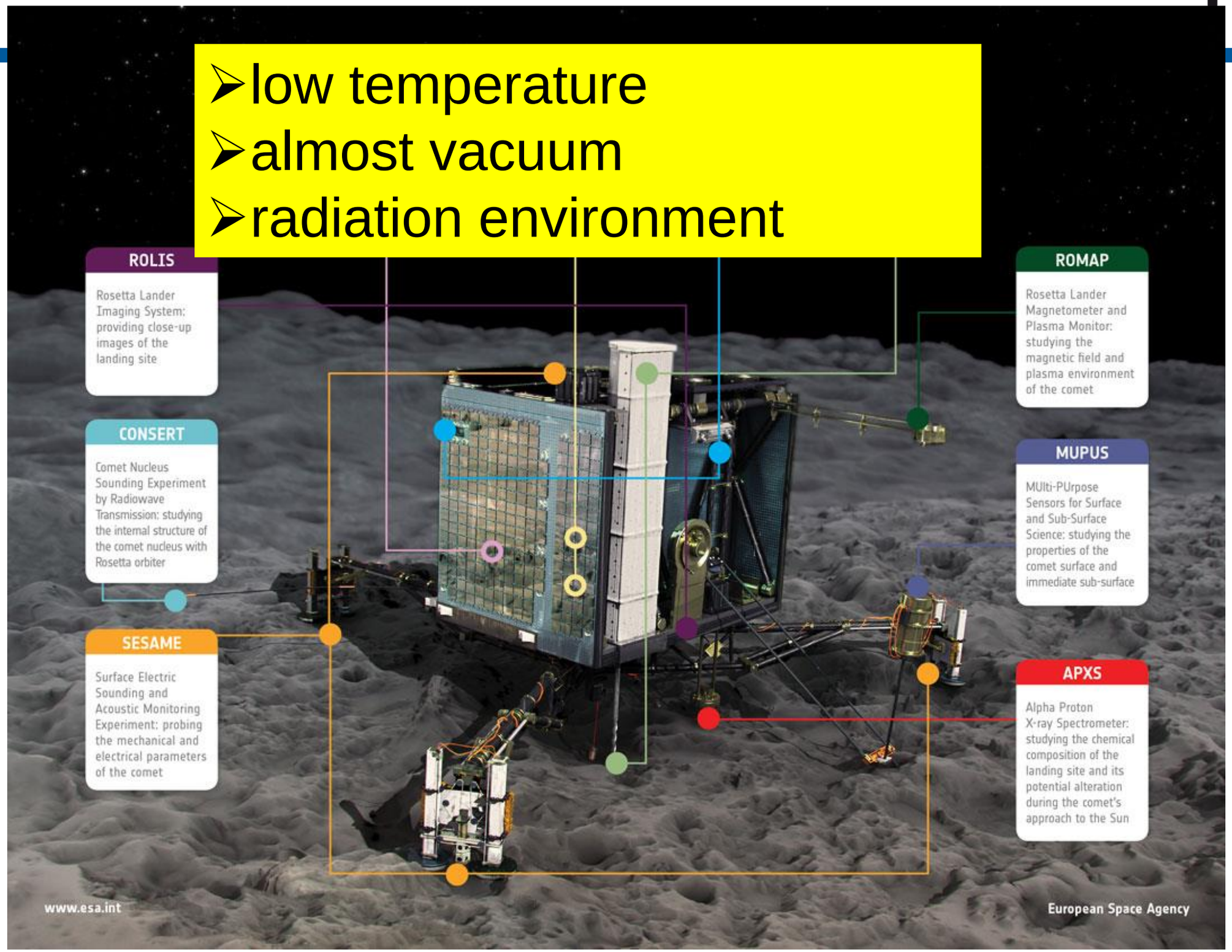
ROLIS descent image and –
- Welcome to a comet

C67/P Churyumov - Gerasimenko

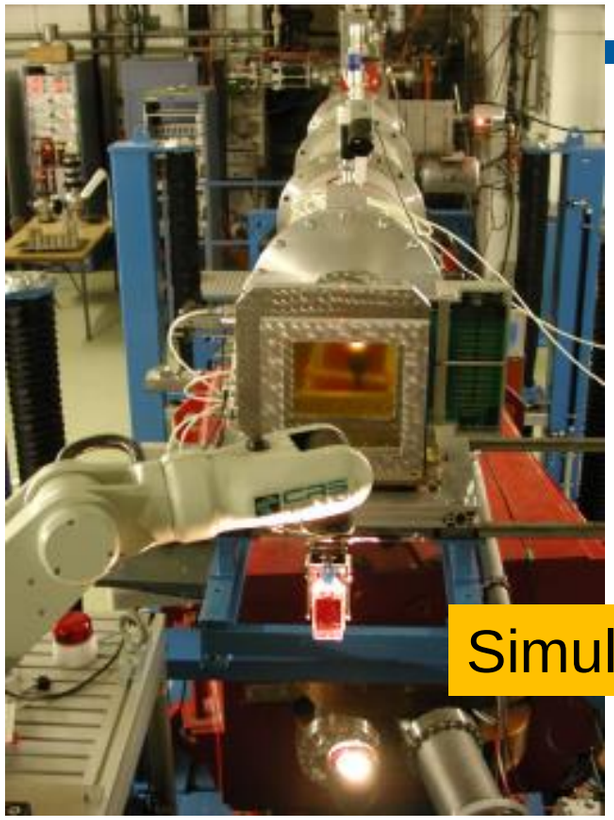


Philae landing module

- low temperature
- almost vacuum
- radiation environment



Space Research at GSI



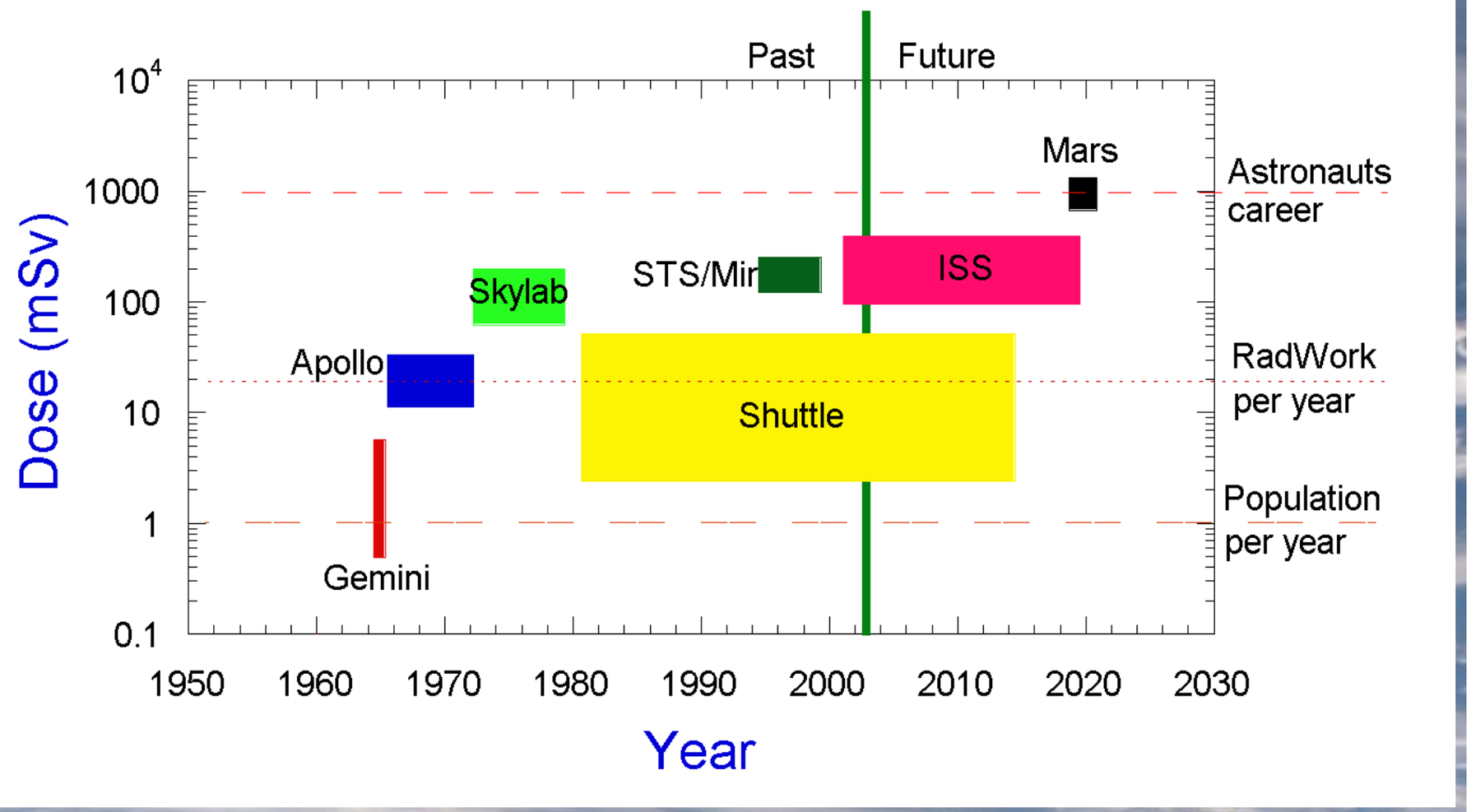
- Radiation environment in space has severely adverse aspects on human, electronics and materials
- Effects of highly charged highly energetic (HZE) heavy ions in the space are the most challenging

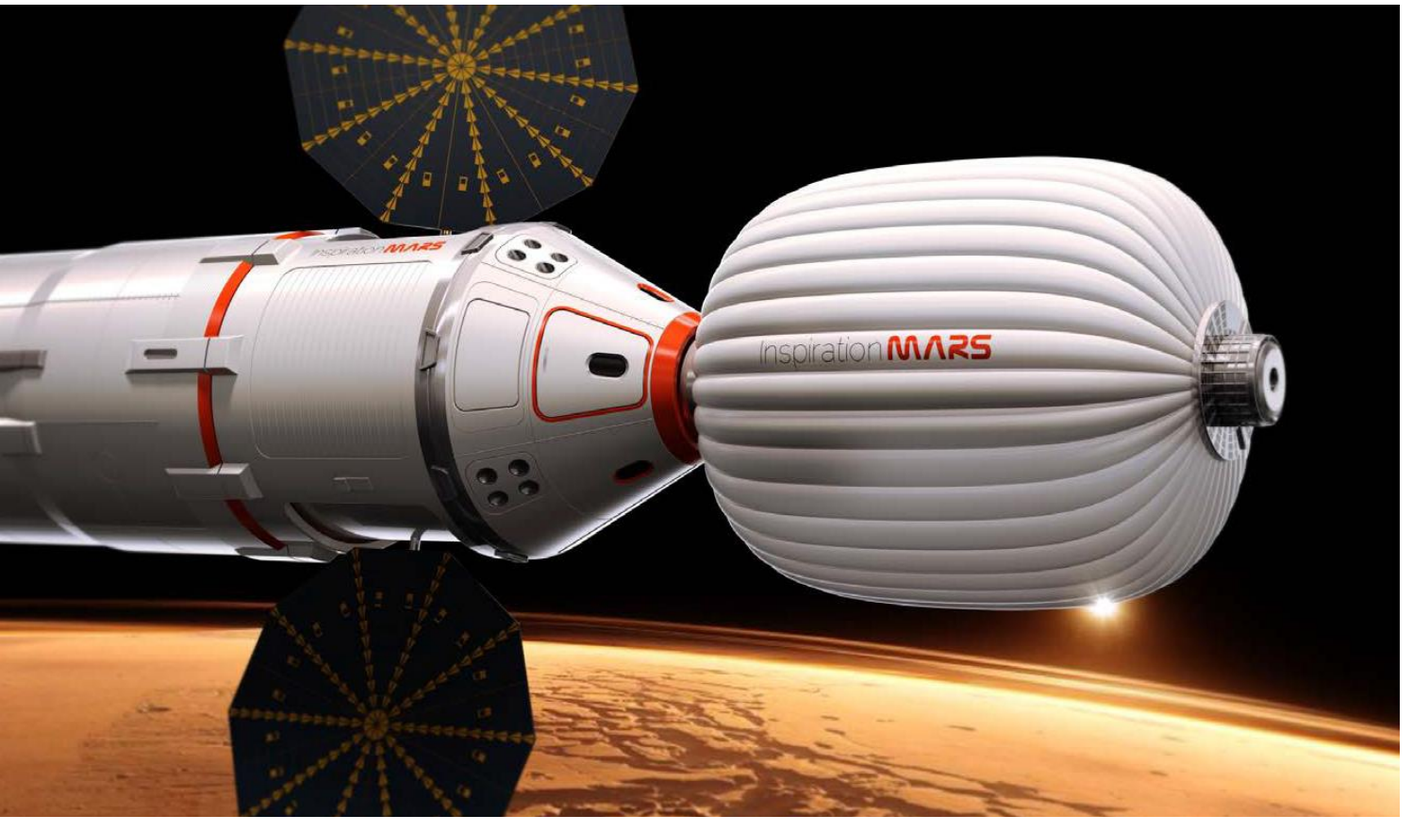
Simulation of cosmic particle radiation using high-energy accelerators

- Radiobiological effects on human beings *(risk assessment for manned space missions)*
- Electrronic components *(radiation hardness tests)*
- Shielding materials
- Test and calibration of space flight instruments

Radiation Dose in Different Missions

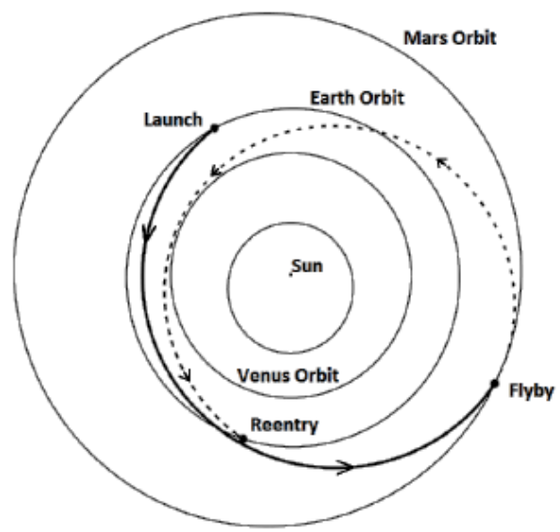
- STS and ISS programs will be dropped, in favour of Moon and Mars manned exploration
- Radiation risk is a big problem for human planet exploration

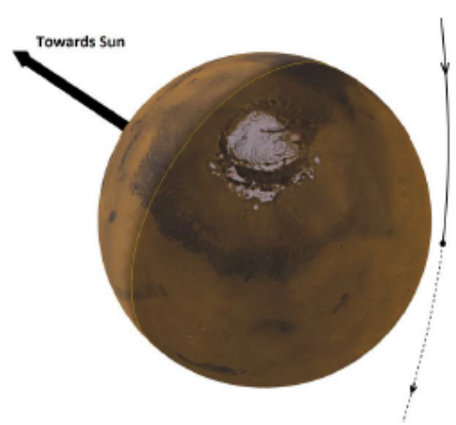




April, 3, 2013

- A 501-day "free-return" Mars flyby passing within a hundred miles of the surface
  - Only small correction maneuvers are needed during transit
- Simple mission architecture lowers risk
  - No entry into Mars atmosphere
- An exceptionally quick free return occurs twice every 15 years
  - 1.4 years duration vs. 2 to 3.5 years typical
  - Launch Jan 5, 2018, (or 2031)
  - Mars on 20 Aug 2018 (227 days)
  - Earth on 20 May 2019 (274 days)
  - At Mars, Earth is 38,000,000 miles away
- Video
  - http://www.youtube.com/watch?v=IBGIYNd2tmA





Tito, MacCallum, Carrico, Loucks

FISO 3 April, 2013

The New York Times

Space & Cosmos

WORLD | U.S. | N.Y. / REGION | BUSINESS | TECHNOLOGY | SCIENCE | HEALTH | SPORTS | OPINION

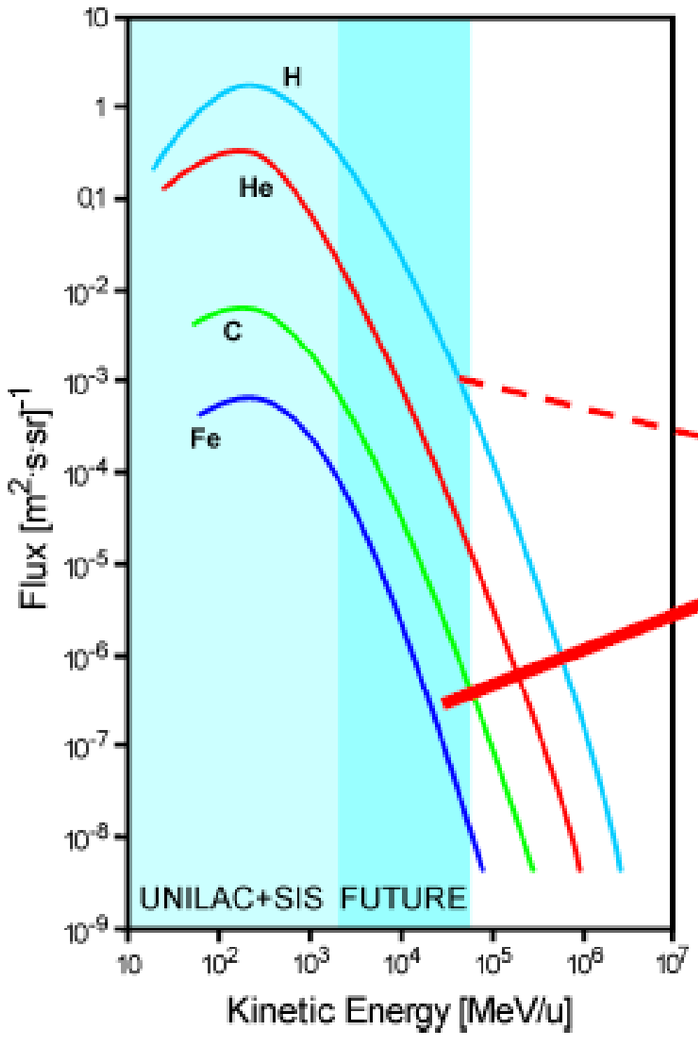
ENVIRONMENT SPACE & COSMOS

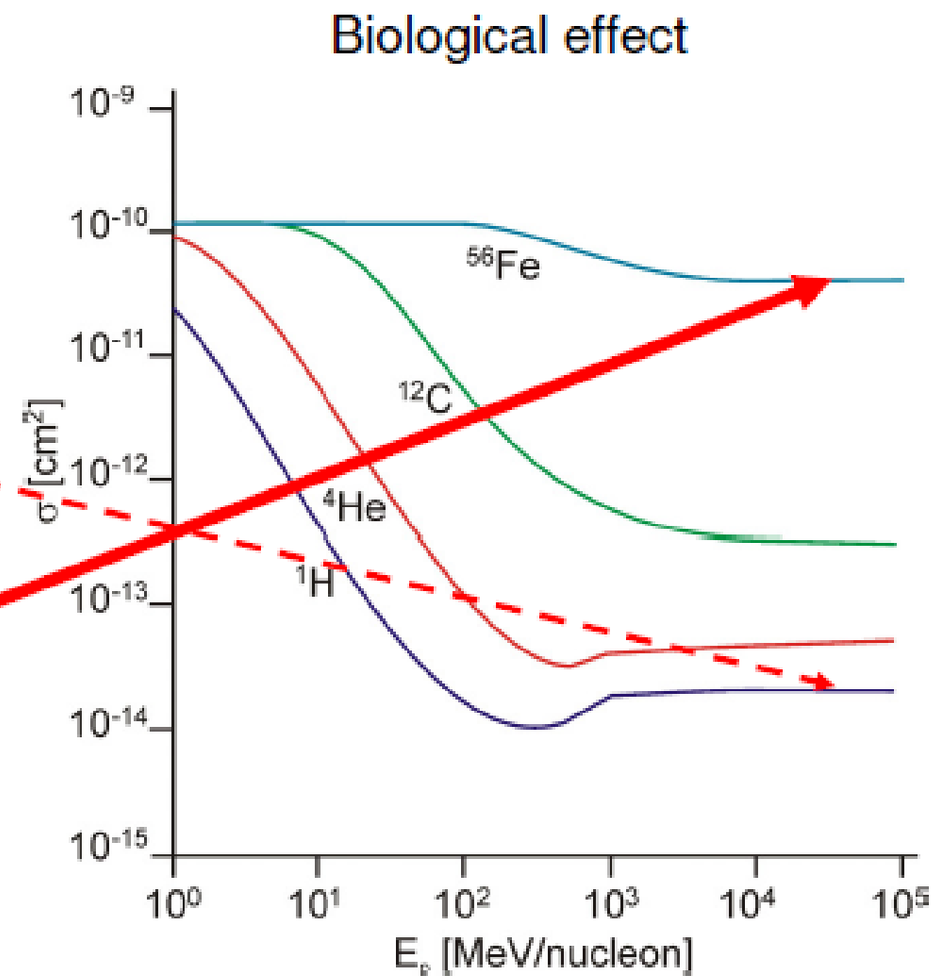
May, 30, 2013

Data Point to Radiation Risk for Travelers to Mars

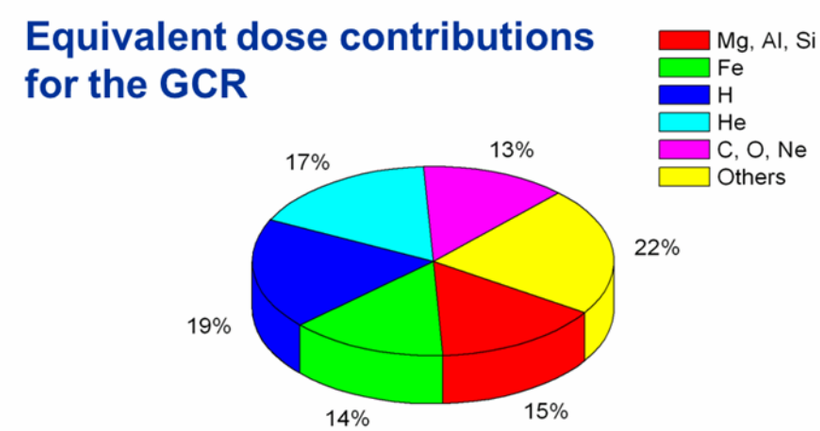
Dose=1.8 mSv/dayx501x2=1.8 Sv

Galactic Cosmic Radiation (GCR)

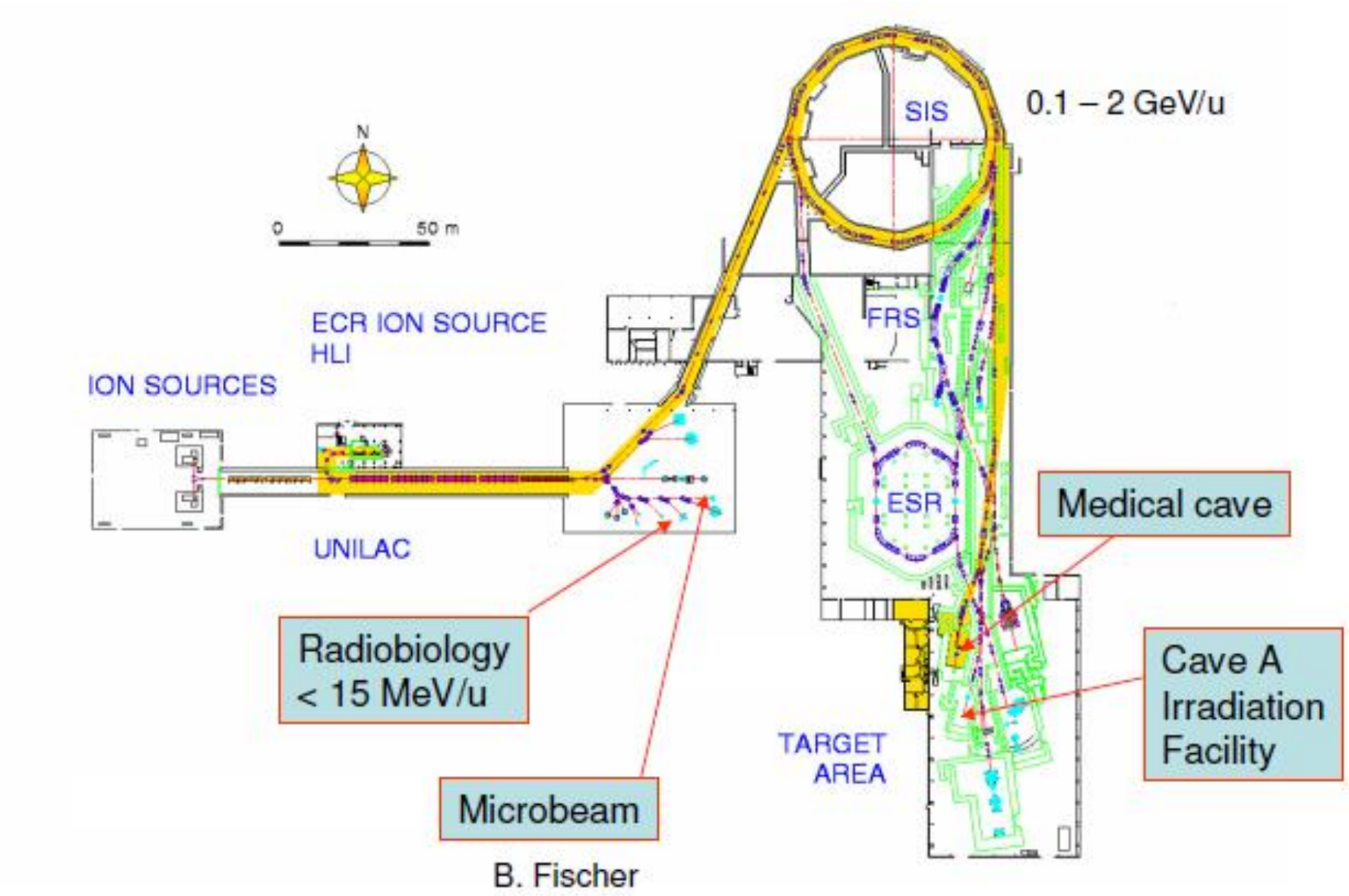




- 2% electrons / positrons
- 98% particles
  - 87% protons
  - 12% helium
  - 1% heavier particles



Irradiation Facilities at GSI



High-Energy Irradiation Facility Cave A

Basic Specifications

- All ions from H to U
- Energies 50 – 2000 MeV/u
- Particle fluence 10^2 – 10^{12} ions/cm^2
- Max. Fieldsize 20 x 20 cm^2

Beam delivery system

- Rasterscan-System intensity-controlled
- Excellent Homogeneity for large-area irradiations
- On-line beam monitoring

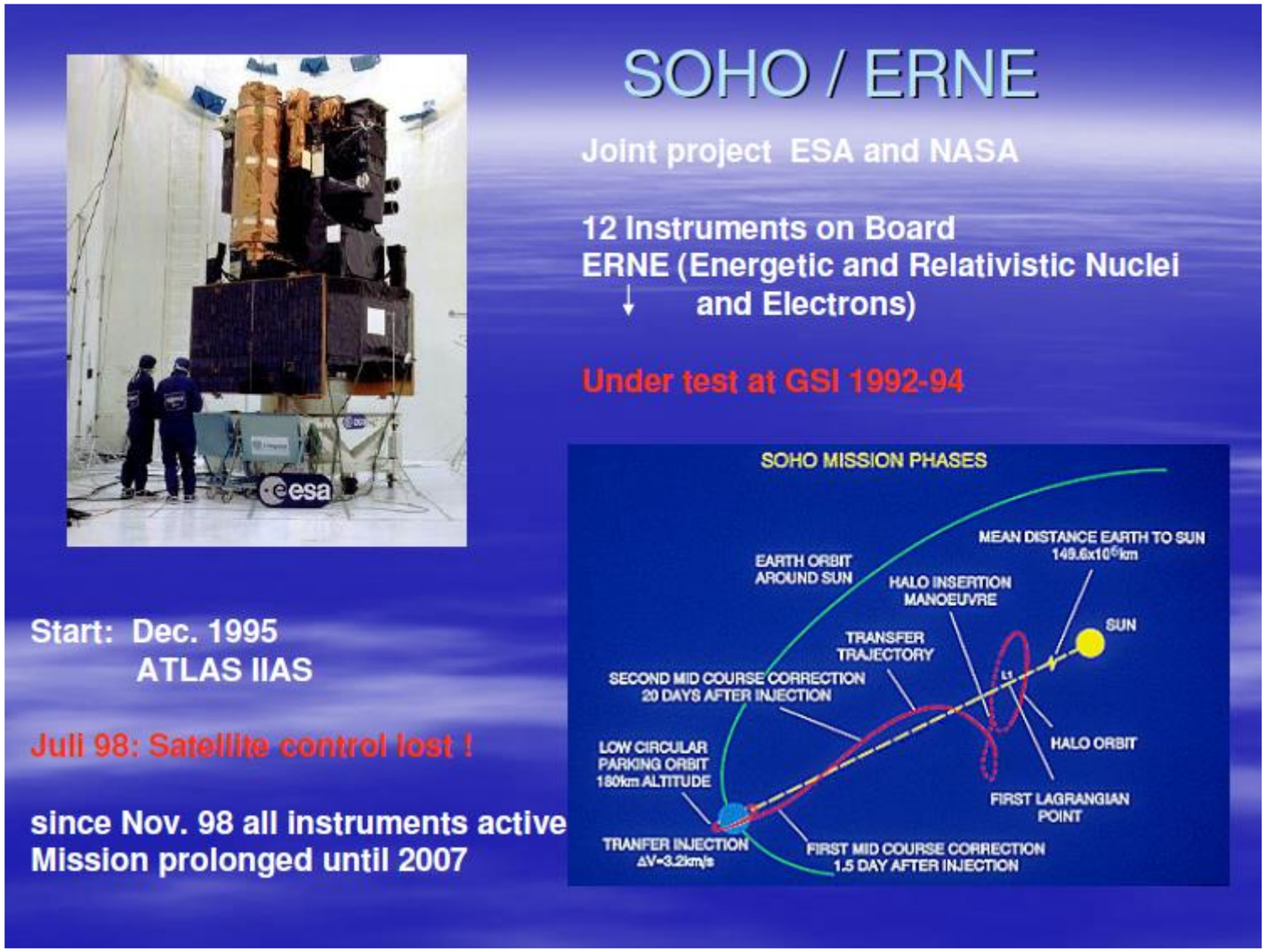
Sample handling devices

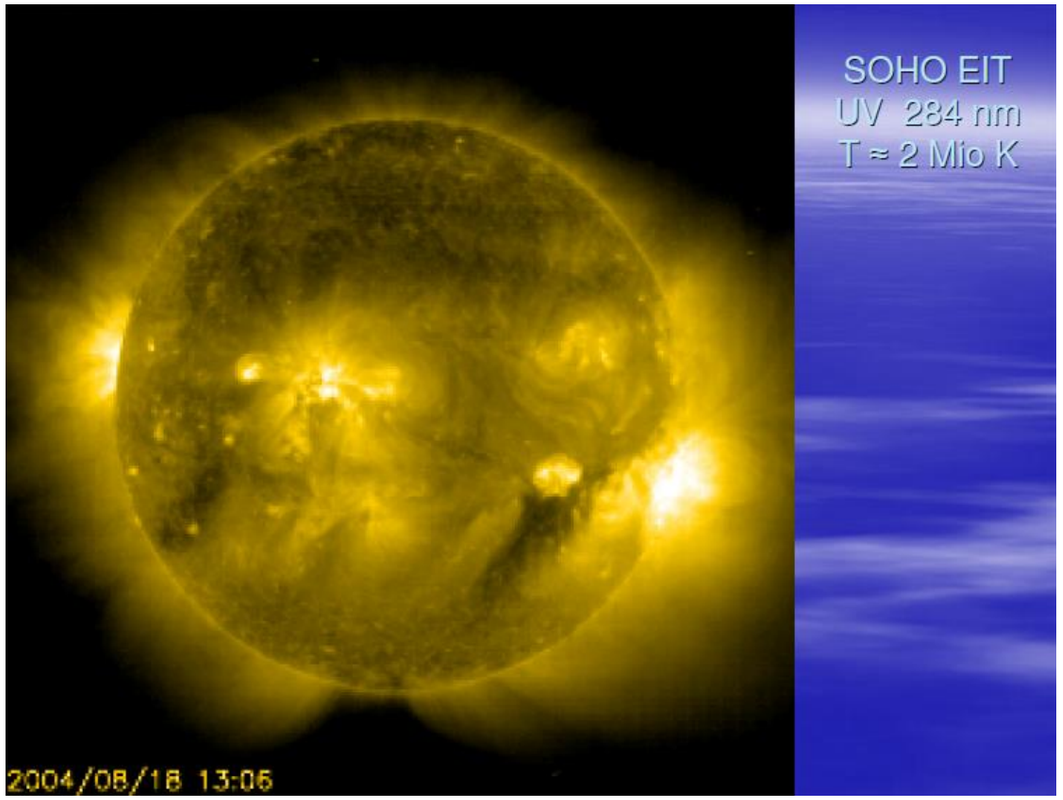
- Robot System
- Linear tables
- Positioning-Lasers
- TV-System remote-controlled

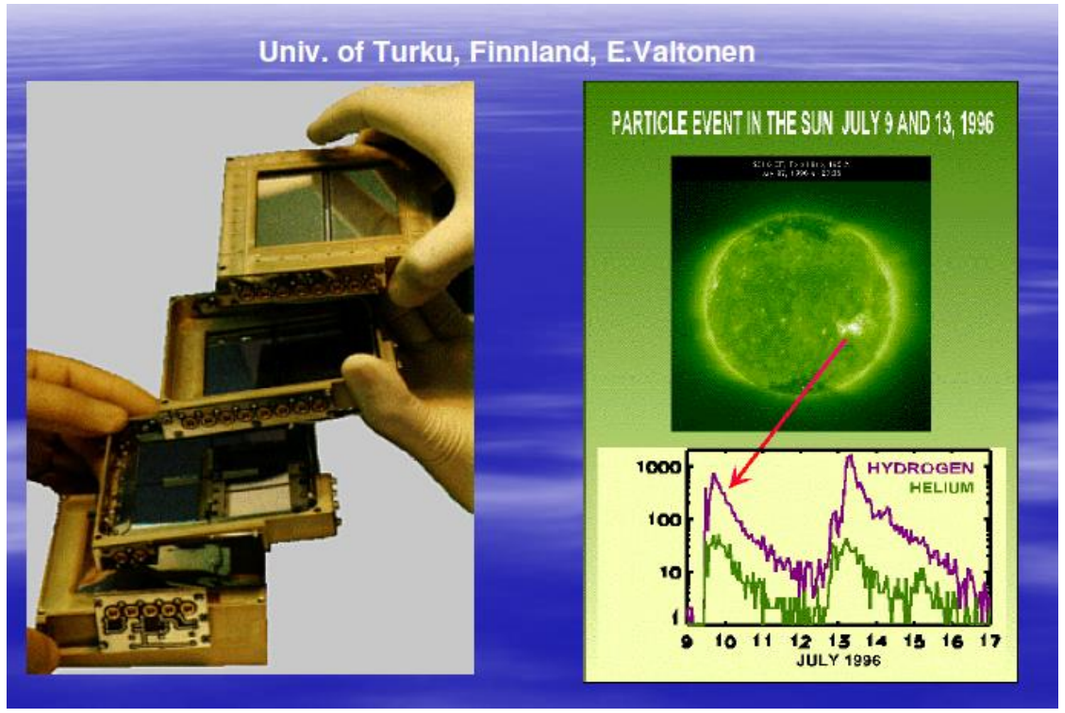
Space Flights Instrument at GSI

AMS-Kollaboration	2000-2005	Alpha Magnetic Spectrometer (ISS)
		Hardware Data acquisition system
INFN Frascati	2000	VLSI-Chips
		RESURS-Satellit (Russ.)
ALTEA Kollaboration	1997/2001	Detector Telescope NINA
	2002-2005	ALTEA (ISS) "Phosphenes"
Univ. of California	1999	Glass Detectors (flown in MIR)
CALTECH Pasadena &	1997	Advanced Composition Explorer
Goddard Space Flight Center		ACE (in orbit)
Space Res. Lab Turku	1992/94	ERNE-Detector
		SOHO (in orbit 1995)
Univ. Salt Lake City		Nuclear track detectors
IBM Manassas USA		Microprocessors
Dublin Institute of Physics		Nuclear track det. (airplanes)

Example 1 (SOHO/ERNE)





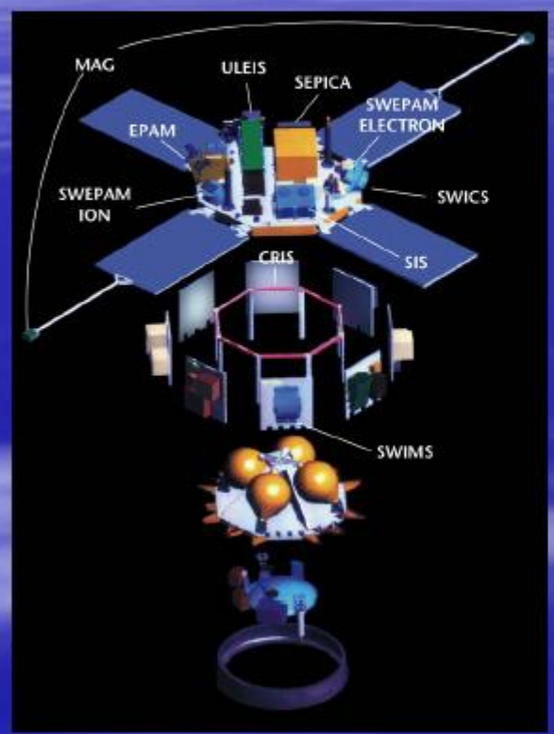


Example 2 (ACE)

Advanced Composition Explorer ACE

NASA / Caltech Pasadena / Goddard Space Flight Center

Sun



Earth

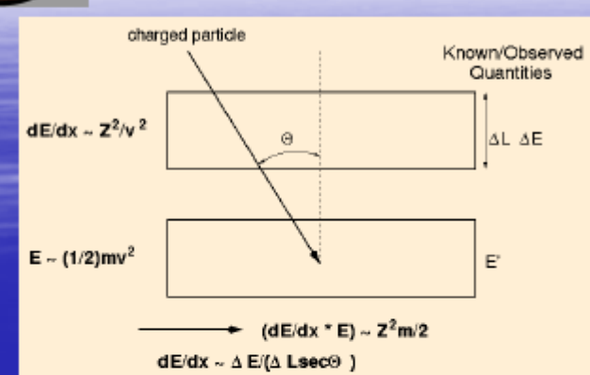
9 high-resolution spectrometers exploring the solar and cosmic particle radiation

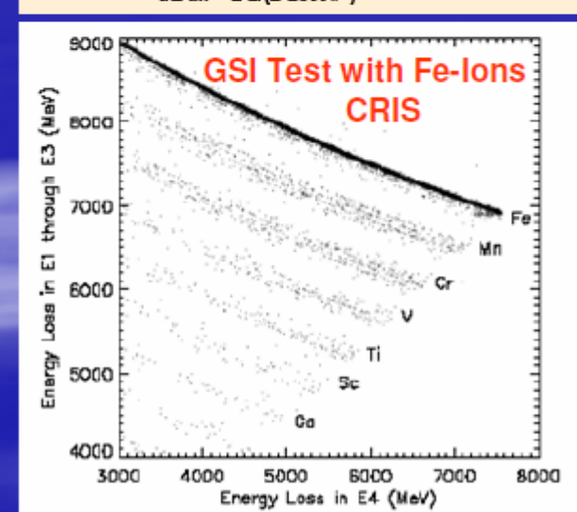
CRIS and SIS were tested and calibrated at GSI

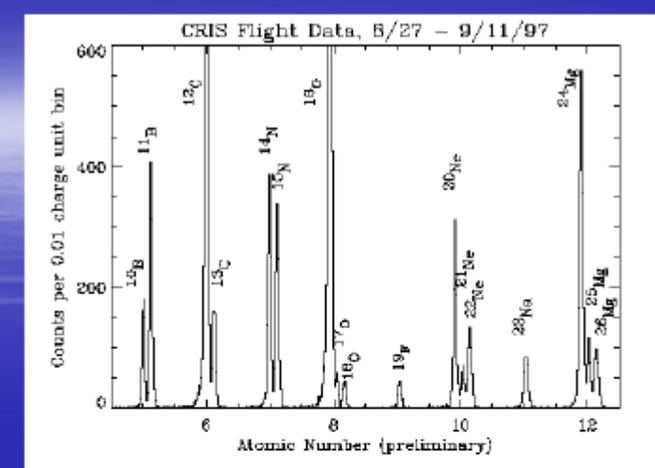
Since Aug.1997 in space (L1)

Particle identification

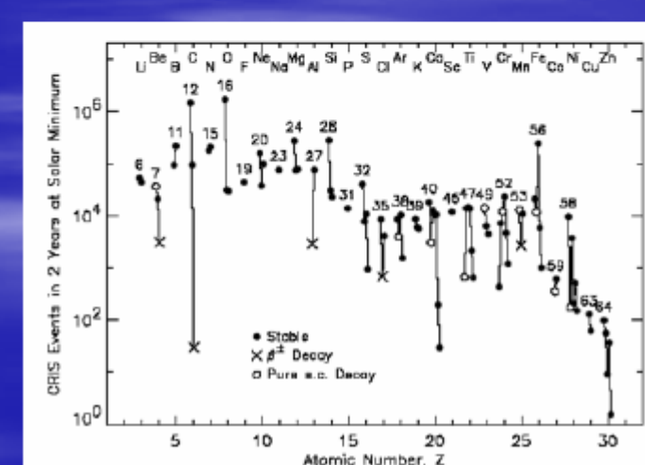
ΔE, E, angle θ







Element abundance in GCR



Example 3 (AMS)

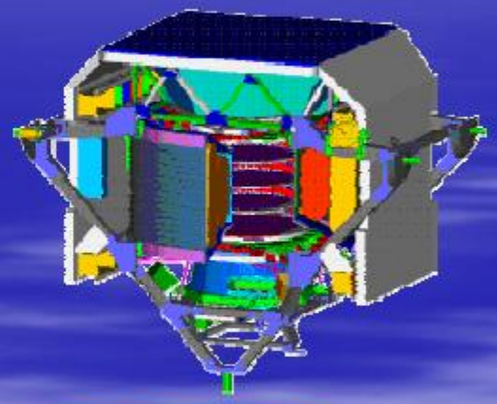
Alpha Magnetic Spectrometer AMS

Particle detector to be mounted at the International Space Station ISS

> 500 Scientists / 56 Institutions in 15 countries

Search for Antimatter and Dark matter
Origin of cosmic radiation

AMS-02



Tests of electronic components of the
Data acquisition system at GSI
Kr/Xe/Au/U Ions 2000/01/02/05

Launch 2009/2010 ?

Assembly at CERN
Tests at ESA-ESTEC
3 years on ISS

AMS-Test at GSI

Test conditions

- Ion source – Au^{79};
- Energies: 120, 150, 200, 400 and 800 MeV/nucl;
- LETs: 12, 16, 23, 28, 33 MeV/(mg/cm^2);
- Intensities: up to 10^5 ions/spill;

ACOP components

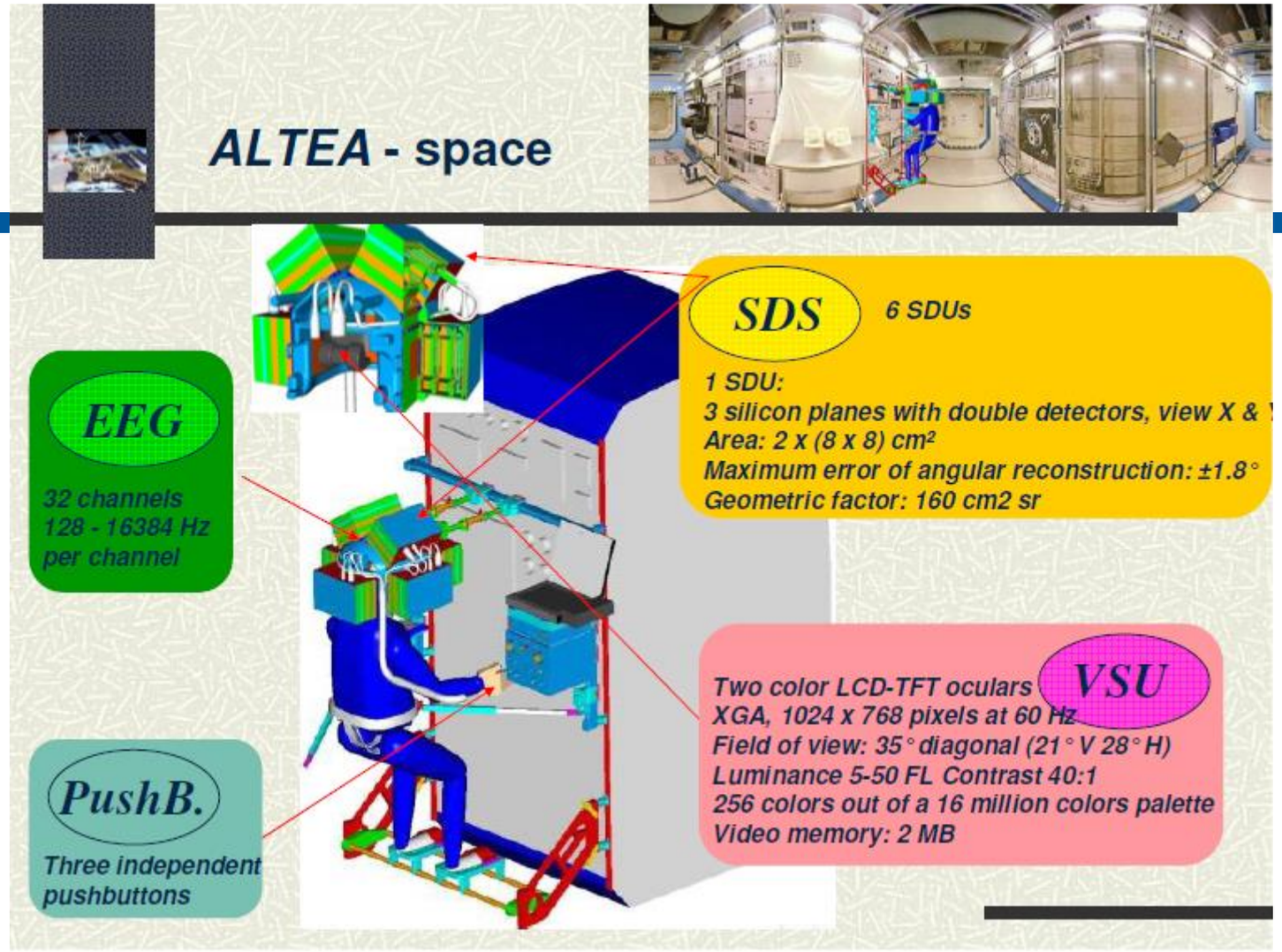
- DP83316 (NS), Ethernet Controller, SEL rate on ISS ~ 10^{-6} day^{-1}, accepted;
- AM79C973 (AMD), Ethernet Controller, SEL rate on ISS ~ 10^{-6} day^{-1}, accepted;
- 82551IT (Intel), Ethernet Controller, SEL rate on ISS ~ 10^{-3} day^{-1}, rejected;
- PDC2032 (Promise), SATA Controller, SEL rate on ISS ~ $2 \cdot 10^{-5}$ day^{-1}, not recommended;
- SiI3114 (SI), SATA Controller, SEL rate on ISS ~ 10^{-5} day^{-1}, accepted w/reserv – test lower LETs;

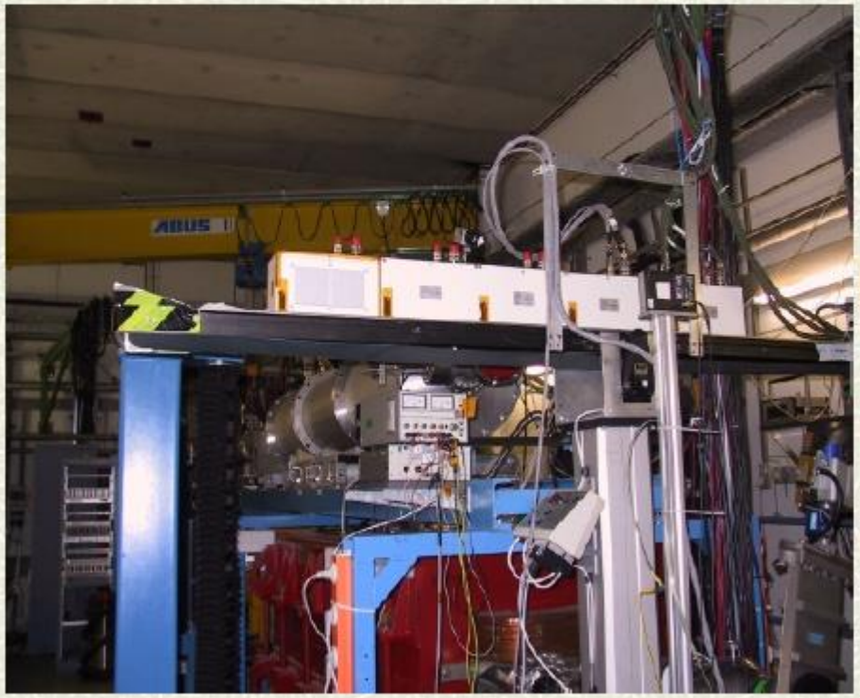
Example 3 (AMS)

Example 3 (AMS)

Example 4 (ALTEA)

Astronauts Sunita Williams and Michael Lopez-Alegria

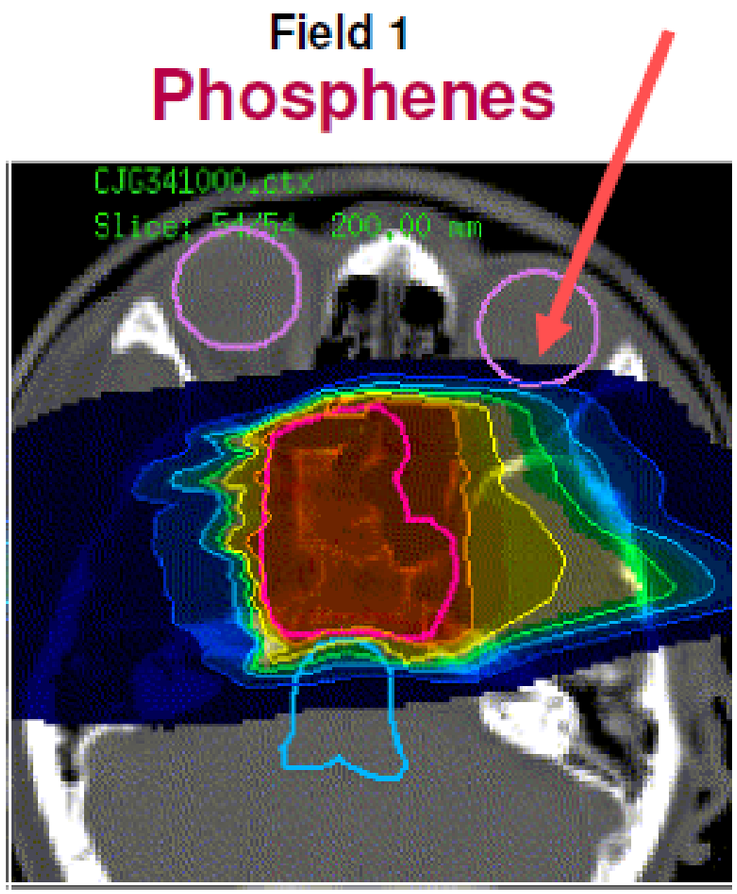


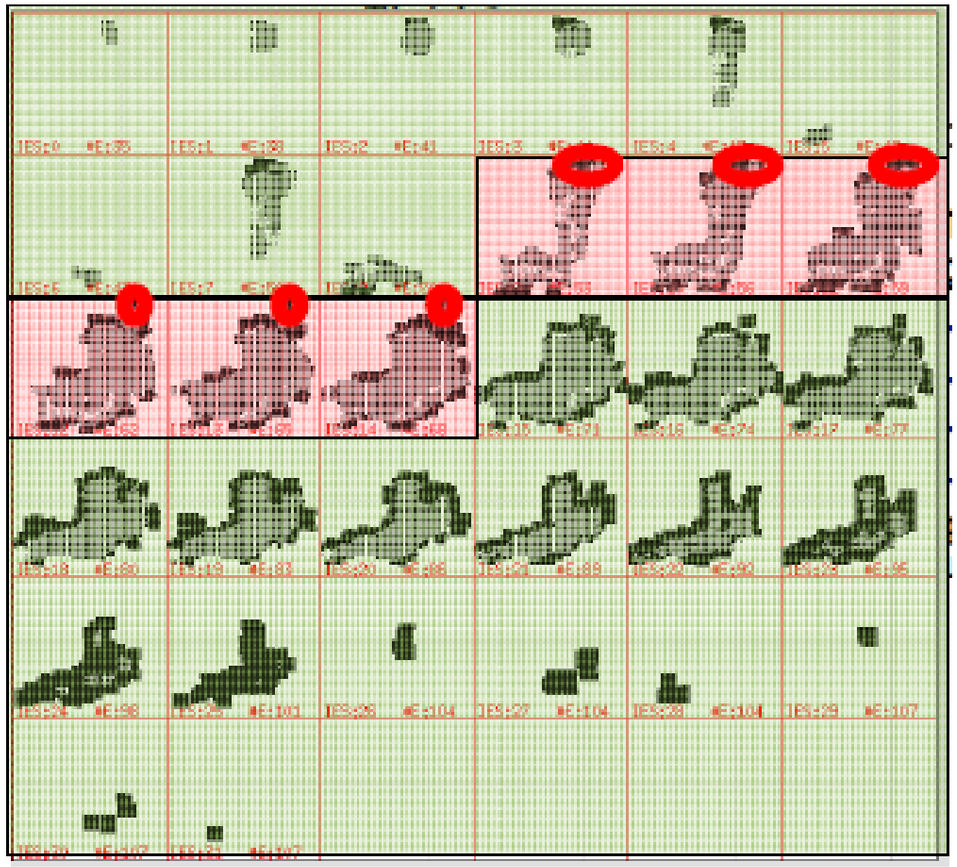


Calibration at GSI

- November 2003 (SDU-FM1)
  C @100, 150, 400, 600 MeV/n
- April 2004 (all SDUs)
  C @ 100, 600, 1000 MeV/n
  Ti @ 200, 600 MeV/n

Example 5 –
- Phoshenes in Radiation Therapy with C-Ions





39 patient studied at GSI (O. Kavatsyuk, D. Schardt, M. Krämer)

Radiation Damage in Electronic Components

Single energetic particles may cause malfunctioning of microelectronic devices
SEU = Single Event Upset
e.g. Bit-Flip in Storage-Chips
http://ams.cern.ch/AMS/Beamtest/

Results of GSI beam times (AMS-Collaboration)

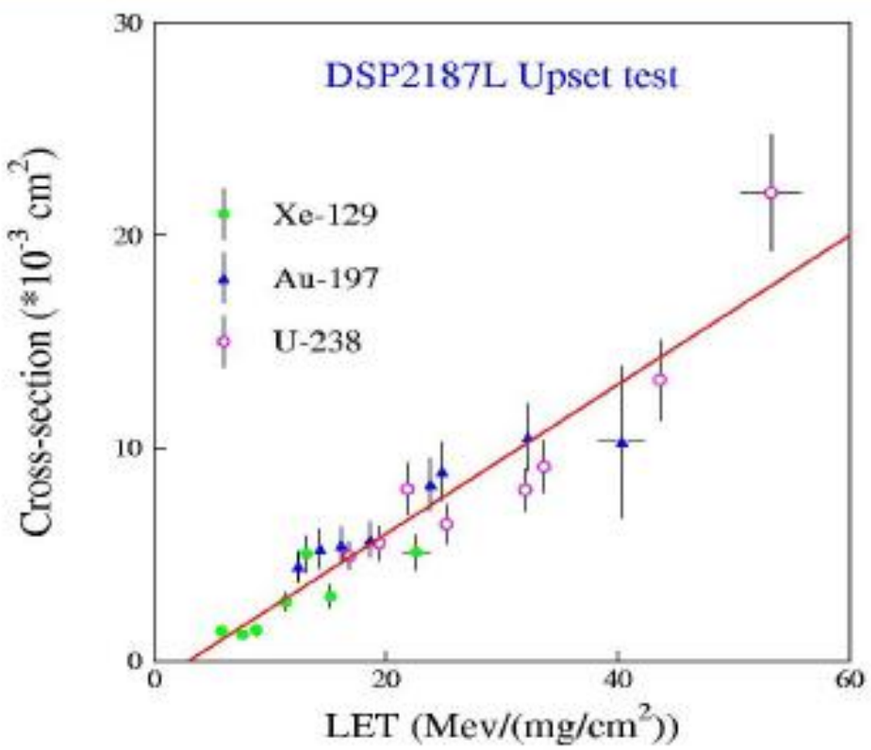
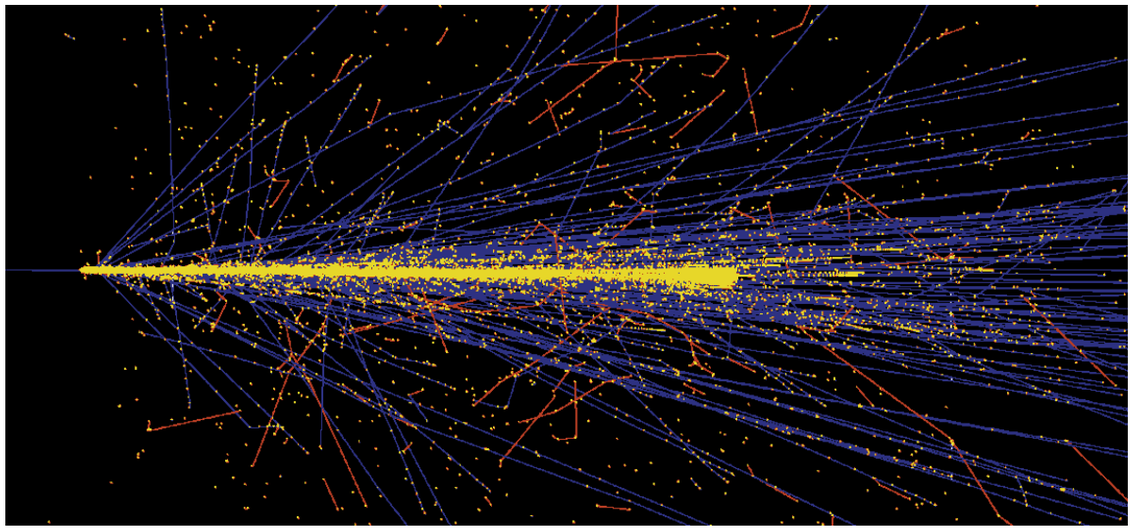


Table 2: Estimate of SEE rates per component on ISS.

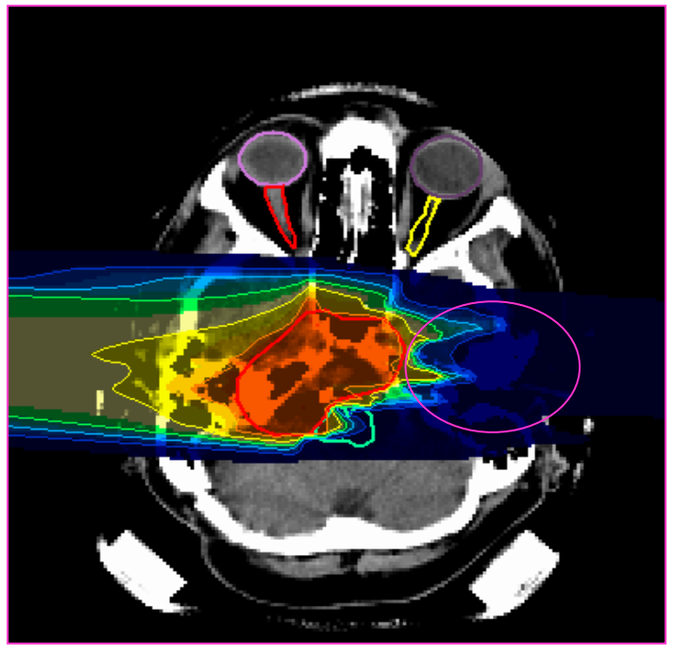
Component	Part Number	SEL rate (day^{-1})	SEU rate (day^{-1})
DSP	ADSP2187L	$8 \cdot 10^{-8}$	$1 \cdot 10^{-4}$
DSP	ADSP2189M	$2 \cdot 10^{-7}$	$2 \cdot 10^{-4}$
DALLAS controller	DS80C390	$2 \cdot 10^{-3}$	
CPU	PPC750	$3 \cdot 10^{-13}$	-
Host/PCI bridge	CPC700	$1 \cdot 10^{-10}$	-
PCI Adaptor	PLX PCI9080	$1 \cdot 10^{-3}$	-
Watchdog Timer	AMD679	$5 \cdot 10^{-9}$	$4 \cdot 10^{-8}$
CPLD	CY3700	$2 \cdot 10^{-12}$	$3 \cdot 10^{-5}$
SDRAM 128 Mbit	MT48LC8M16A2	$1 \cdot 10^{-11}$	$3 \cdot 10^{-3}$
FLASH memory	MBM29DL324TE	$1 \cdot 10^{-8}$	$3 \cdot 10^{-7}$
HV controller	MHV100	$2 \cdot 10^{-6}$	$1 \cdot 10^{-4}$
PGA	QL12X16BL	$3 \cdot 10^{-7}$	$5 \cdot 10^{-8}$
PGA	Actel 54SX32	$4 \cdot 10^{-13}$	$3 \cdot 10^{-9}$
RICH FE chip	AMS	$4 \cdot 10^{-8}$	$8 \cdot 10^{-8}$
ECAL FE chip	AMS	negl	-
HCC	AMS	$2 \cdot 10^{-7}$	negl
Digital Coupler	ISO150	negl	$5 \cdot 10^{-4}$
Digital Coupler	ADM	$6 \cdot 10^{-9}$	negl
ADC	ADS803U	$3 \cdot 10^{-9}$	$2 \cdot 10^{-7}$
VA32 old		$1 \cdot 10^{-6}$	-
VA32 new		$2 \cdot 10^{-8}$	-

Significance of nuclear fragmentation in RT

High-energy carbon beam stopping in water



I. Pshenichnov



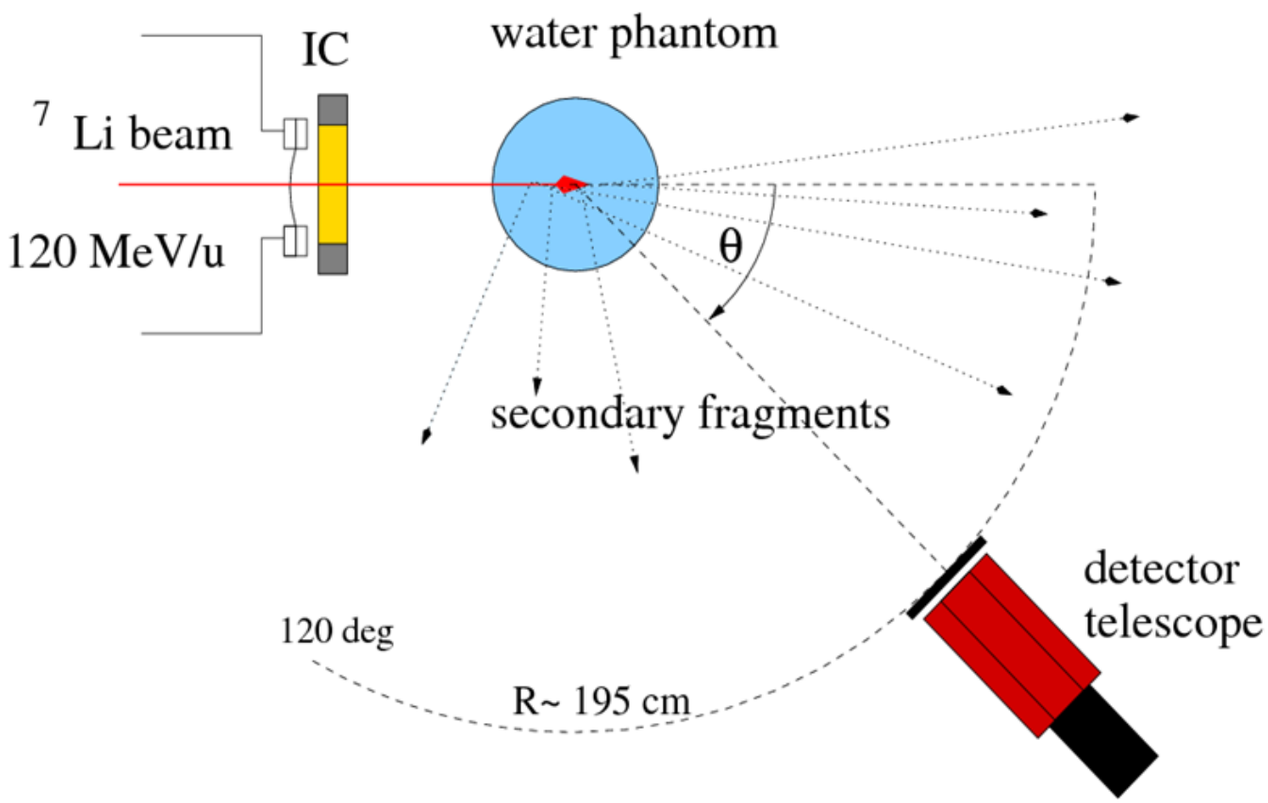
Carbon ion therapy
100-400 MeV/u

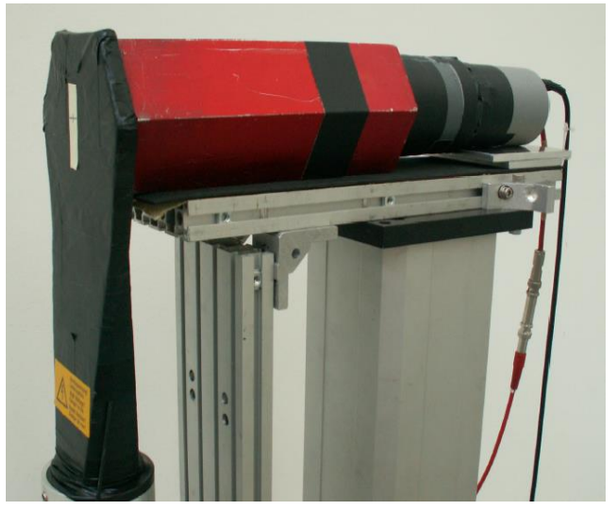
Nuclear fragmentation

→Loss of primary ions → depth-dose, RBE

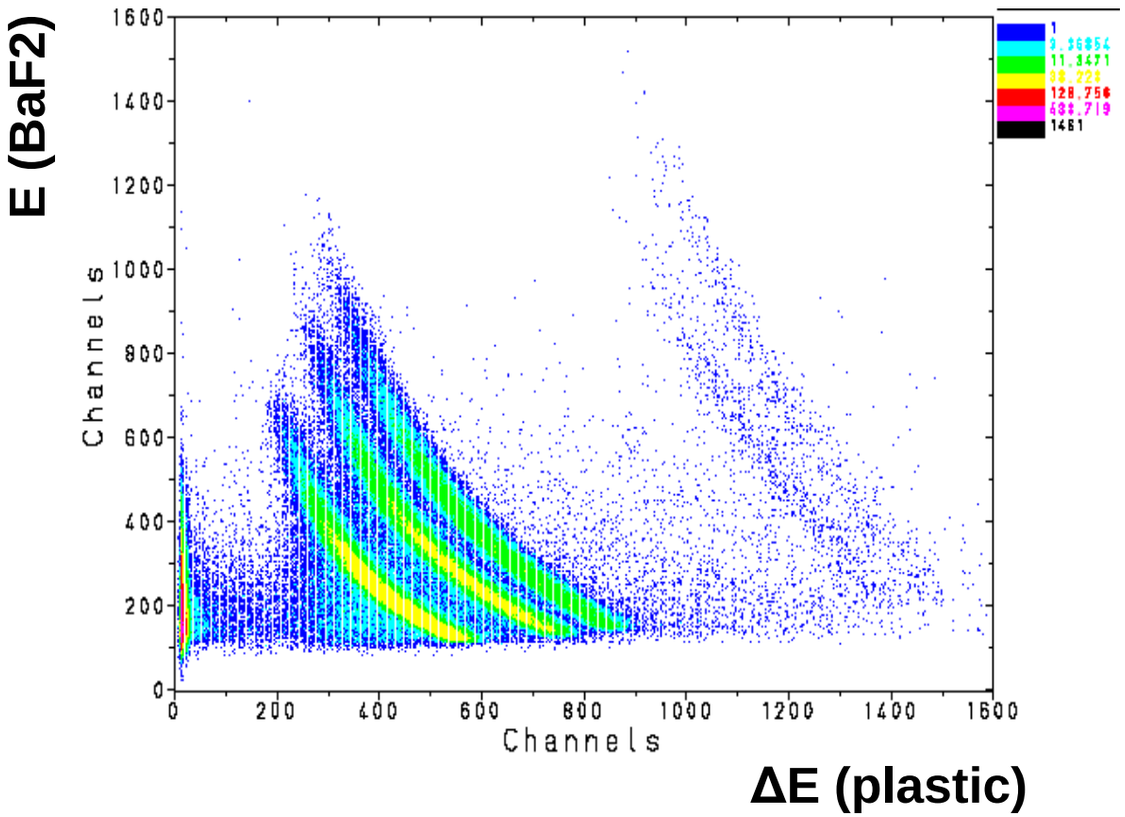
→Buildup of secondary fragments → dose-tail, lateral dose

Detector setup for nuclear fragmentation





The ΔE–E telescope detector



Angular distribution setup
→ Beam energy of 120 MeV/u
→ Cylindrical water target (diameter of 150 mm)
→ Telescope positionned at 0°, 20°, 30°, 60°, 90° and 120°

FIRST – experimental setup in cave C

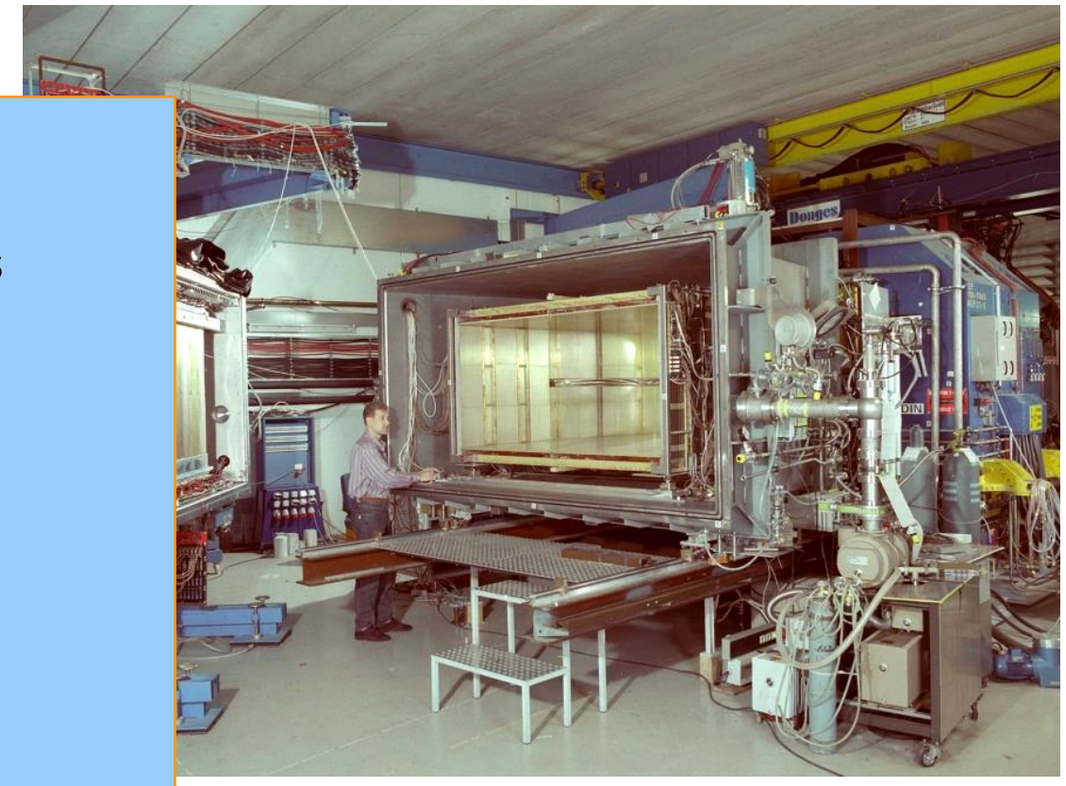
→ Beam dia
→ New dete
→ ALADIN
→ MUSIC +
→ LAND

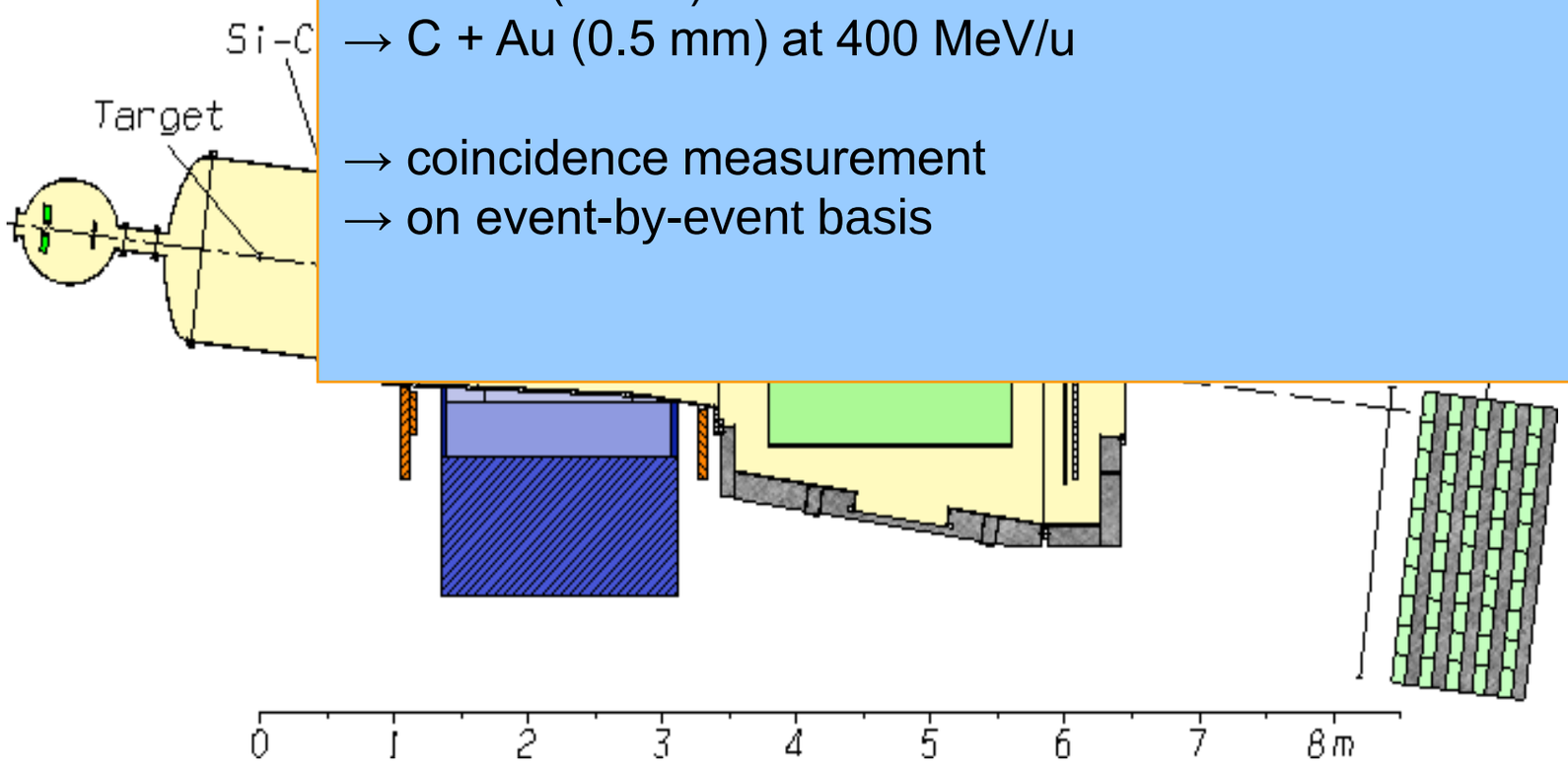
Measurable
→ Double-differential cross-section for Z particles

Experiment in August 2011
(carbon beam fragmented on thick targets)

→ C + C (5 mm) at 400 MeV/u
→ C + Au (0.5 mm) at 400 MeV/u

→ coincidence measurement
→ on event-by-event basis

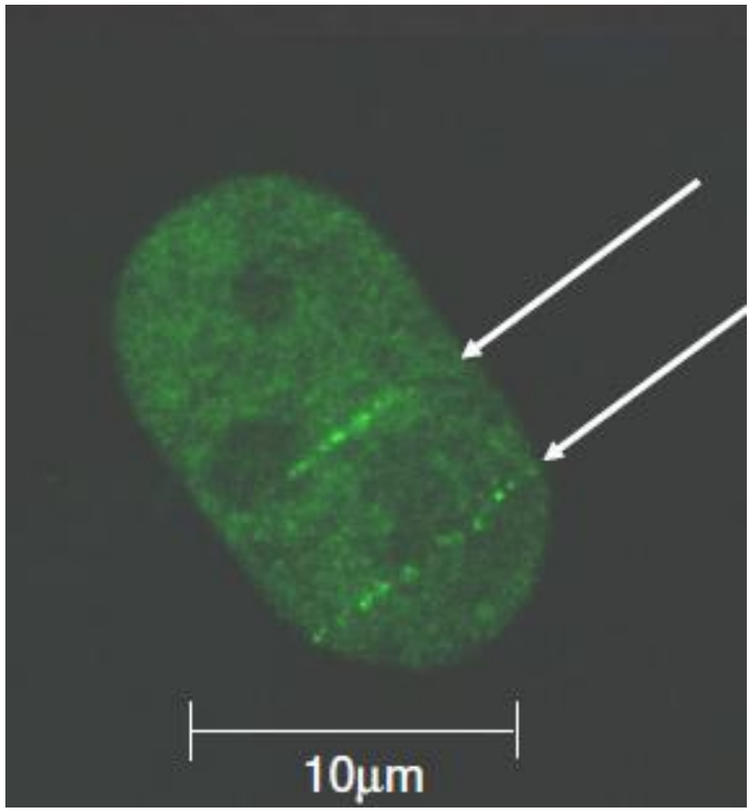




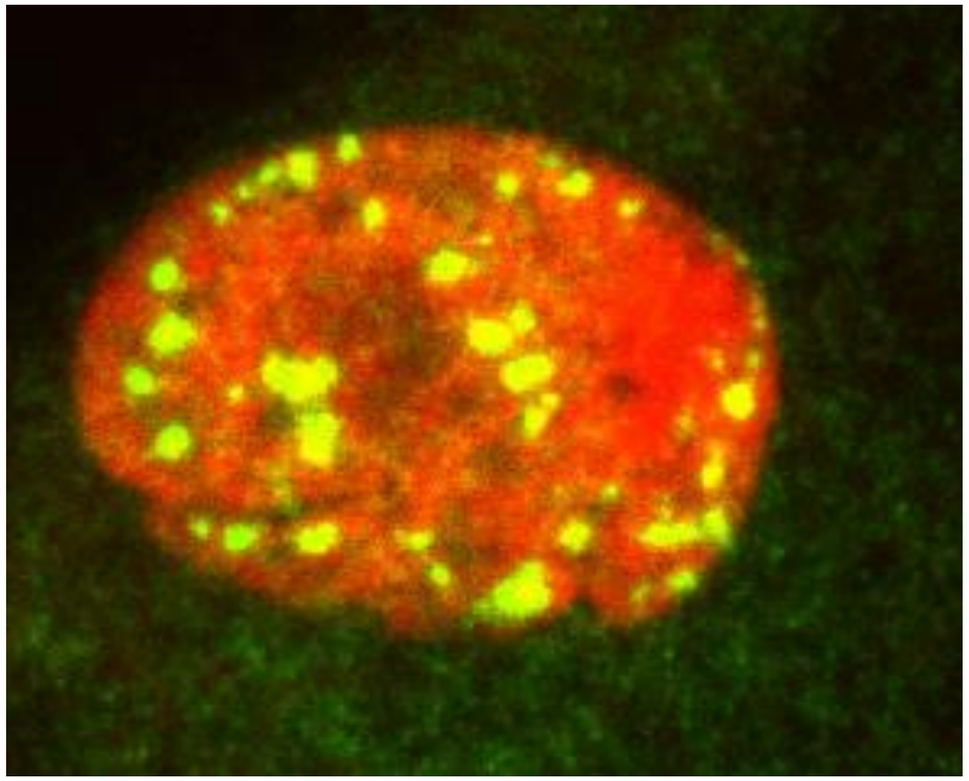
IR – START scintillator
IR – Beam Monitor
IR – Target
IR – Si Pixel Vertex Detector
IR- KENTROS
ALADIN Magnet
TP-MUSIC IV
TOF wall
LAND

Microbeam – Irradiation of single cells

Nucleus of a human fibroblast cell



B. Jakob et al., Rad. Res. 163, 681 (2005)



Biological response visualized by immuno-staining; Barberet et al., Rad. Res 166, 682 (2006)

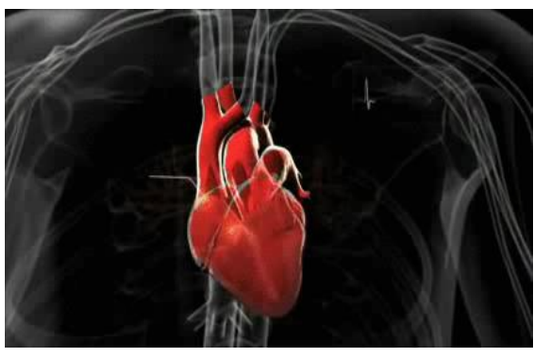
Heart Arrhythmia Project

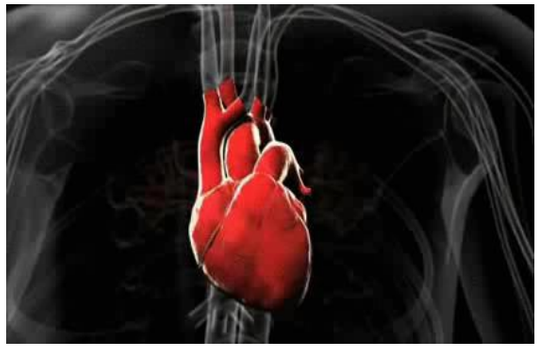
Description

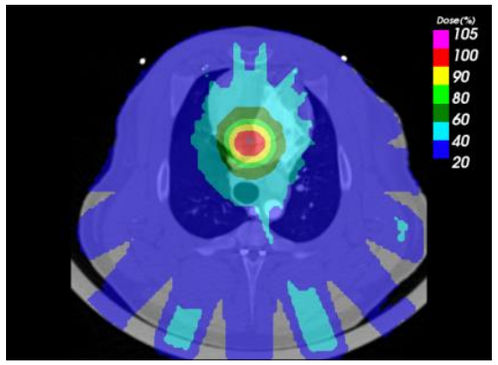
- First worldwide experiment in July 2013 in swines for the treatment of heart arrhythmia with heavy ions
- collaboration with Mayo Clinics, USA, and Heidelberg University Clinics
- First experiment at GSI (cave M) from July 17 -23, 2014

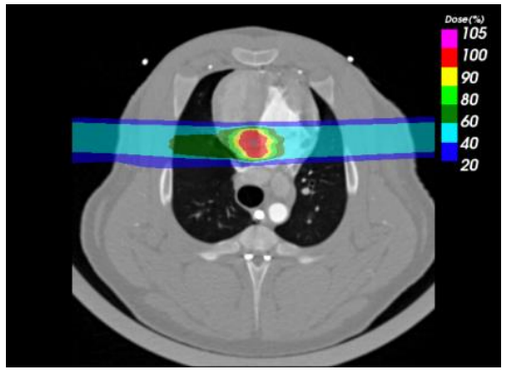
Specification

- Update of the electronics for the beam scanner currently in Cave M
- Authorization by Hessian authorities for animal experiments at GSI/FAIR, including swines

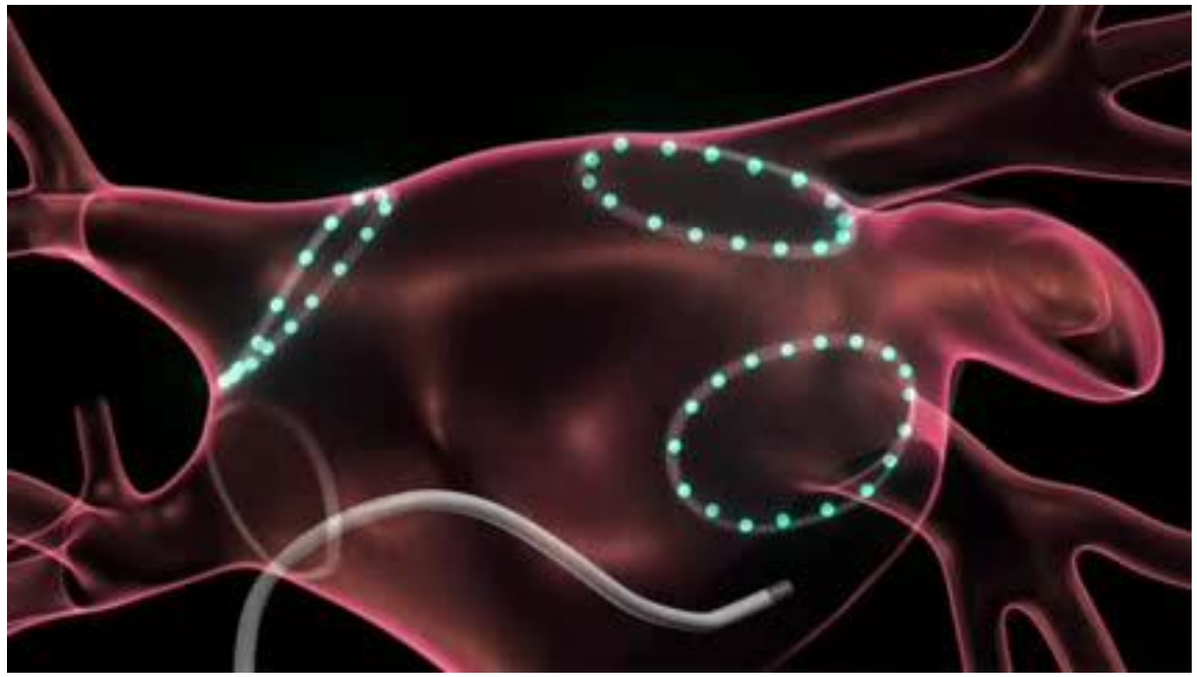








Catheter ablation



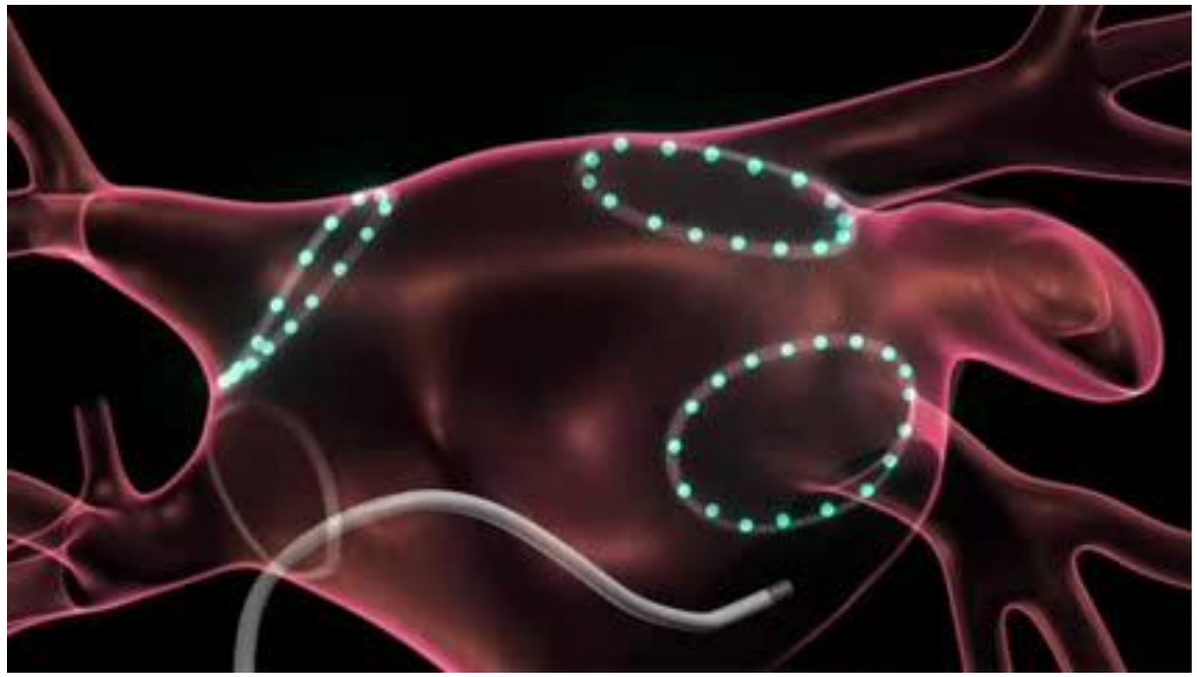
<u>drawbacks</u>:

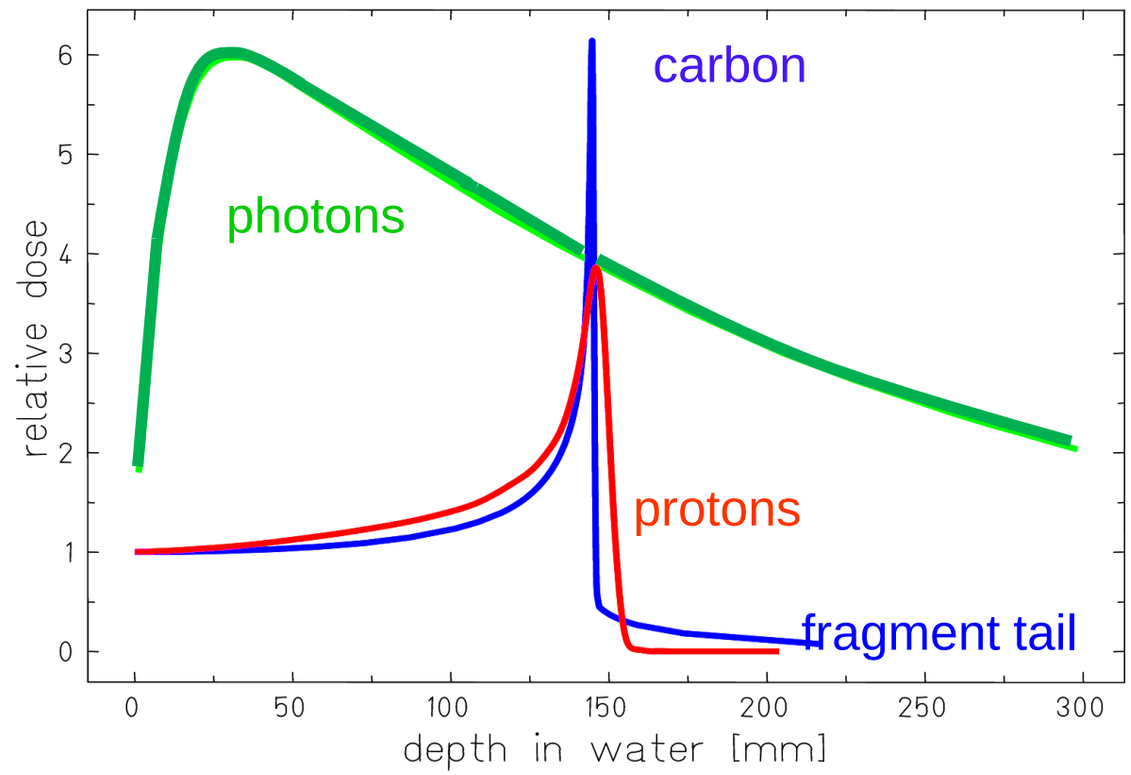
- invasive method
- long (several hours)
- severe complications
- about 30% of the procedures need to be repeated after 1 year

Video: Catheter Ablation for Atrial Fibrillation, Cleveland Clinic, 2011

Cappato R et al., Circulation 111(9), 2005 und Cappato R et al., Circ. Arrhythm. Electrophysiol 3(1), 2010; Jongbloed MR et al., Radiology, 234(3), 2005

Radiosurgery as arrhythmia treatment?





Radiotherapy

- Non-invasive
- Reduced treatment time

Why scanned carbon ions?

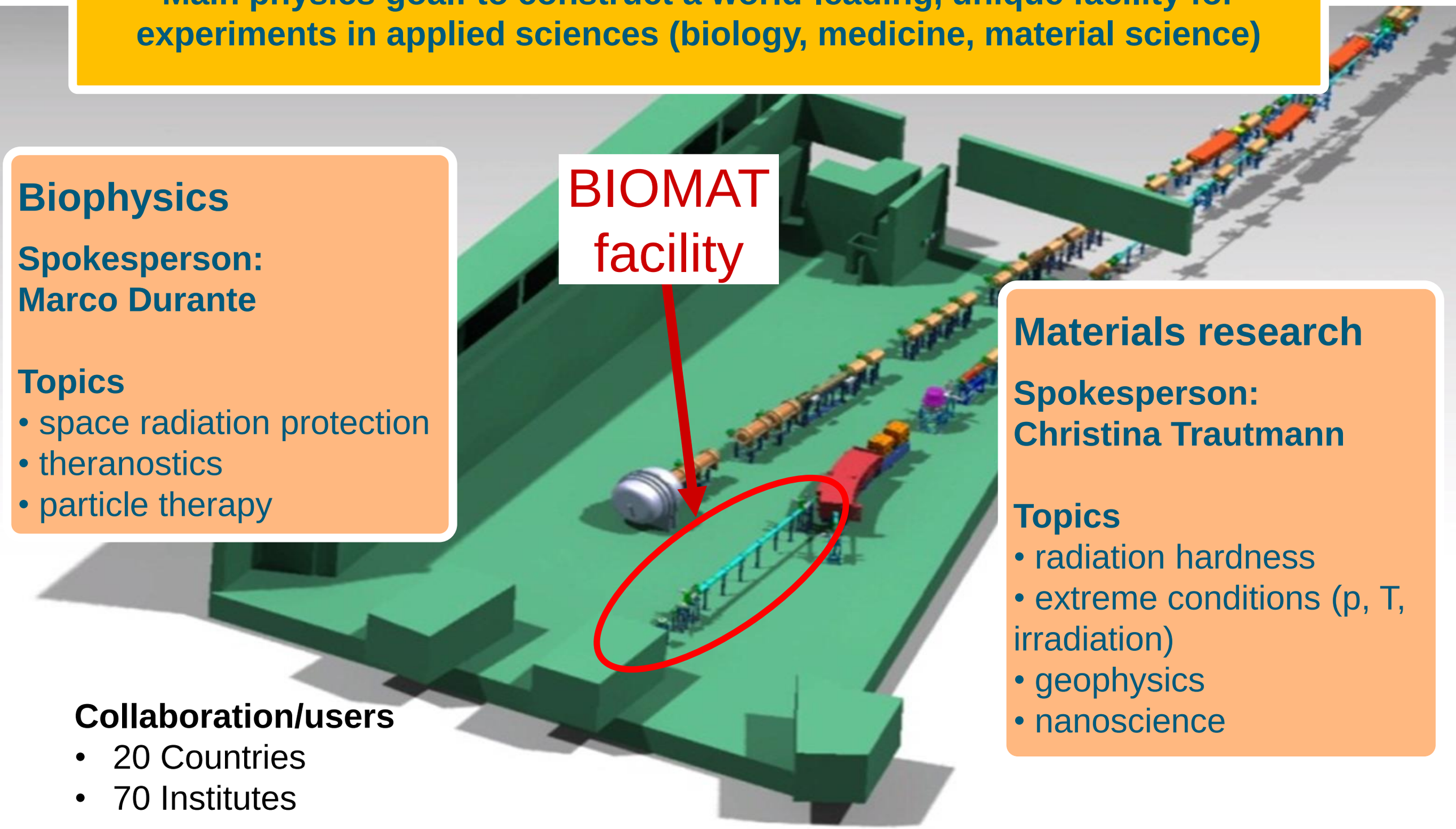
- High precision
- Good sparing of surrounding tissue

Feasibility study at GSI

Photo: Matthias Prall, GSI

BIOMAT - User Facility and Collaborations

Main physics goal: to construct a world-leading, unique facility for experiments in applied sciences (biology, medicine, material science)



Biophysics

Spokesperson:
Marco Durante

Topics
- space radiation protection
- theranostics
- particle therapy

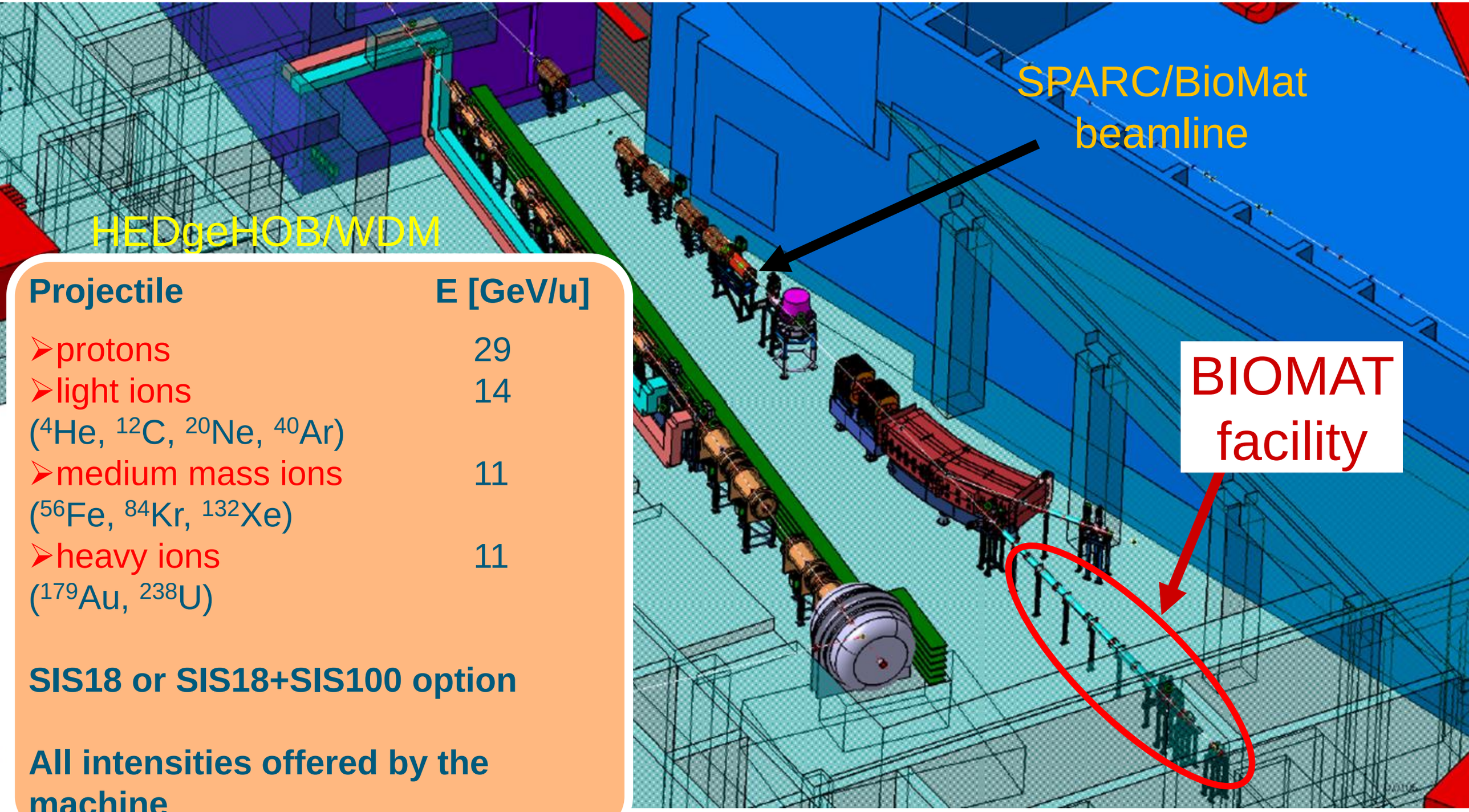
Materials research

Spokesperson:
Christina Trautmann

Topics
- radiation hardness
- extreme conditions (p, T, irradiation)
- geophysics
- nanoscience

Collaboration/users
- 20 Countries
- 70 Institutes

BIOMAT Irradiation Facility in APPA Cave



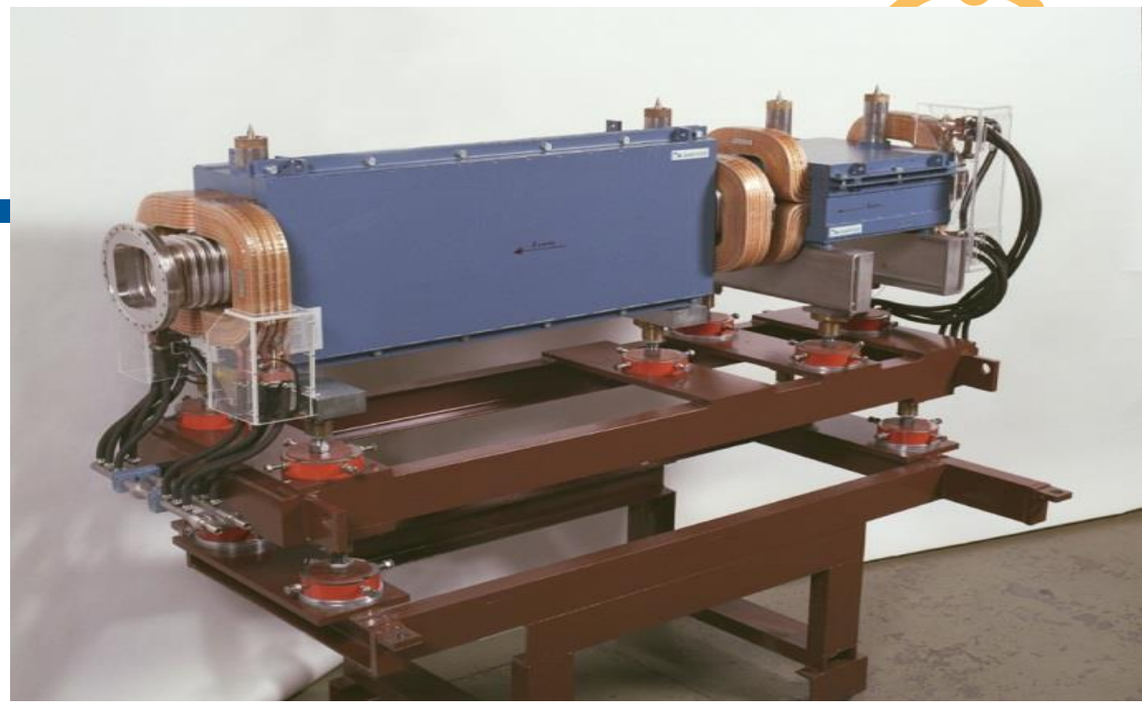
Projectile	E [GeV/u]
➢protons	29
➢light ions (^{4}He, ^{12}C, ^{20}Ne, ^{40}Ar)	14
➢medium mass ions (^{56}Fe, ^{84}Kr, ^{132}Xe)	11
➢heavy ions (^{179}Au, ^{238}U)	11

SIS18 or SIS18+SIS100 option

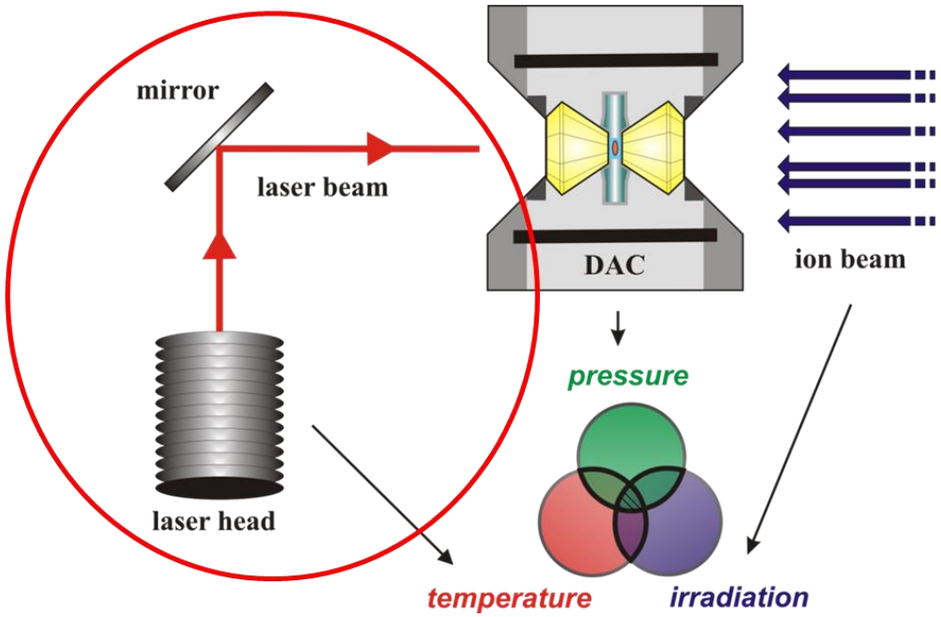
All intensities offered by the machine

BIOMAT Beamline

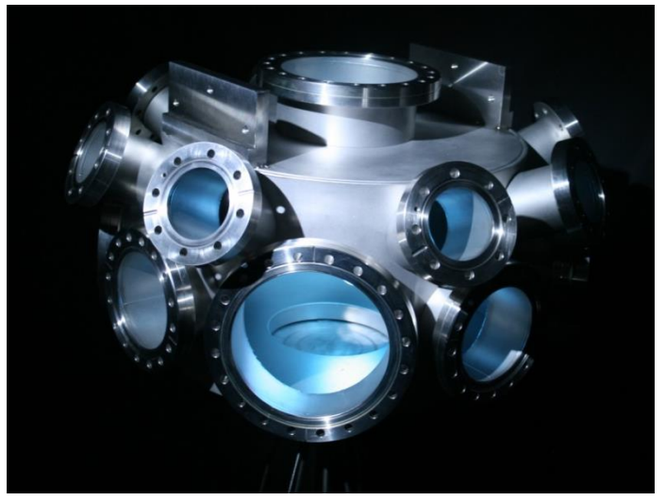
- Beamline
  (ion optics, vacuum, beam diagnostics)
- Control room
- Beam scanning system
- Target station
  (target handling, multi-purpose UHV chamber, high-pressure equipment, X-ray machine)



Intensity-controlled raster scan technique allows high-quality irradiations of larger sample areas (max. irradiated area of 10 x 10 cm²)



High-pressure cells (PE type) and laser heating system



UHV target chamber for sample irradiation and in-situ analysis

BioLab Equipment

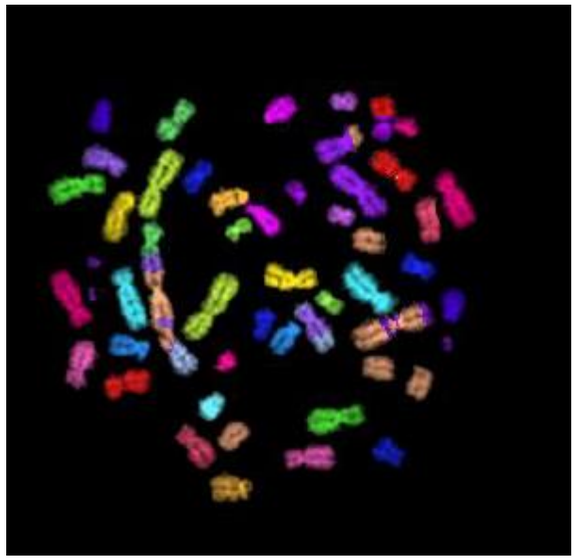
Description

Preparations of biological samples before irradiation and analysis of the samples after irradiation

Specifications

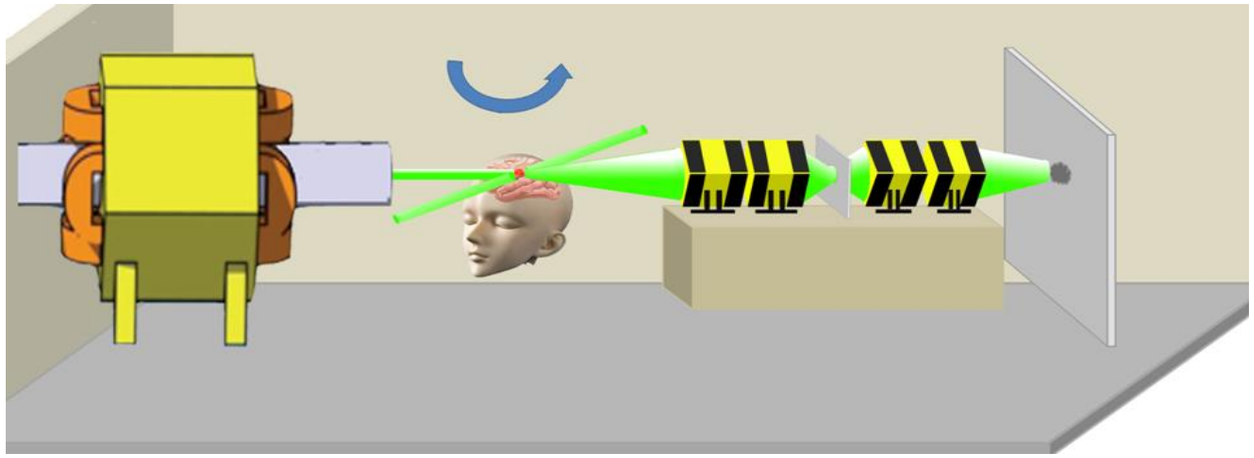
Very close to the irradiation facility, equipped with incubators, laminar flow boxes, Coulter counters, microscopes, etc.

T- Reiter (ESA) visiting GSI in 2013

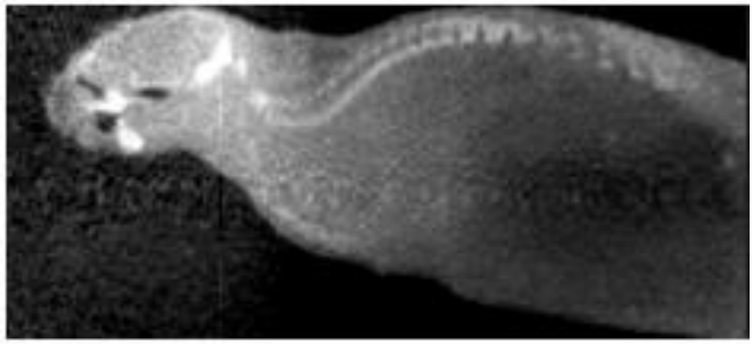


PANTERA Project

- Proton therapy and radiography
- Collaboration between biophysics and plasma physics
- to exploit the PRIOR setup for therapy
- Relativistic protons (4.5 GeV) for image-guided, high-resolution, real time, stereotactic radiosurgery at PRIOR setup
- First image of a biological target (zebra fish) with 800 MeV protons at ITEP in 2011
- Images of human-like phantom and mouse recorded at LANL using 800 MeV protons in 2013



Proposed setup for image-guided stereotactic particle radiosurgery



Zebra fish, first image of biological target

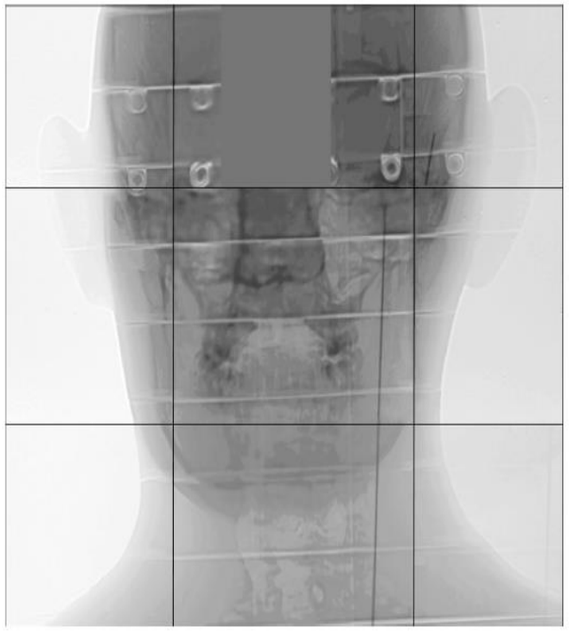
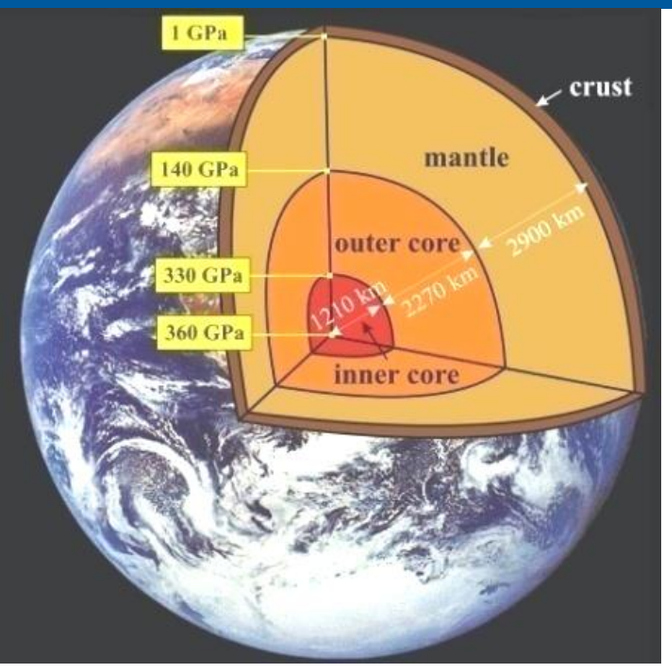
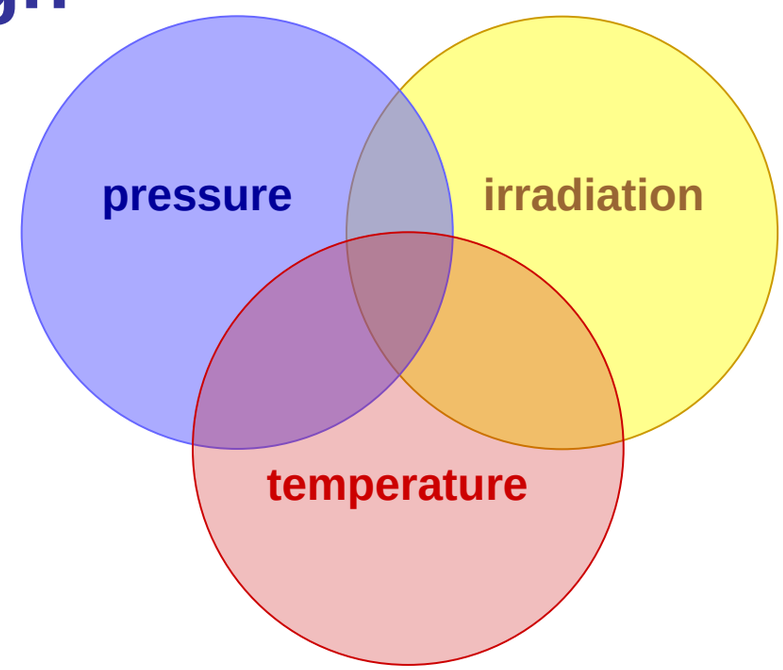


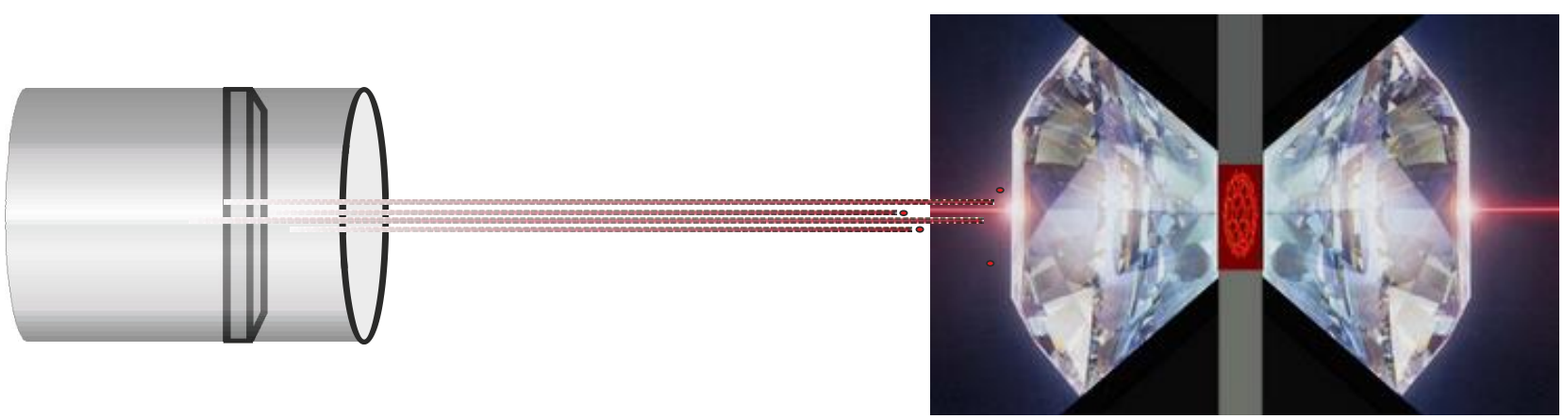
image of anthropomorphic phantom

Matter under extreme conditions

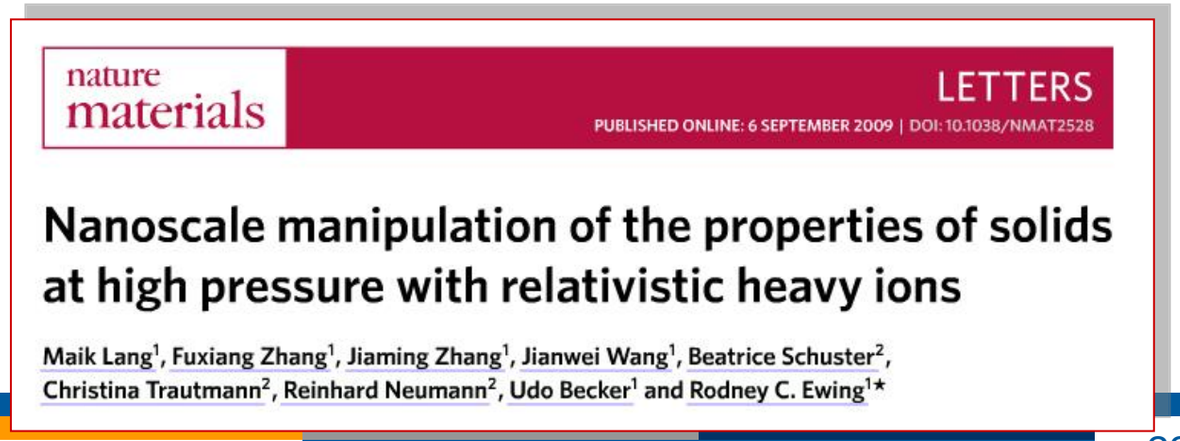


- **Simulating geological processes in the inner Earth**
- **Ion-beam stabilized high pressure phases**





During irradiation T and p like in the inner earth is applied to minerals. So, tracks induced by natural fission fragments in the minerals of the inner earth can be simulated.


nature materials LETTERS
PUBLISHED ONLINE: 6 SEPTEMBER 2009 | DOI: 10.1038/NMAT2528

Nanoscale manipulation of the properties of solids at high pressure with relativistic heavy ions

Maik Lang[1], Fuxiang Zhang[1], Jiaming Zhang[1], Jianwei Wang[1], Beatrice Schuster[2], Christina Trautmann[2], Reinhard Neumann[2], Udo Becker[1] and Rodney C. Ewing[1]*

Summary / Outlook

- Broad scientific program
- Large International collaboration / user community
- Nuclear fragmentation important in space research and radiotherapy
- Future experiments at Cave A, M and APPA Cave
- Cooperation with European Space Agency