IBA

Future trends

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Introduction

- “small accelerators”: a definition
  - industrial context: commercial product

    ⇒ customer or client

    ⇒ provider – client relation: win-win

    ⇒ demands
  - several units foreseeable

Introduction

- so:

Future trends are driven by customers' demands

- and:

Customers have applications

obvious?

Introduction

- new demands lead to new technical solutions
- research placed in present European political context (rules) :
  - funded research projects organized in IP
    - research institutes
    - universities
    - industrial companies
  - industrial approach from start

Introduction

- discussion organized around the applications of accelerators from an industrial point of view (“small” accelerators)
  - research
  - medical
  - industry
  - …

application domains

	hadrons	electrons
existing	• PET (hospital based) • medical isotope production • p-therapy	material irradiation
planned	• BNCT • C-therapy	food irradiation
future prospects	continuous fast n-production • without multiplication • with	safety

aspects

To what aspects of the commercial product ‘accelerator’ do the customers’ demands relate?

		existing	planned	prospects
economy	price	[red]	[red]	[red]
economy	• cost of operation • ease of operation • availability • maintainability & dismantling	[red]	[red]	[red]
psychology	high-tech	[red]	[yellow]	[green]
technique	beam energy	[green]	[red] [yellow]	[red]
technique	beam current	[yellow]	[green] [red]	[red]
technique	beam quality	[green]	[red]	[red]

standpoint and limits

- most common demand: CW beams
- remaining technology of first choice:

H^{-} cyclotron

- limits, due to nature of H^{-} :
  - energy: fundamental, contradiction
  - intensity: ion sources

standpoint and limits

- limits, intrinsically due to cyclotron :
  - energy: focussing
  - intensity: space charge
  - reliability

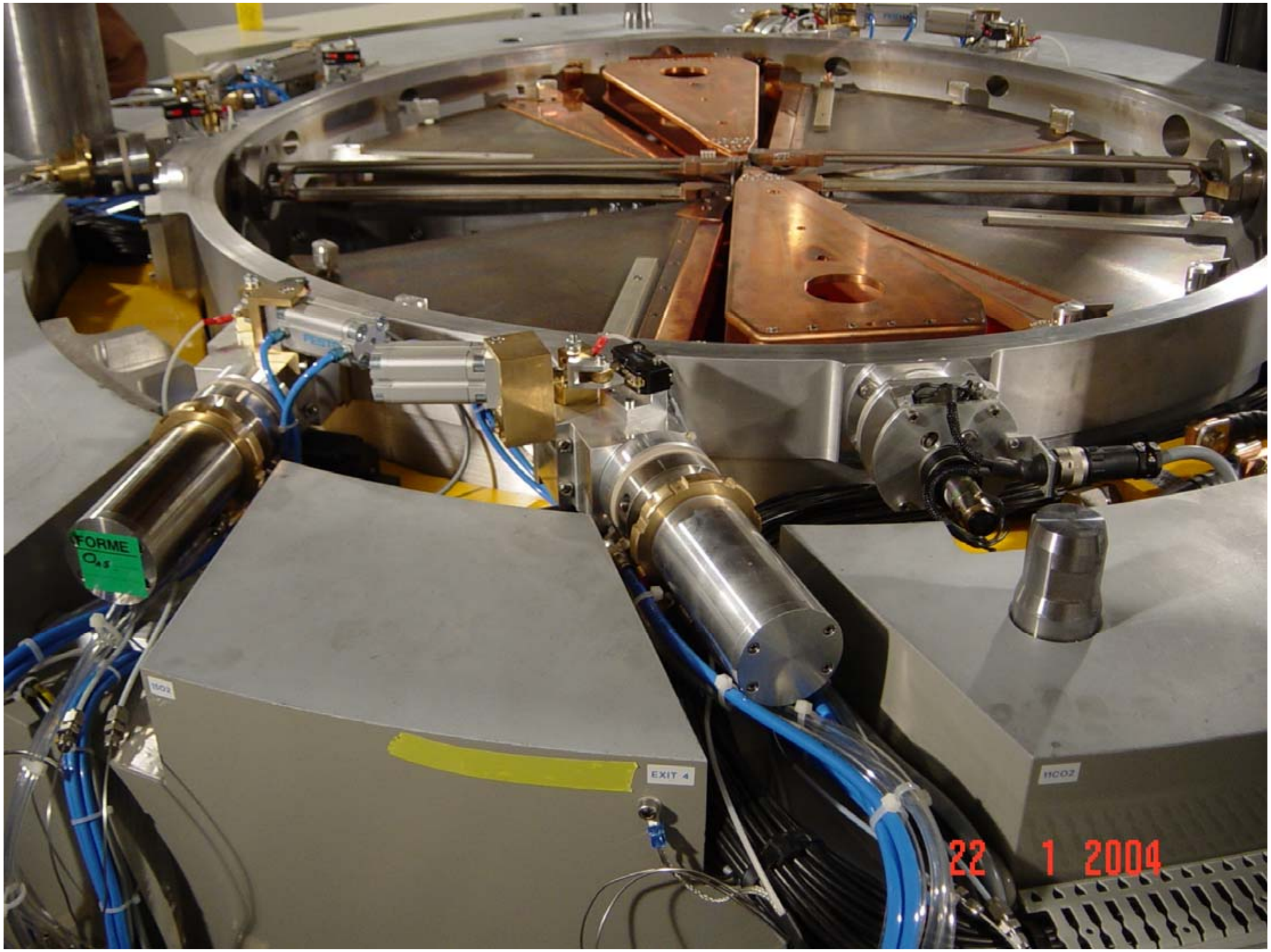
PET isotope production

- requests:
  - < 20 MeV p, 200 μA (↗)
  - d-beam from same machine
  - multi-beam extraction
- no doubt about technology:
  - cyclotron, RT
  - accelerate H^-, D^-
  - 2 internal ion sources

PET isotope production

- competitive market → "classical" marketing problems:
  - economical optimisation
  - reproducibility in manufacturing
  - optimize reliability
  - high-tech aspect
- no accelerator technology challenge

PET isotope production



industry/research isotope production

- requests:
  - 14 MeV p, > 2 mA : Pd
  - 30 MeV p, > 1.2 mA : general purpose
- present technology: RT cyclotron
  - H^+ with self-extraction
  - H^- with stripping extraction

satisfying for now, but both reaching their intensity limits

industry/research isotope production

- future is technically challenging:
  - upgrading the present solutions

  if intensity demands continue rising
  - start looking beyond cyclotron limits
- competitive market:
  - economical optimisation

protontherapy

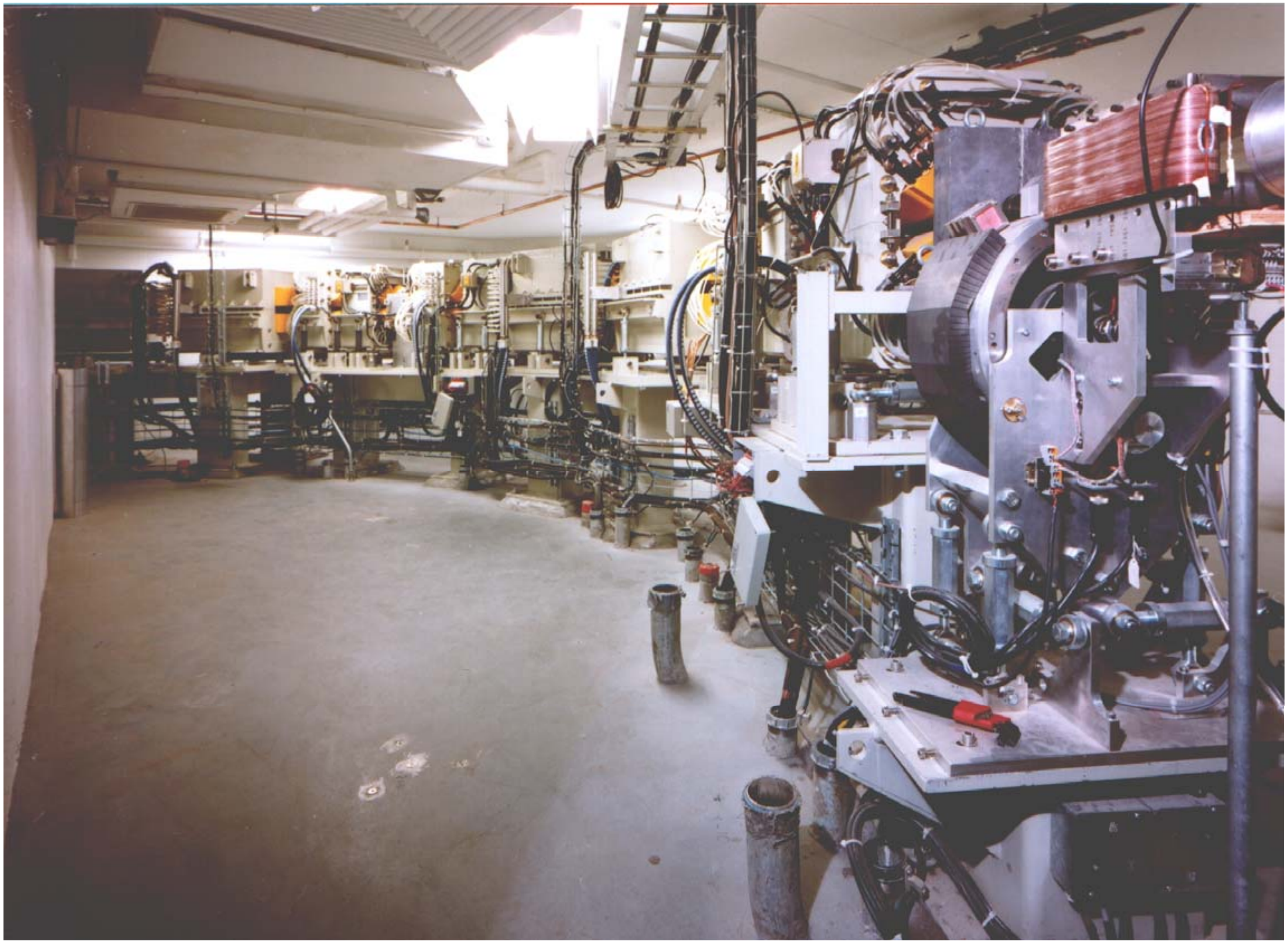
- requests:
  - 230 – 250 MeV p, few nA of beam delivered to patient: unchanged
- technology:
  - H^- now excluded ⇨ H^+
  - borderline region ⇨ several technical answers:
    - RT cyclotron (IBA)
    - SC cyclotron (Accel)
    - synchrotron (Hitachi)

protontherapy

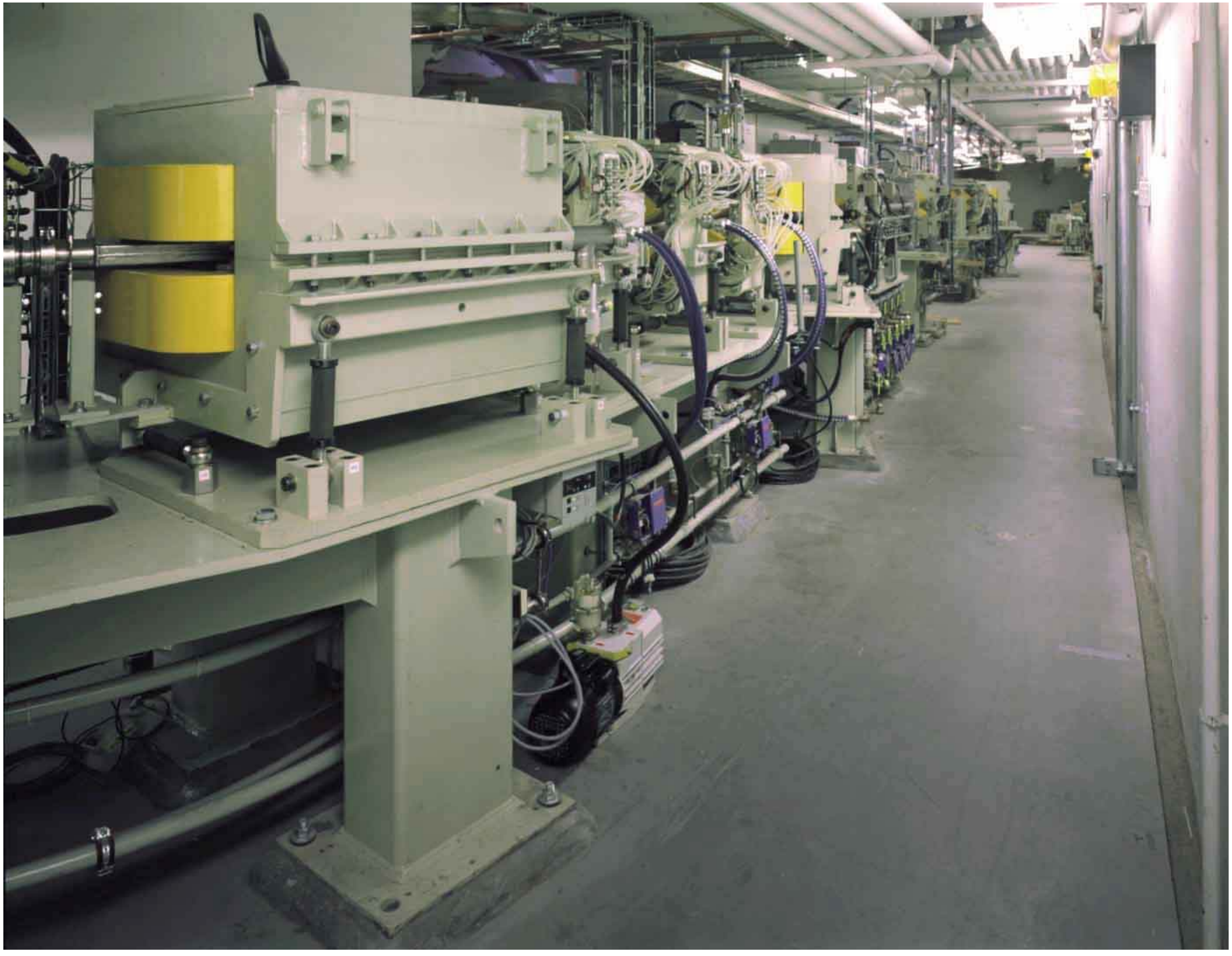
protontherapy

- no new technology
- competition of coexisting technologies
  ⇨ marketing problems
- but: PT is much more than an accelerator …

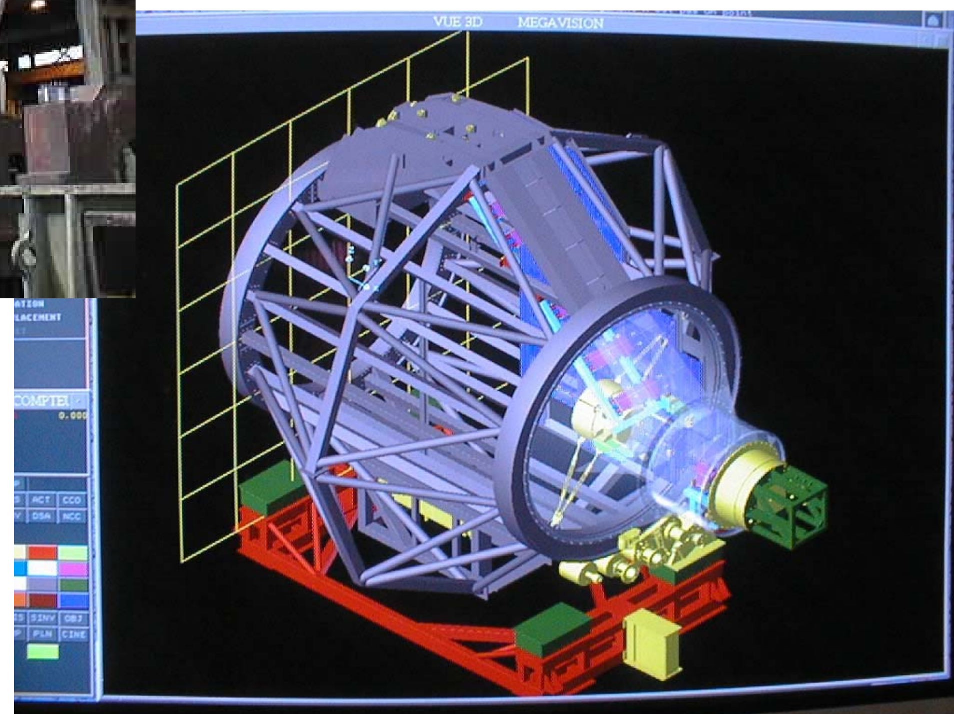
protontherapy



protontherapy



protontherapy



C-therapy

- not new, already applied esp. Japan (HIMAC, Chiba, since 1993)

- HICAT: European installation at GSI

C-therapy

- now seems to emerge on European marketplace
- like p-th: low intensity beams
- unlike p-th: energy scale: 400 A·MeV

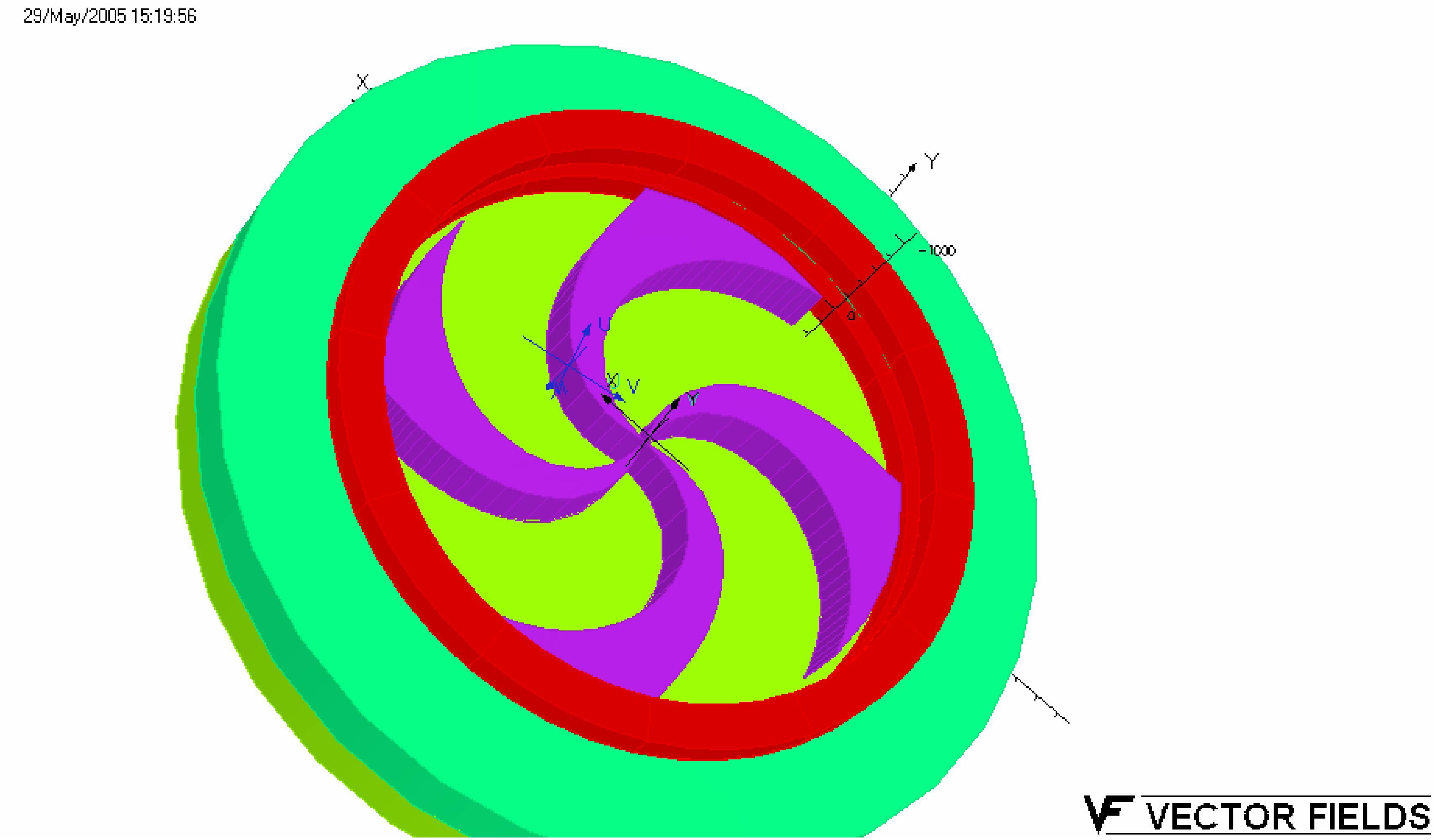
  $B\rho$ = 6.4 Tm $\Longleftrightarrow$ 2.35 Tm
- accelerated ion: fully stripped C

  ECR ion source

C-therapy

- choice of accelerator:
  1. synchrotron: all existing projects use it
  2. cyclotron, SC
     + CW, compact size, (price)
     – fixed energy
- synchro:
  – standard technology
  – to be made “industry-standard”
- cyclo:
  – extrapolation of existing high level technology

C-therapy



C-therapy

- more than accelerator
  - transport line
  - treatment room
    - fixed
    - gantry: 6.4 Tm ⟹ depart from isocentric
- R&D topics:
  - acceptable gantry design
  - rotating SC magnets

future trends in modelling

- EM modelling tools today
  - design: CAD tool using the ACIS kernel
  - meshing: fully automatic 3D
  - solver: FE ⟺ FD
  - post-processor
- demands:
  - 3D accuracy of former 2D level
  - independent on mesh (at constant size)
  - “full” models

future trends in modelling

- how ?

  handle more mesh points

  use massive memory and computing power
- another demand: optimisation

  combine

  - upgraded modelling tools
  - new optimisation algorithms
  - massive computing power, clusters

neutron applications

- several projects need neutrons
- traditional neutron sources
  - research reactors tend to disappear
  - miss flexibility

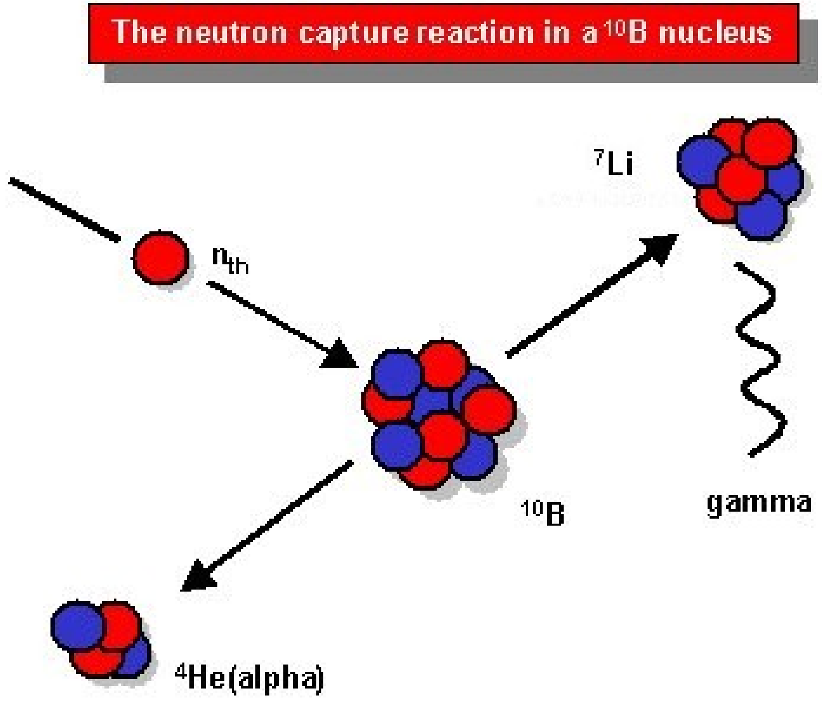
future trend:

use of accelerators for neutron production

- common needs:
  - current
  - CW

BNCT

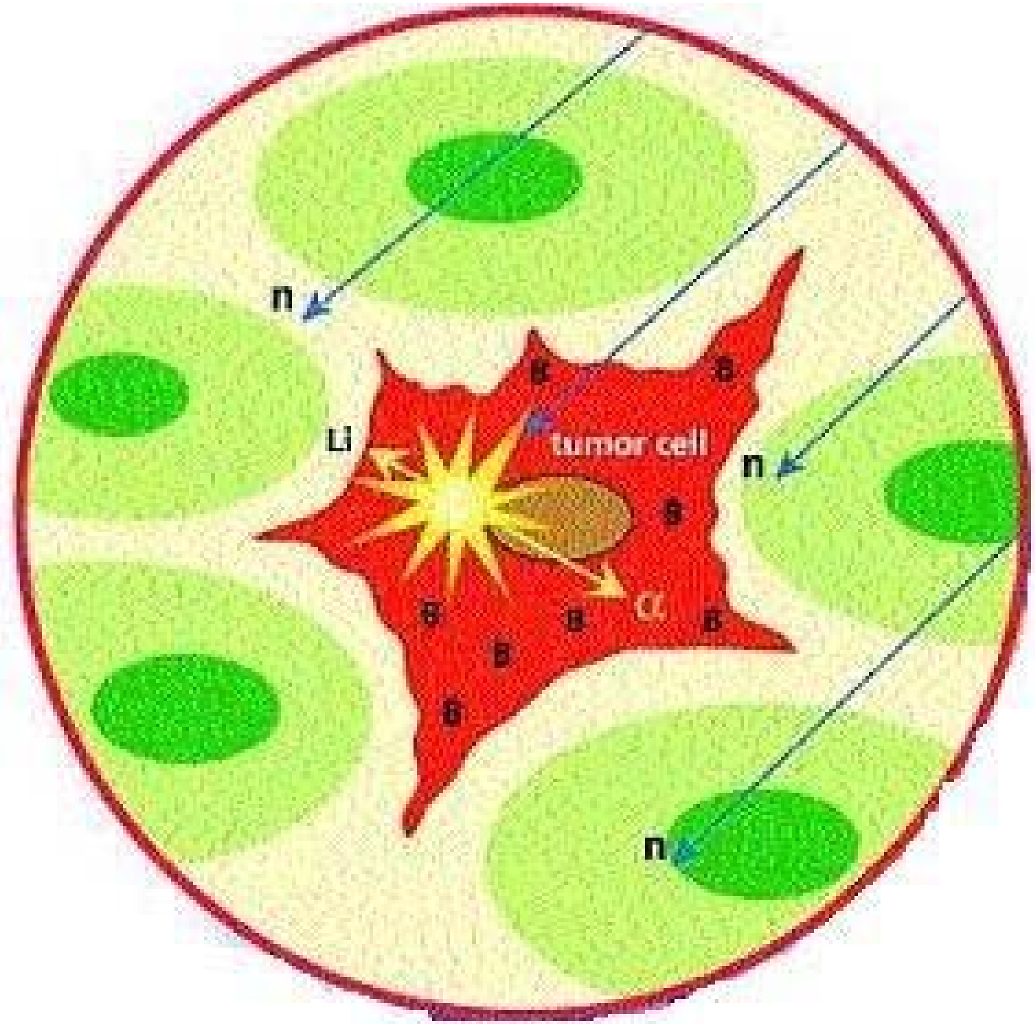
- what is it ? what is needed ?



$$^{10}B + n_{th} \longrightarrow {}^{7}Li\ (0.84\ MeV) + {}^{4}He\ (1.47\ MeV) + \gamma\ (0.48\ MeV) \quad 93.7\%$$

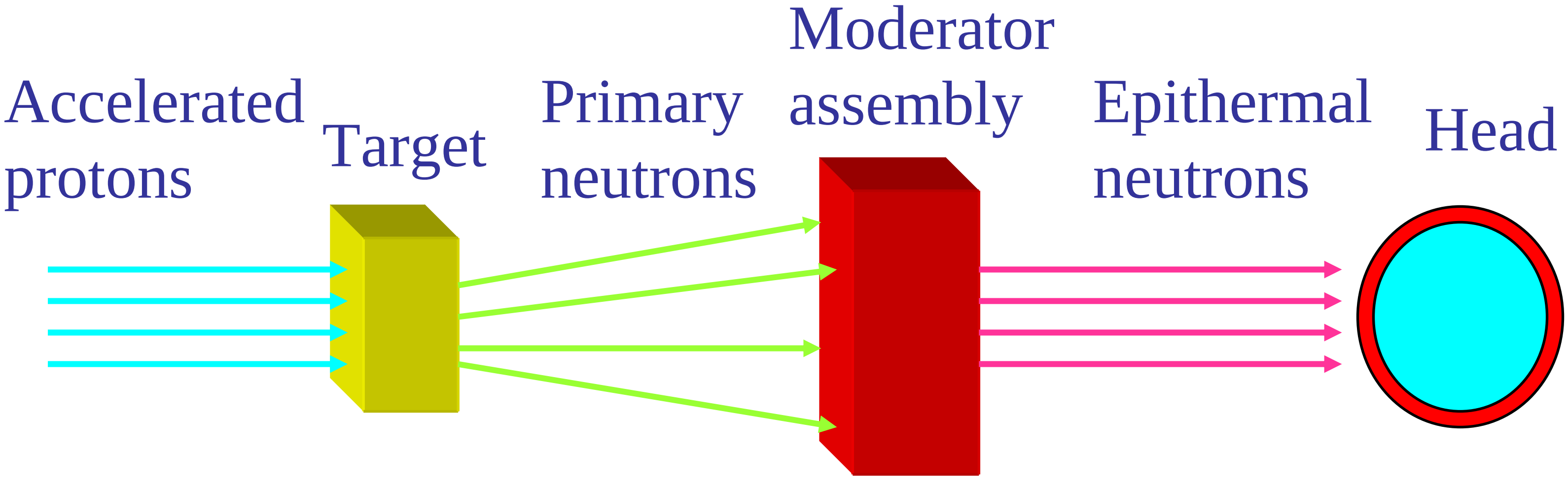
$$^{10}B + n_{th} \longrightarrow {}^{7}Li\ (1.01\ MeV) + {}^{4}He\ (1.78\ MeV) \quad 6.3\%$$

BNCT

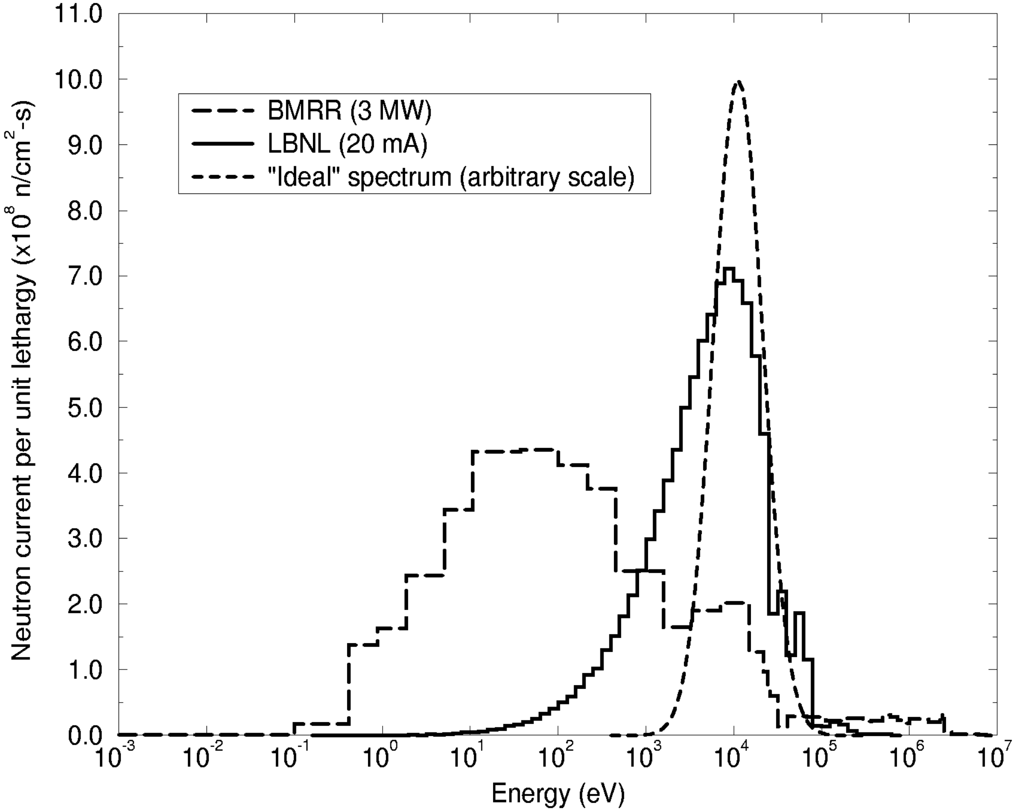


BNCT

Accelerator-based BNCT System



BNCT



beam: 2.8 MeV, 20 mA CW

BNCT: the CW accelerator

- recall limits: 20 mA!
- choices:
  - electrostatic
    - bulky
    - reliable
    - readily available
  - RFQ
    - inefficient
    - CW just coming up

BNCT: the CW accelerator

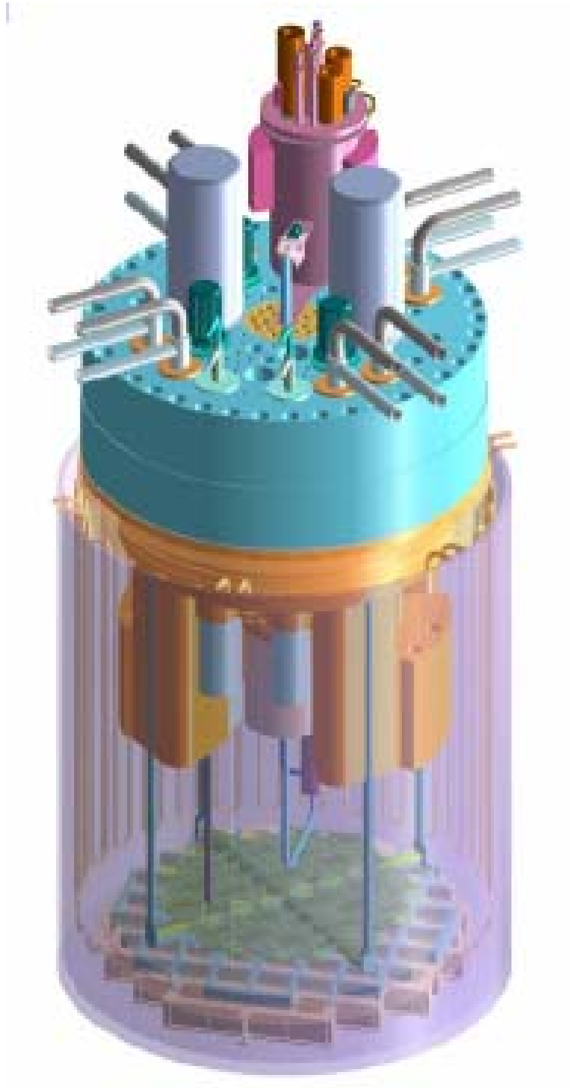
- RFQ + linac section
  - lowest possible linac injection energy
  - new developments
- SC RFQ
  - dream for the future

- don't forget the target!
  - reaction: (p,^{7}Li $\rightarrow$ ^{7}Be,n)
  - Li-target, > 50 kW : challenge !!

fast neutron production

- spallation reaction
  - heavy target
  - useful energy > 150 MeV, < 1 GeV
  - high intensity
  - trade-off energy/intensity
  - beam power domains and corresponding targets:
    - (10’s of kW : research)
    - MW range
      - direct use, no multiplication
      - with multiplication
      - subcritical reactor

Myrrha



- small scale "ADS" ~ 50 MW_{th}
- beam 350 MeV, 5 mA: 1.75 MW
- experiment on the way to an industrial transmuter
- target: liquid Pb-Bi in the centre of matrix of fuel elements

subcritical reactor: demands

- continuous → cyclotron ⟺ linac
- energy: 350 – 600 MeV … 1 GeV
- intensity: 5 – 6 mA … 10 mA

- + : "extremely high" reliability
  - expressed in # beam trips > 1 s
  - typically 2 orders of magnitude better than usual

reliability

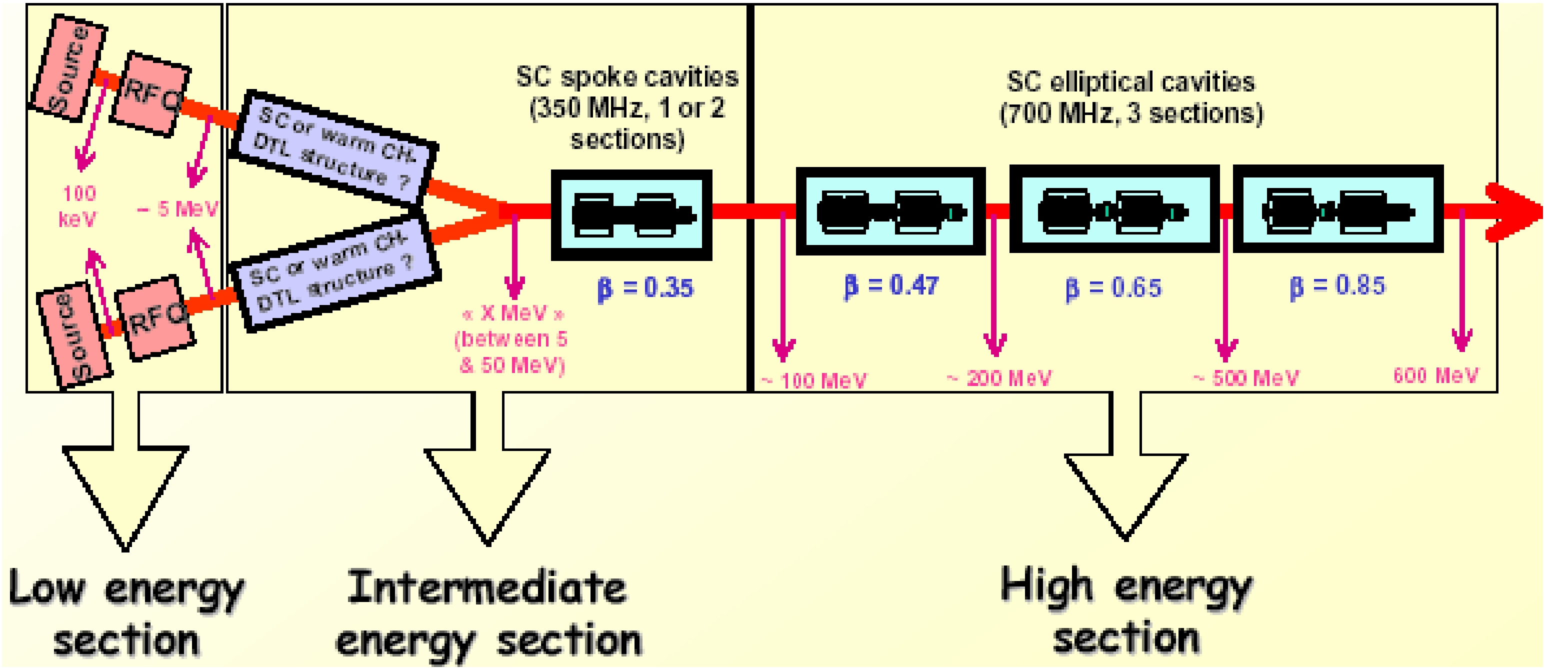
- why?
  - thermal cycling
  - reactor operation
- how?
  - reduce MTBF
    - redundancy
    - downrating
    - stay away from limits
  - fault tolerance
    - modularity
    - design

the accelerator

- cyclotron is not able to fulfil the demands
  - too close to limits
  - cannot be made fault tolerant
- CW linac is solution of choice
  - much higher beam current limit
  - straightforward energy increase
  - fundamentally modular
  - can be made fault tolerant!

the XADS accelerator

Schematic fault tolerant XADS linac



redundancy

modularity

with missing element scheme

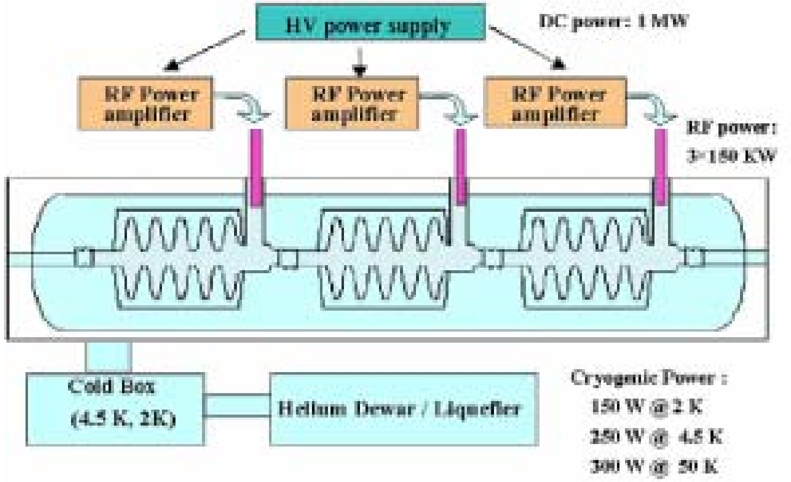
the R&D program

- FP6: IP EUROTRANS
- objectives:
  - focus on reliability
  - experimental approach on single modules
  - SC as early as possible
  - take over from RFQ as early as possible

the R&D program

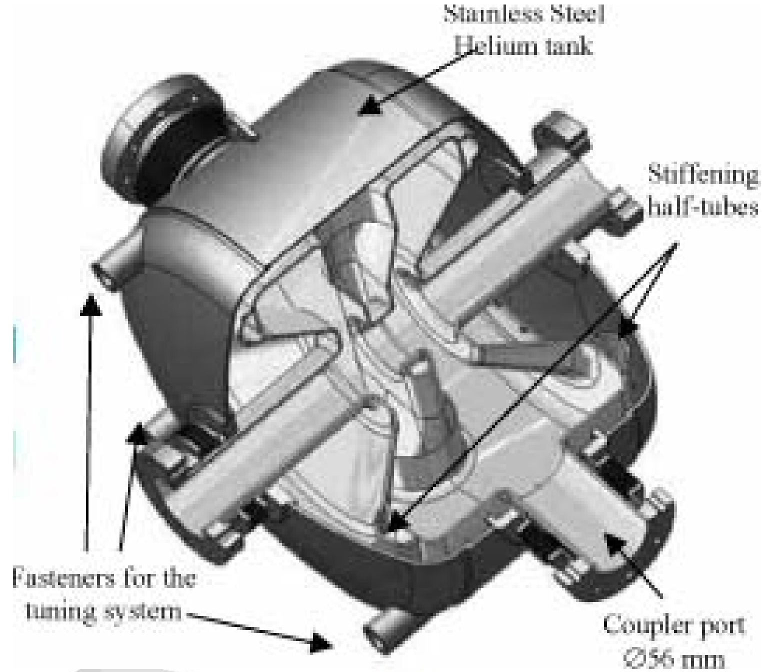
- low energy: ECR ion source + RFQ

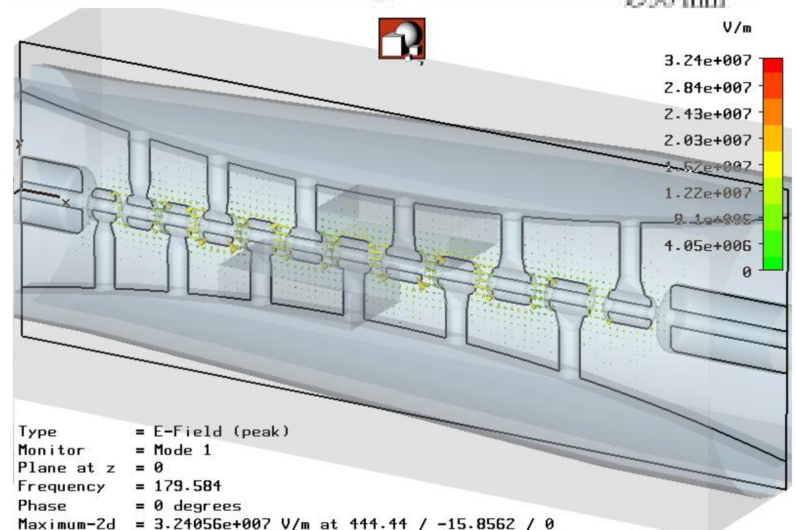
- high energy (> 100 MeV): elliptical SC cavities



the R&D program

- intermediate energy
  1. > X: spoke SC cavities
     - 2-gap
     - modular
  2. < X: H-type structures
     - multigap
     - CH SC
     - IH RT





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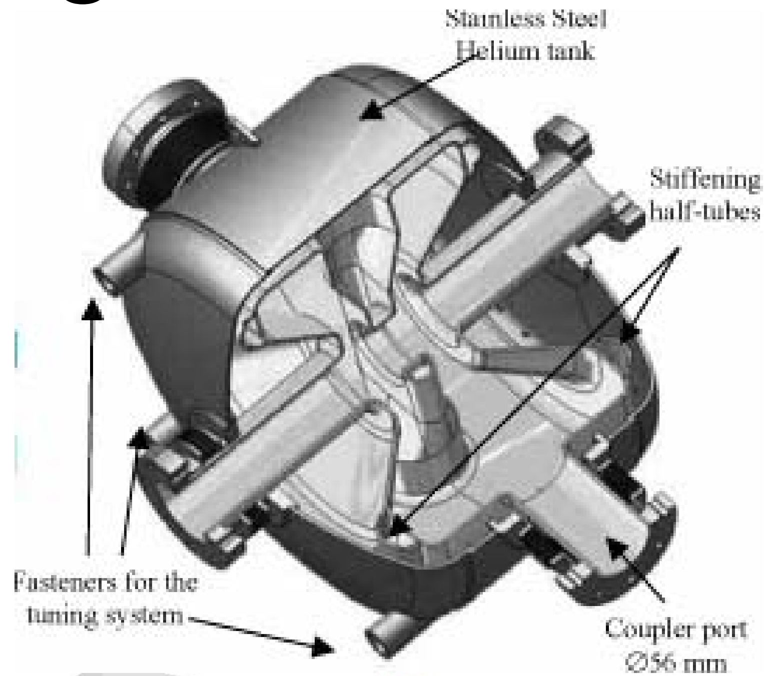

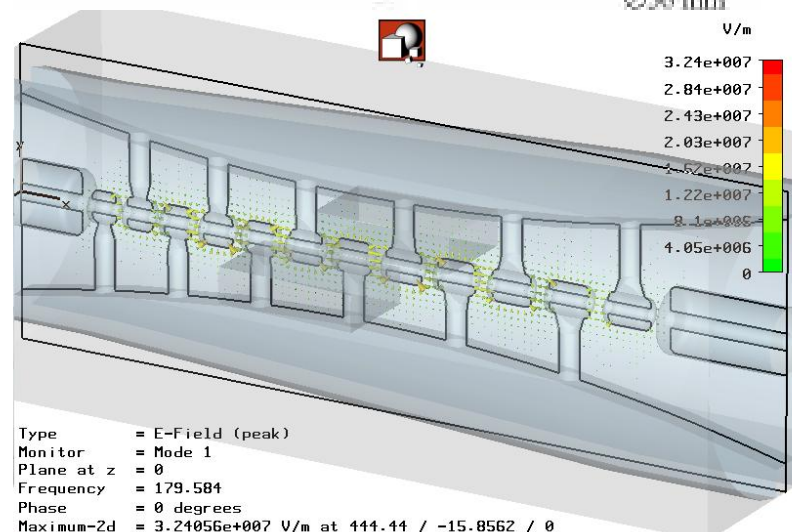

electrons

- irradiation of materials
  - ⇒ NO ACTIVATION ⇒ < 10 MeV
- X-ray conversion: inefficient
  - ⇒ high power
- rhodotron
  - – compact
  - – efficient: coaxial cavity, recirculating
  - – TT100, TT300, TT1000: 700 kW beam power
- no new demands foreseeable

conclusion

2.5 types of future trends:

- future machines for existing applications
  - accelerator = standard high-tech component
  - evolution: economical & commercial laws
  - known techniques are upgraded and "industrialised"
- future machines for future applications
  - neutrons
  - new demands needing new solutions
  - high power in CW

conclusion

  - reliability never achieved
  - CW ⇒ efficiency ⇒ SC
- HI-therapy: questions
  - take-off ?
  - coexisting technologies ?

personal final conclusion

future of new “small” accelerators:

- neutrons
- SC linear accelerators
- heavily depending on political choices