Opportunities of Basic and Applied Research at MEDAUSTRON

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Introduction

PRIMARY SCOPE

MEDAUSTRON is a project for a centre for cancer therapy treatment with clinical and non-clinical research facilities.

Grouped around a synchrotron which delivers protons and carbon ions to the irradiation stations in the energy range of hundreds of MeV/nucleon.

Full operation of MedAustron: 1200 patients per year treated

MEDAUSTRON centre – only accelerator of this size in the region
Infrastructure and installations should also be used for non-clinical research in medical radiation physics, radiation biology and experimental physics.

The WHITE PAPER

med austron White Book

Physics Opportunities at MedAustron

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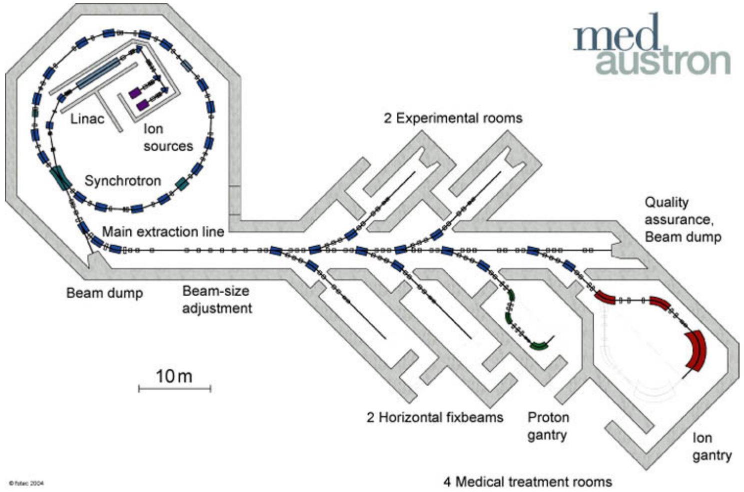
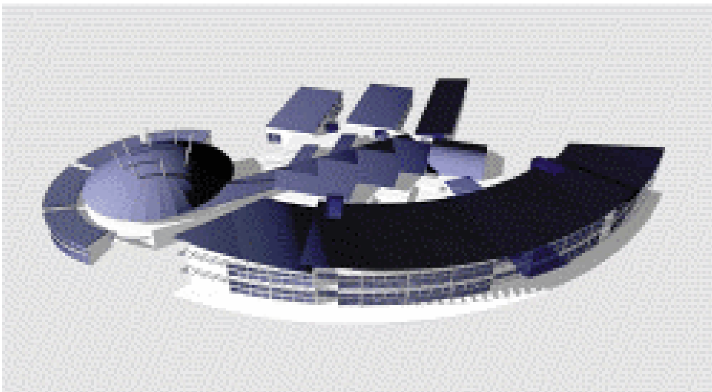
Content



The MEDAUSTRON facility



- Introduction
- Test of particle detectors
- Proton scattering facility
    - proton-nucleus scattering
    - proton-proton scattering
    - nuclear reactions
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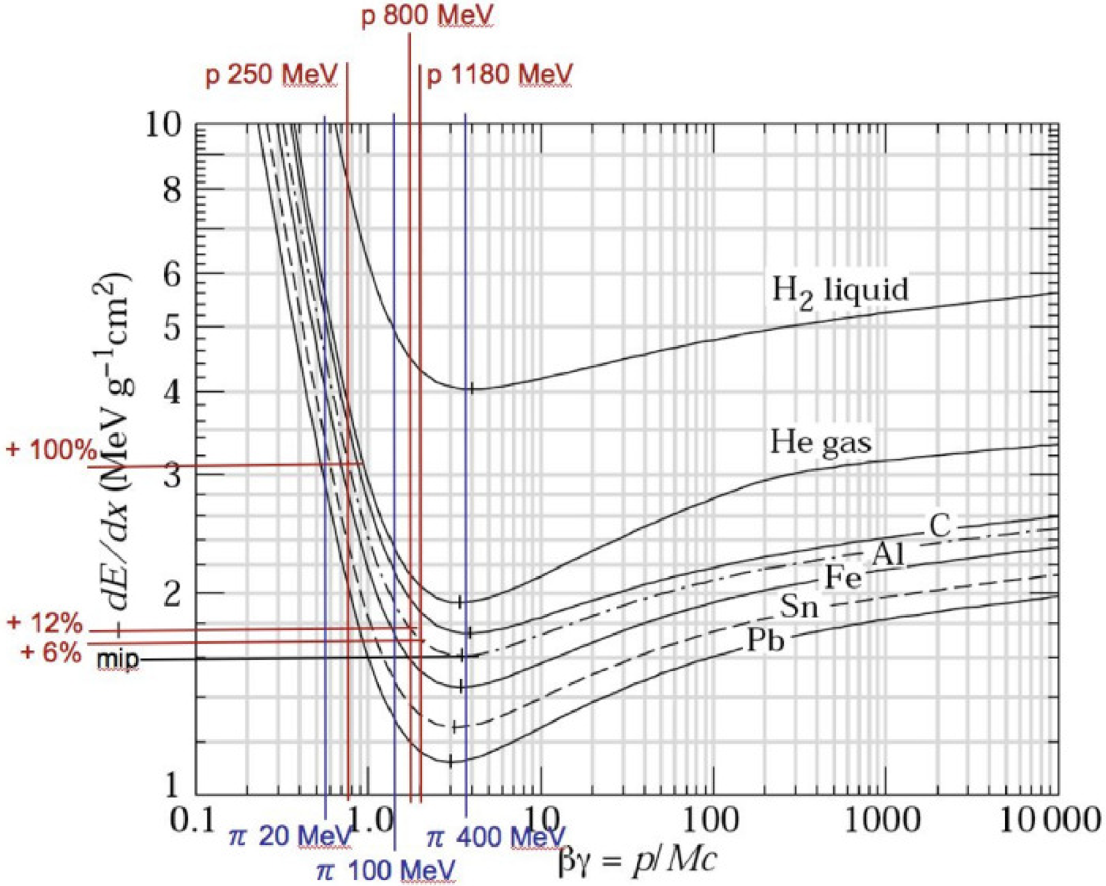
- Summary

Accelerator options

	Medical research	Non-clinical research	
protons	*Option 1*	*Option 2*	*Option 3*
beam energy	60-250 MeV	60-800 MeV	60-1180 MeV
beam intensity	1×10^{10} ppp	$< 1 \times 10^{10}$ ppp	$< 1 \times 10^{10}$ ppp
Extraction duration	0.1-1 s	0.1-1 s	0.1-1 s
Repetition rate	1 Hz	1 Hz	1 Hz
carbon ions			
beam energy	120-400 MeV/u	120-400 MeV/u	120-400 MeV/u
beam intensity	4×10^{8} ions pp	$< 4 \times 10^{8}$ ions pp	$< 4 \times 10^{8}$ ions pp
Extraction duration	0.1-1 s	0.1-1 s	0.1-1 s
Repetition rate	1 Hz	1 Hz	1 Hz

Energy loss in detector material

Energy loss described by Bethe-Bloch theory



Source: W.-M. Yao et al., J. Phys. G 33 (2006) 1

Type of detectors at test at MEDAUSTRON

Tracking detectors:

(energy important, no signal saturation)
semiconductor, gaseous, scintillating fibres; MEDAUSTRON well suited

Calorimeters:

(variation of beam energy 60-800 MeV interest for nuclear physics)
for high energy physics the maximum energy is too low at MEDAUSTRO

Time-of-flight detectors:

MEDAUSTRON beam may be used for tests of radiation hardness and ageing tests → especially PANDA TOF detectors at FAIR

Irradiation studies:

At MEDAUSTRON tests possible up to an irradiation of about 10^{14} particles per cm^2 not suited for tests requiring higher flux

Rate studies:

MEDAUSTRON has capability for tests of electronics of data acquisition system

Proton scattering facility

Energy range of MEDAUSTRON 60-800 MeV
from low energy nuclear structure to high energy nuclear physics

Several specific questions – no beam time at dedicated machines

Despite the low intensity delivered, it is very promising to set up a proton scattering facility at MEDAUSTRON for nuclear physics research with a complementary programme to the dedicated machines:

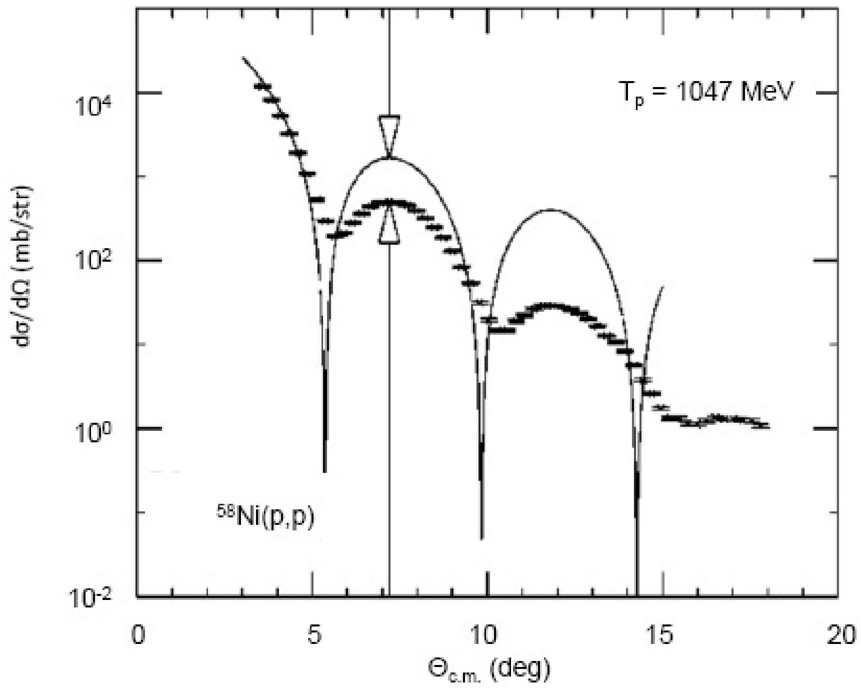
reaction spectroscopy at medium (~300MeV) and high energies
Provide a unique machine for nuclear structure research in this energy regime

- nuclear radii
- relativistic optical potentials
- nuclear reactions relevant for nuclear data basis

- proton-proton scattering
- proton reactions in few-body systems

Nuclear Radii from Fraunhofer Scattering

Fraunhofer scattering



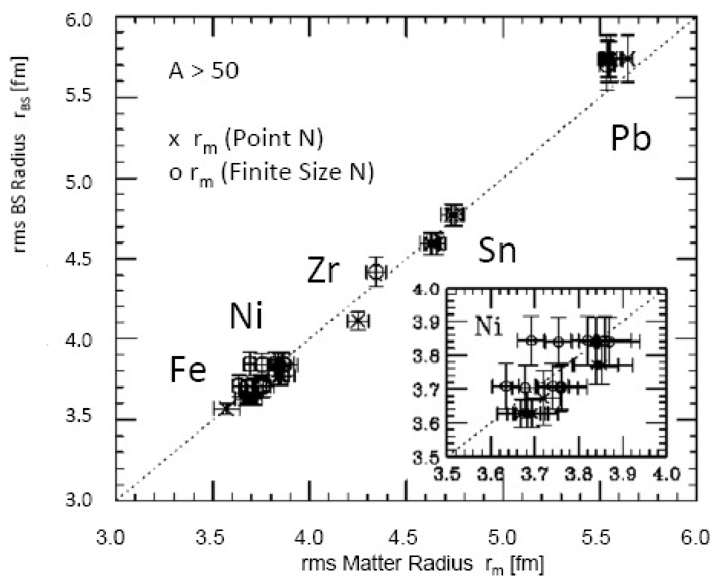
Source: R.M. Lombard, G.D. Alkhazov, O.A. Domchenkov, Nucl.Phys.A 360 (1981)233

BLACK SPHERE MODEL

first diffraction maximum at Θ_M

$$r_m \approx r_{BS} = \frac{3.9780}{2p\sin(\Theta_M/2)}$$

with $r_{BS} = \sqrt{\frac{5}{3}}\,a$



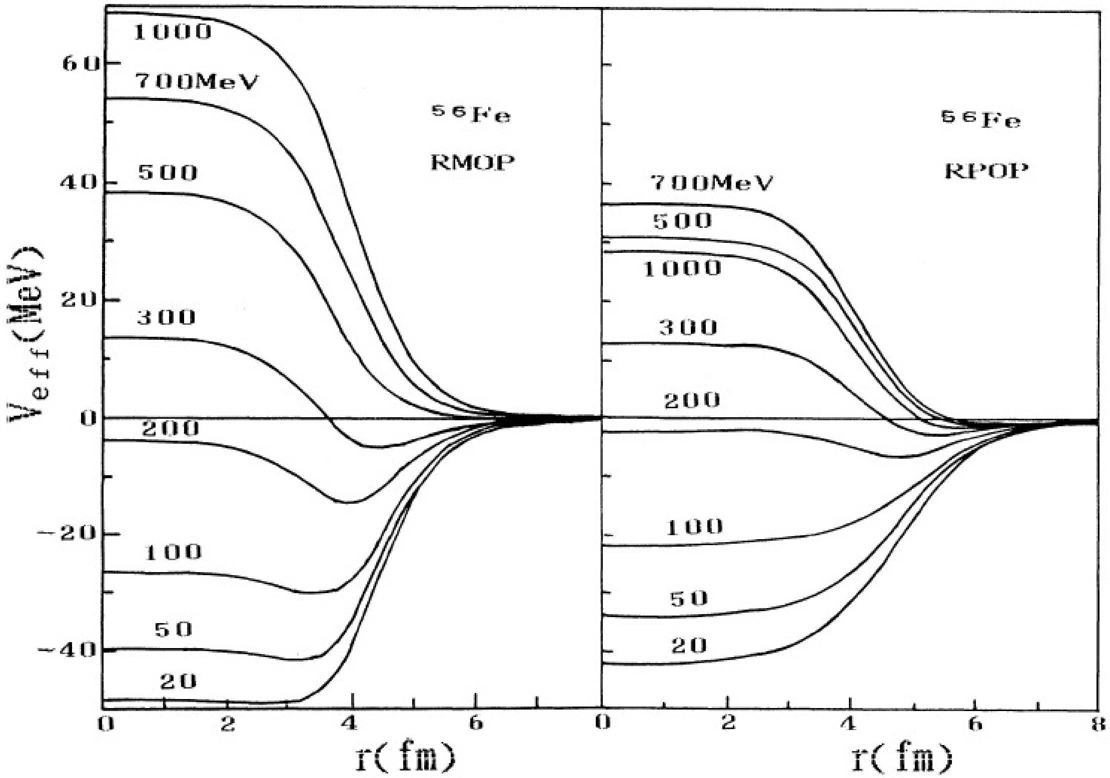
equivalence of r_{BS} with r_m

Relativistic optical potentials

Systematic analysis of elastic proton-nucleon scattering allows to extract relativistic optical potentials, essential ingredients for all nuclear reaction calculations → no global relativistic optical potential available

Systematic cross section measurements combined with available polarization data would provide reliable relativistic optical potentials

→alternative to determine the nuclear matter radius r_m



Reaction cross sections

measurements of proton-induced reaction cross section from several MeV to GeV provide an invaluable input to nuclear data bases:

- fundamental physics (reaction mechanisms, nuclear models, nuclear poperties with increasing excitation energy)
- feasibility and design concepts of advanced nuclear facilities, e.g. the development of accelerated driven systems (ADS) for destruction of long-lived radioactive waste, weapons materials and energy.
- application in radioprotection, e.g. for aviators, cosmonauts, staff of nuclear facilities, protection measures at fusion reactors and high energy accelerators.
- complete nuclear data basis providing benchmarks for nuclear data files which are based on model calculations due to lack of experimental data
- material properties – in particular embrittlement by gas producing reactions, e.g. A(p,α)B, A(p,t), A(p,d), A(p,nα), …
- radio nuclide production

Reactions at MEDAUSTRON

Energy range fits between low and intermediate energy facilities

Possible experimental programme:

- charged particle production and spectra (p,n_i,c_i)
  (p,p‘),(p,yp),(p,xt),$(p,^{3}He)$, …
- neutron production (p,xn)
- γ-production and spectra (p,γ)

Measured quantities:

cross sections, angular distributions, double differential cross sections and correlations between ejectiles

High particle energies will require individual detector developments → potential innovation

Materials, reactions, observables

Main limitation will be the comparable low intensity.

Spallation materials: W, Pb – neutron multiplicity

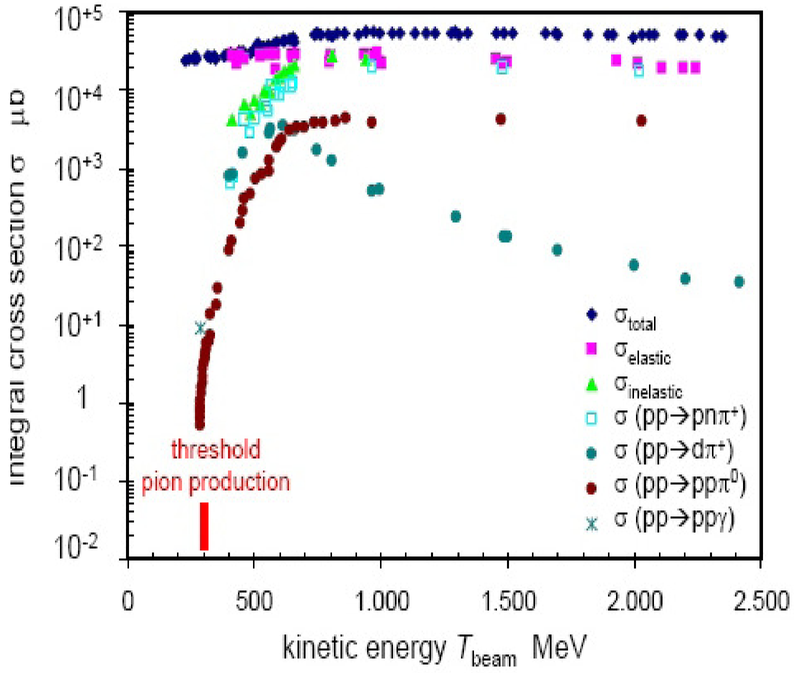
Shielding materials: Fe – energy-angle distributions of sec. particles and activation cross sections

Nucleon-nucleon interaction

Proton-proton scattering is an elementary process used to extract the nucleon-nucleon interaction, especially in photoproduction and pion Production interesting information on off-shell effects could be obtained

Beam parameters of MEDAUSTRON are comparable to that of dedicated Facilities, except for the lack of polarization

	COSY	AGOR	TRIUMF	MEDAUSTRON
town country	Jülich Germany	Groningen Netherlands	Vancouver Canada	Wr.Neustadt Austria
energy range MeV	175-2880	200	180-500 65-200	60-800
intensity 10^{10}	10	4	3(6)	1
polarized beam	yes	yes	yes	no
polarized target	no	yes	no	yes
cooled beam	yes	no	no	no



Requirements for pSF

availability of 800 MeV proton beam
energy spread of the beam less than few 100 keV
intensity 10^9-10^{10} protons/s
emittance about 1 π mm mrad
spill time ~ 1 s

Absolut determination of beam energy better than few MeV
(Schottky noise Fourier Frequency measuring technique allows $\Delta E/E=10^{-4}$)
beam resolution also about 10^{-4} via slow extraction mode

Improvement of absolute scattering angle measurement to less than 0.01 °
It requires good emittance of beam ~1π mm mrad, position sensitive detectors of less than 1mm at distances of about 1 m.

Other physics applications

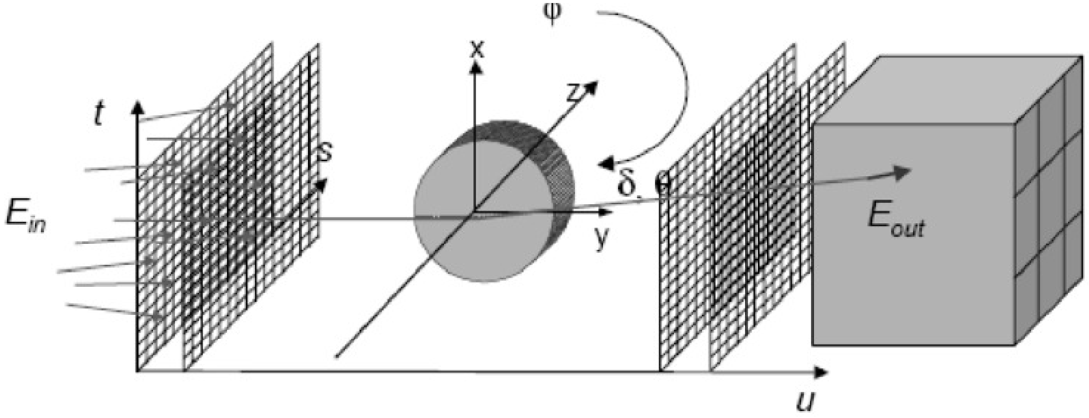
- High energy proton computerized tomographiy (HepCT)
- Radiation damage in high temperature superconductors
- Dosimetry
- Single-hit ion microprobe

Proton Computerised Tomography (pCT)

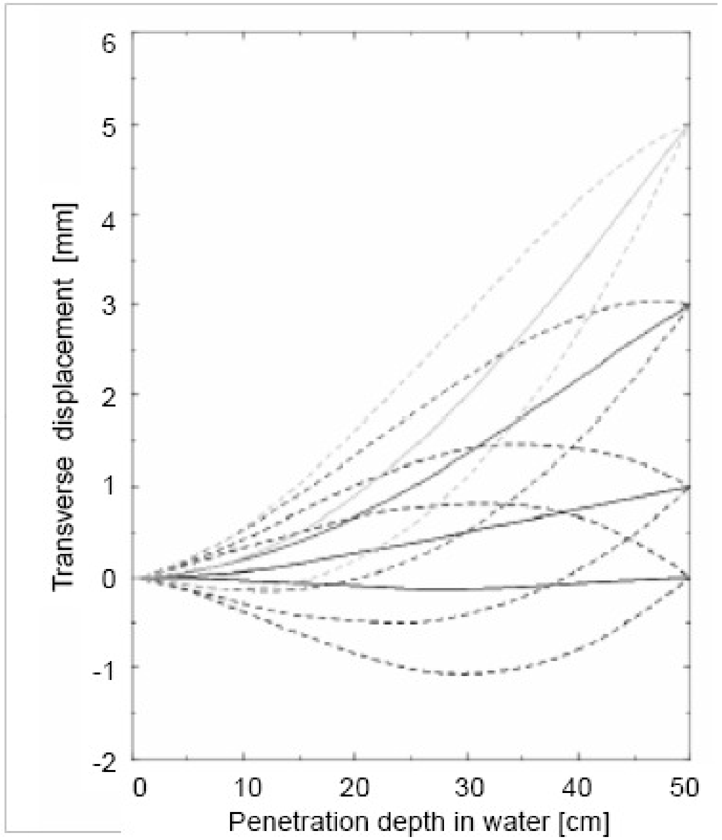
Mean energy loss dE/dx given by the Bethe-Bloch equation

$$-\frac{dE}{dx} = \eta_e \; F\left(I(\mathbf{r}), E(\mathbf{r})\right)$$

Electron density η_e relative to water



HepCT setup



Multiple scattering leads to different Paths in the medium, MC simulation HepCT improvements 1/βp

proton computed tomography

Proton computerized tomography (pCT) is proposed for imaging of electron density distributions (Benton et al. 1973).

Basic idea of pCT: measuring proton loss along the transversed path

Limitation: multiple Coulomb scattering in materials

Proposal: Development of a high energy pCT using the (800 MeV) and low emittance (~1p mm mrad) proton beam of MedAustron.
High energy pCT (HepCT) provides a unique imaging tool

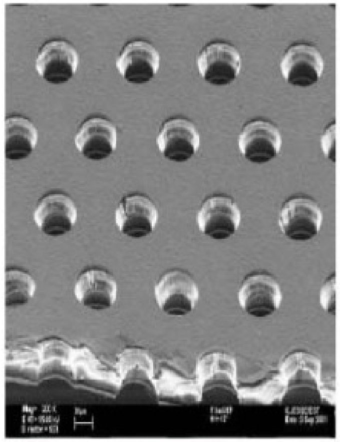
- medical applications, e.g. accurate patient positioning and dose control; in therapy it helps in dose planning, decreasing errors
- high resolutionimaging for structured materials made of metals, ceramics, plastics and construction materials with considerable thickness

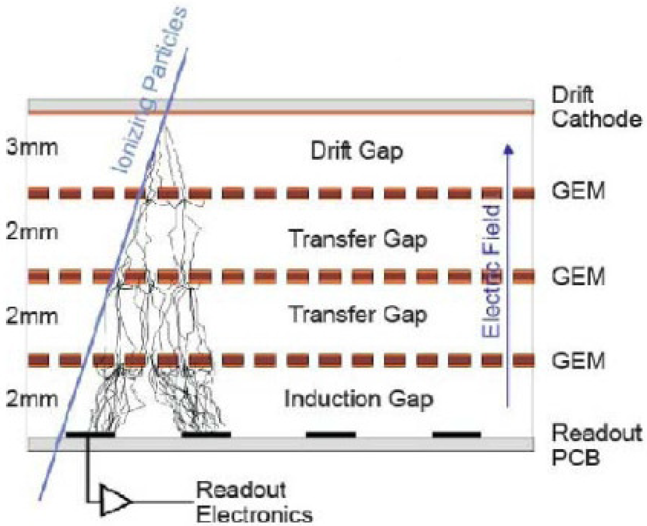
Several pCT setups up to 250 MeV currently in progress

HepCT proton tracking system

Measure entrance and exit points accurately (<1mm x 1mm) requires a two dimensional tracking system with resolutions better than 150 µm

Experience with gas electron multiplier (GEM) based tracking system at SMI

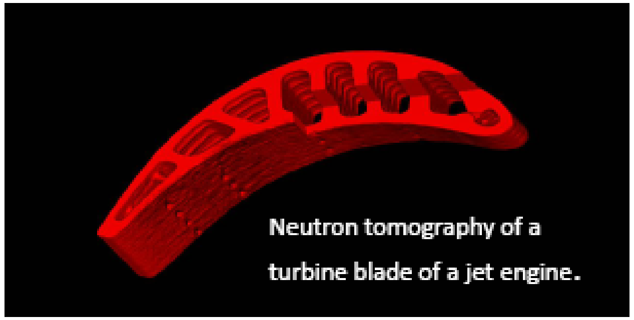




Scheme of triple GEM detector and electron microscope fotograph

Potential applications of HepCT

Some possible pCT applications:
3D studies



automotive parts

aerospace parts

electric/electronic devices

archaeologic items

Education and training

MEDAUSTRON – ideal opportunity to teach, train and educate students with state-of the-art methods and technologies within Austria

fields:

physics, electronics & electrical engineering, computer sciences, mechanical engineering and mechatronics

means:

laboratory courses embedded in the curricula of the University of Vienna, TU Vienna, University of Applied Sciences Wr. Neustadt, …
Master and PhD thesis works

home base:

assembly, extensive tests and possible improvements before transfer to a dedicated facility - significant enhancement in efficiency expected

Outcome of White Book Study

The potential of MEDAUSTRON for non-clinical research investigated

- Proton beam energy increase to 800 MeV best compromise
  - appropriate performance for experimental physics applications
  - avoids major accelerator modifications

- MEDAUSTRON provides an ideal facility for training in various fields using state-of-the-art technology

- Contribution to the development and test of detector technology (the availability of beam energy 800 MeV is essential)

Physics Research Potential

Nuclear Research

MedAustron with its low intensity cannot compete with state-of-the-art nuclear physics research centers, but variable beam energies up to 800 MeV offers interesting possibilities for proton scattering experiments

- nuclear radii
- systematics of optical potentials
- nuclear data relevant reactions
- proton-proton scattering

The possibility of polarization in a forthcoming upgrade would be extremely valuable - polarized p,d beam, polarized target

Other Physics Application

The high energy beam of MedAustron can be exploited for several applications of high scientific interest:

- proton computerized tomography (pCT)
- dosimetry studies (solid-state nano-dosimetry, cosmic ray simulat.)
- single-hit microprobe
- study radiation damage

THANK YOU FOR YOUR ATTENTION

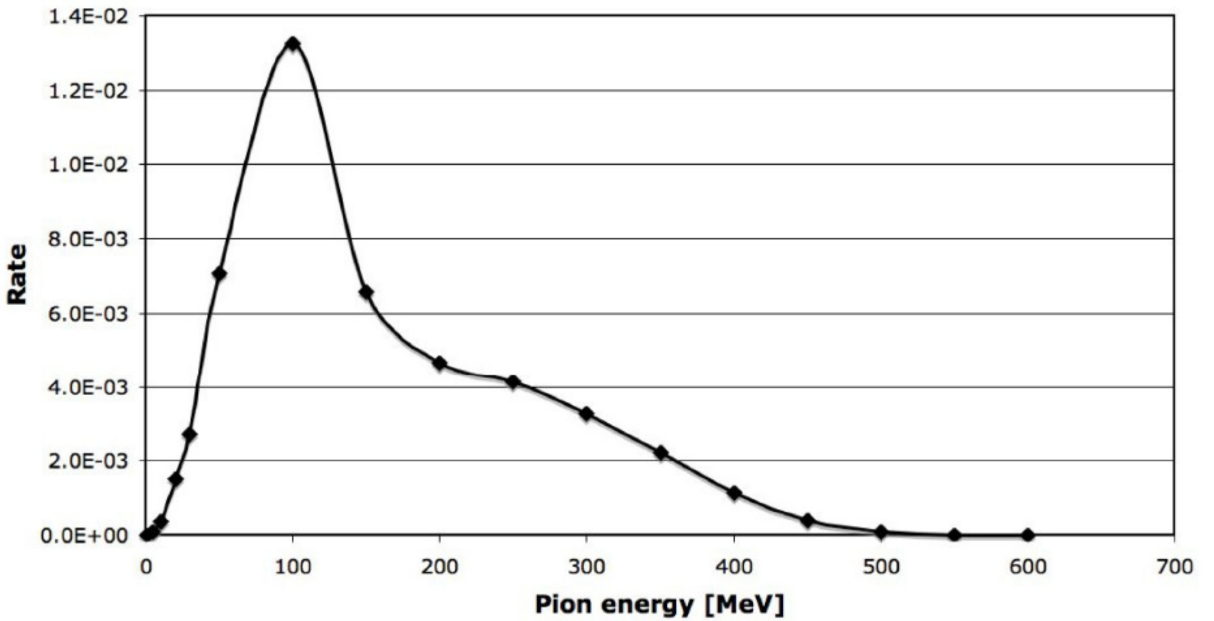
MedAustron versus nuclear physics facilities

Facility City (Country)	Particle	Energy MeV/u	Intensity 10^{10} pps
GSI Darmstadt (D)	$^{12}C^{6+}$ $^{238}U^{73+}$ $^{238}U^{73+}$	50 – 2000 50 – 1000 15, 5	10 0, 2 $1.5^{\dagger}$
COSY Jülich (D)	p,d p,d	up to 300 300 – 3600	< 6250 $< 0,1$
GANIL Caen (F)	$^{12}C^{6+}$ $^{64}Ni^{28+}$	up to 96 up to 60	2000 700
KVI Groningen (NL)	p $^{12}C^{6+}$	120 – 190 35 – 95	65
JYFL Jyväskylä (SU)	p p He,B,C,N,O	up to 70 45 $2 - 130(q/A)^2$	≥ 1600 60000 > 600
IPN Orsay (F)	p ^{12}C	25 69	600 94
IFJ Krakow (PL)	p α	20 – 60 40 – 60	6000 – 600 1560
NSCL-MSU East Lansing (US)	^{16}O up to ^{238}U	150 80	< 78 $< 0,125$
RCNP Osaka Osaka (J)	p ^{4}He	100 – 392 185 – 400	< 240 < 2
RIBF (RRC) RIKEN Nishina Center(J)	p ^{12}C	70 – 210 70 – 135	< 875 < 42
HIMAC Chiba (J)	^{4}He ^{12}C	100 – 230 100 – 430	$< 0,12$ $< 0,18$
MEDAUSTRON Austria (A)	p $^{12}C^{6+}$	60 – 800 70 – 400	< 1 $< 0,04$

Secondary pion beam at MEDAUSTRON

The three beam option have been considered together with the possibility of a secondary pion beam

800 MeV proton beam with 10^{10} protons pp may lead to 5.45 10^8 pions pp



Intensity of secondary pion beam too small
→
not further considered

Pion production rate at 800 MeV protons

Black Sphere Approximation

For proton scattering at incident energies about 800 MeV the **black sphere approximation** is applicable for heavy nuclei A>50.
→ Diffraction of a wave with $\lambda_{Lab}=2\pi/p_{Lab}$ on a disk of radius a in the limit of geometric optics $a/\lambda_{Lab}>>1$ → Fraunhofer scattering

scattering amplitude $$f(q)=\frac{ipaJ_1(qa)}{q}$$

black sphere rms radius $$r_{BS}=\sqrt{\frac{5}{3}}\,a$$

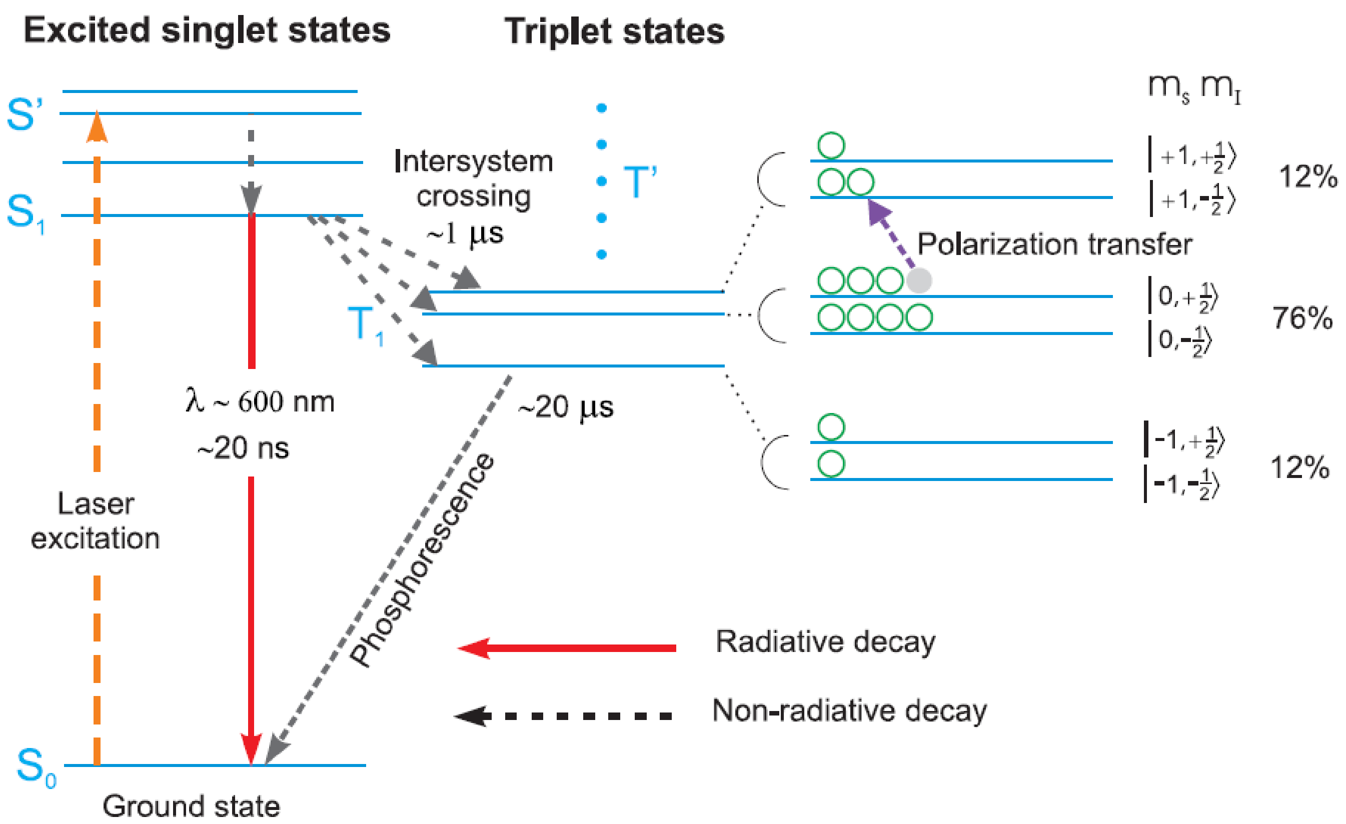
first diffraction maximum at Θ_M leads to a value of r_{BS}

$$r_m \approx r_{BS} = \frac{3.9780}{2p\sin(\Theta_M/2)}$$

Taking the difference to the proton radius (charge distribution) leads to the neutron radius, which is difficult to determine

Polarized proton target

Possibility of a polarized proton target was considered as an upgrade option



Count rate estimates