

RFQ Injector for *PAMELA* FFAG

Matt Easton

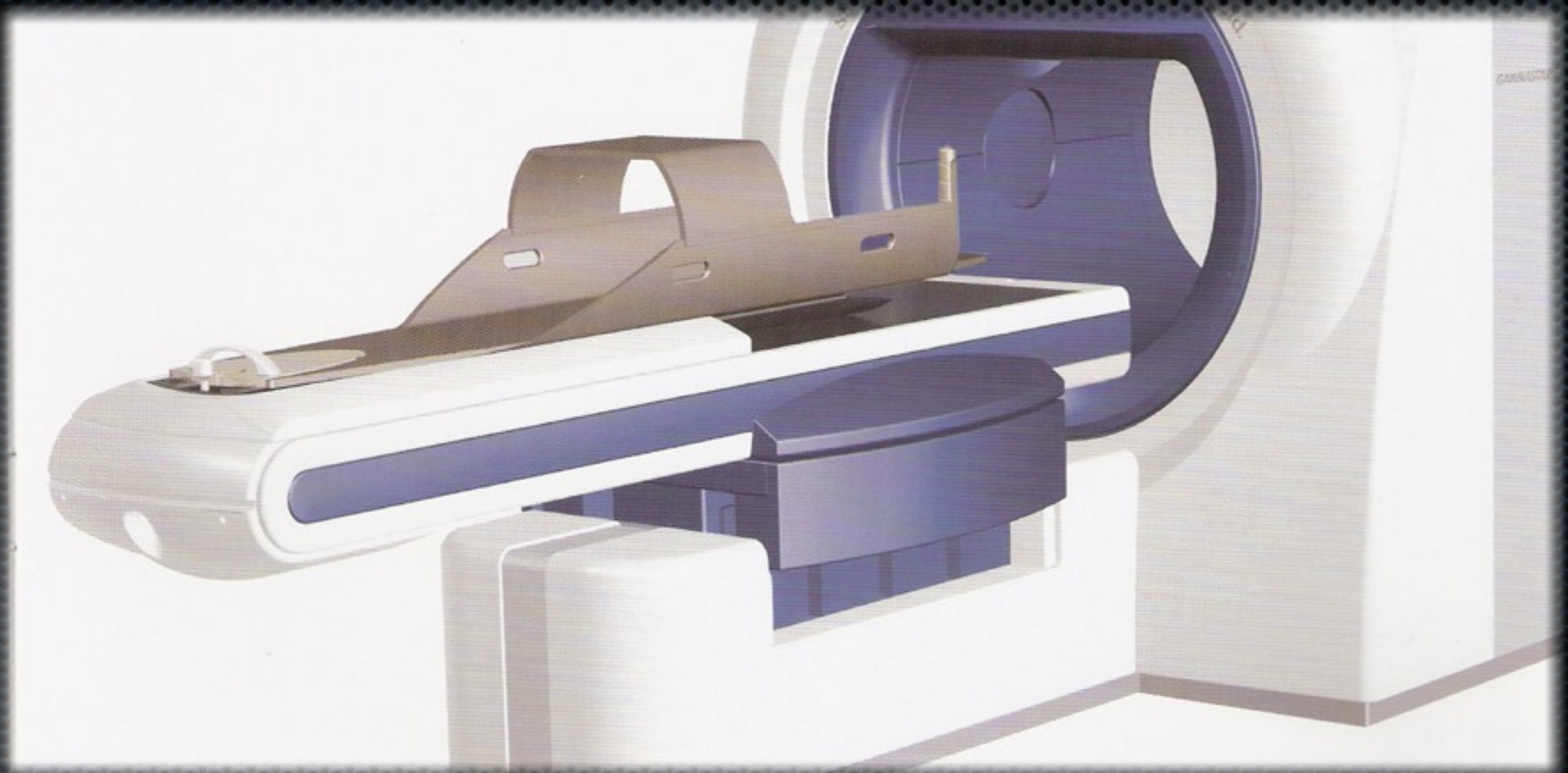
Imperial College London

PAMELA

Fixed Field Alternating Gradient (FFAG) accelerator for cancer therapy using protons and carbon ions

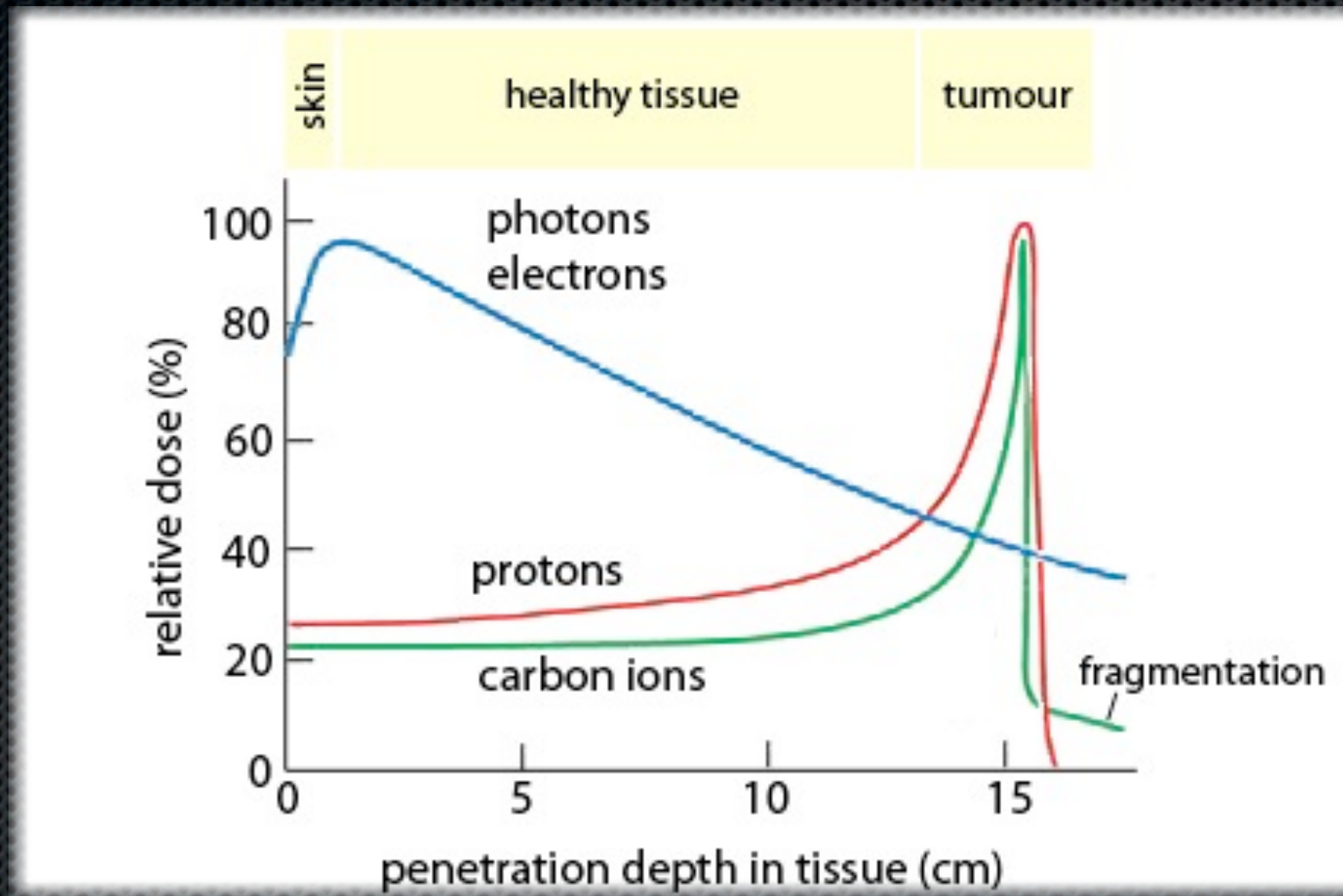
radiotherapy

treating cancer with particles



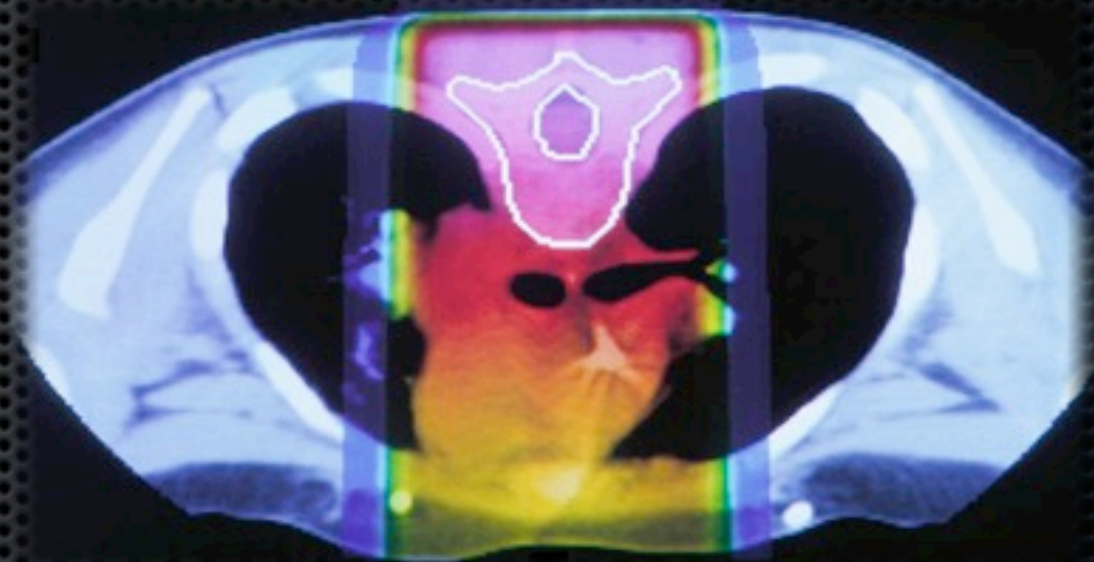
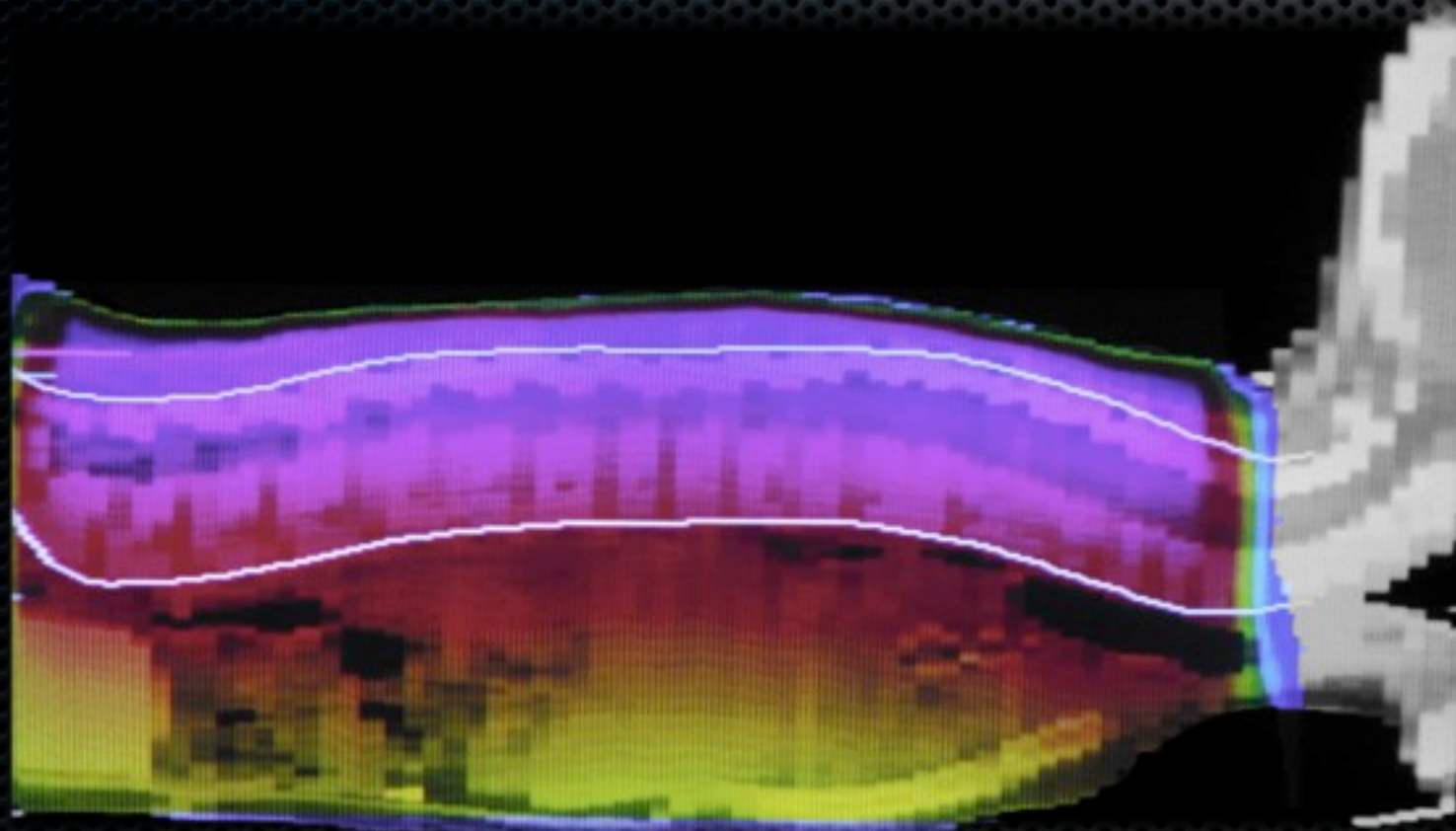
dose profile

showing relative dose to tissue at different depths



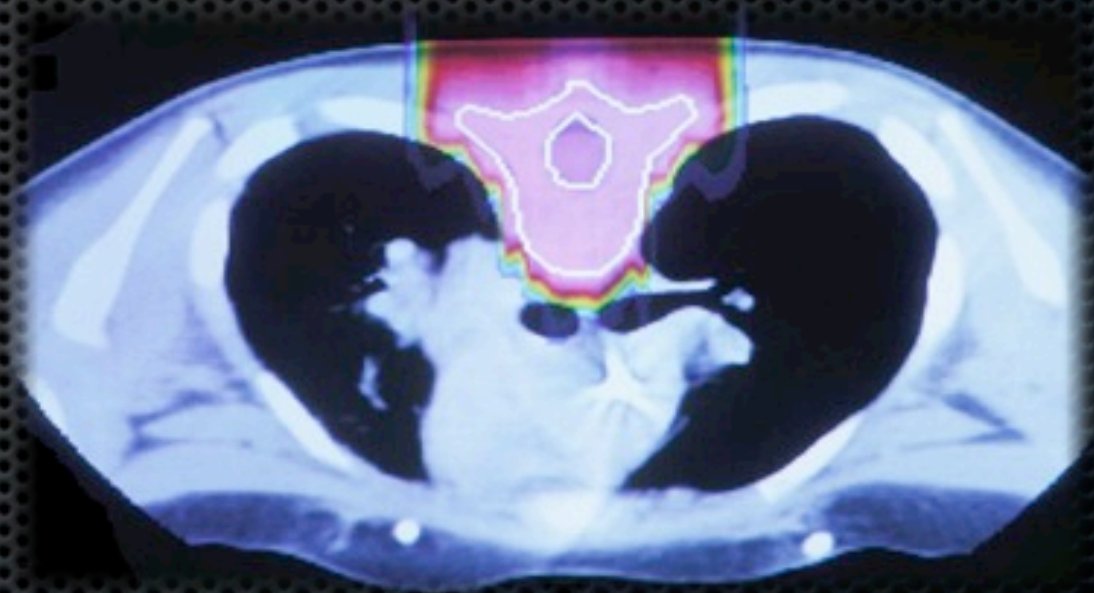
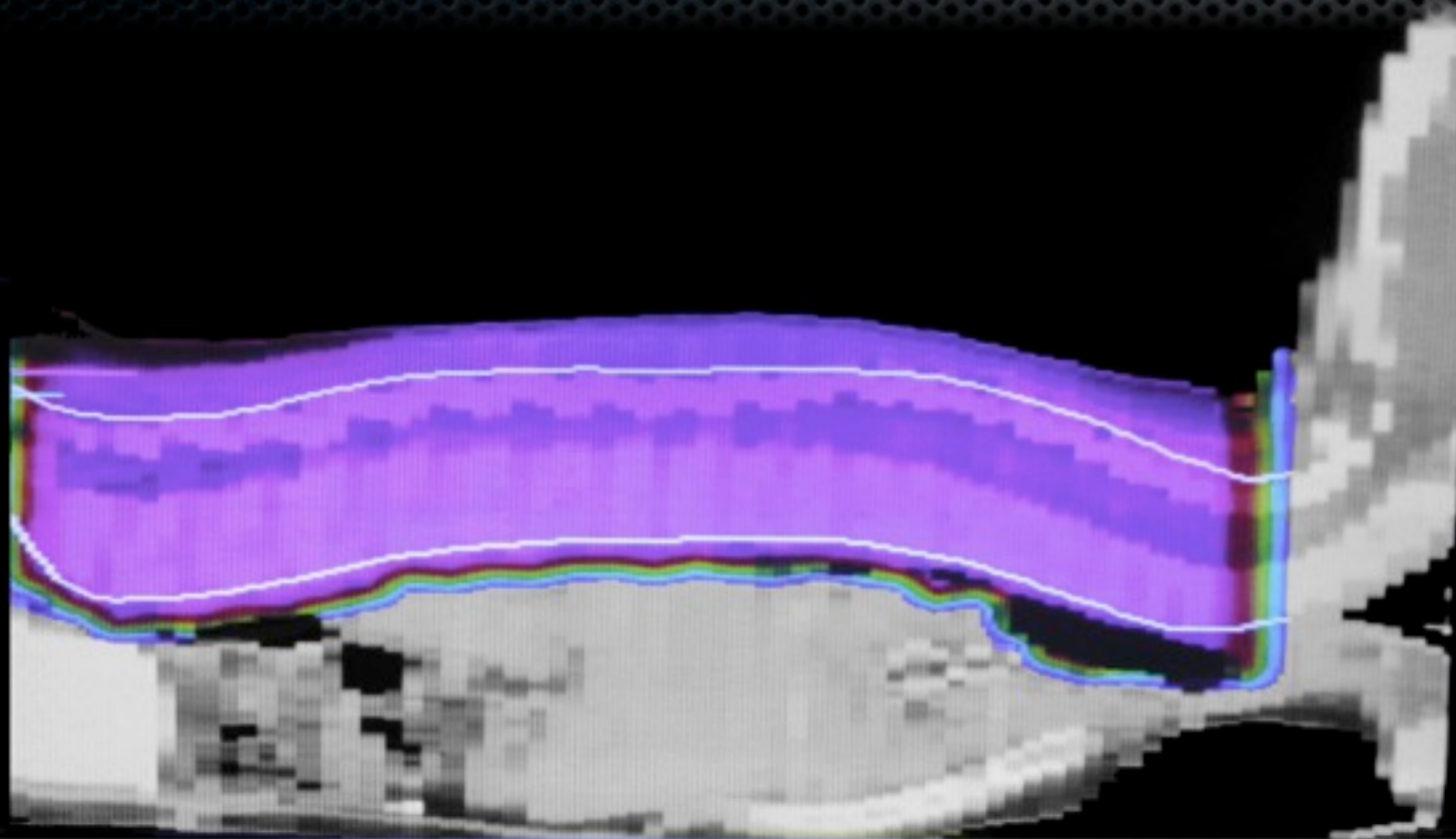
child medulloblastoma

conventional radiotherapy



child medulloblastoma

proton therapy





<http://basroc.rl.ac.uk>

- ✦ British Accelerator Science and Radiation Oncology Consortium
- ✦ academic, industrial and medical contributors
- ✦ aim:
“ the aim of BASROC is to build a complete hadron therapy facility using a novel accelerator technology called a non-scaling fixed field alternating gradient accelerator (ns-FFAG).”



<http://basroc.rl.ac.uk>

- ✦ *EMMA*
Electron Model for Many Applications
- ✦ *PAMELA*
Particle Accelerator for MEdical Applications
- ✦ full clinical facility

FFAG accelerators

Fixed Field Alternating Gradient



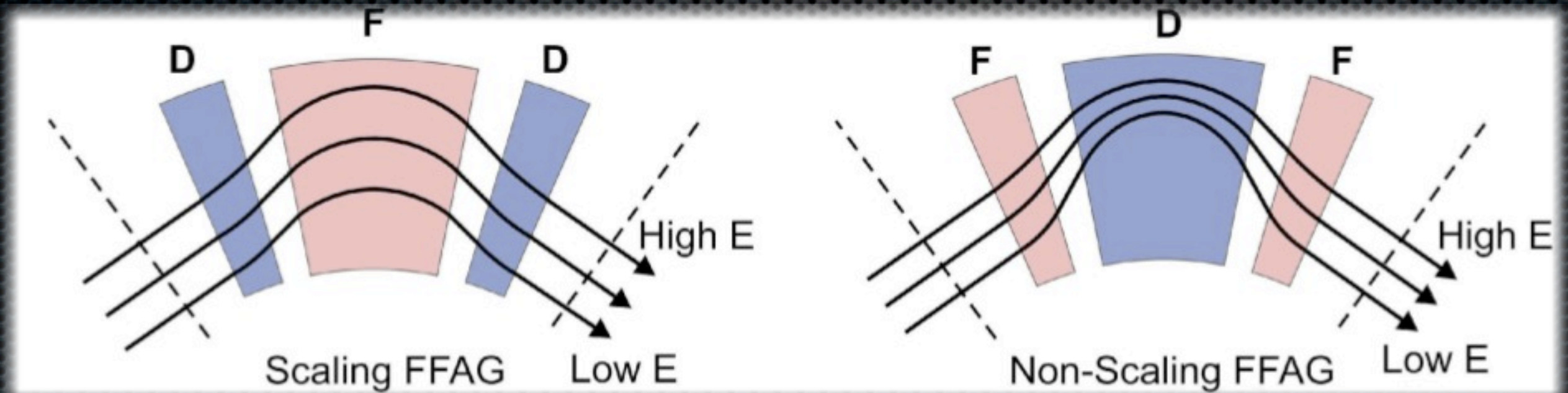
FFAG accelerators

Fixed Field Alternating Gradient

- ✦ fixed field
 - ✦ no field ramping as in a synchrotron
 - ✦ field increases with radius to keep beam orbits within beam pipe at all energies
- ✦ alternating gradient
 - ✦ alternating horizontal and vertical focusing controls betatron oscillations
 - ✦ alternating field directions invoke scalloped orbit shapes

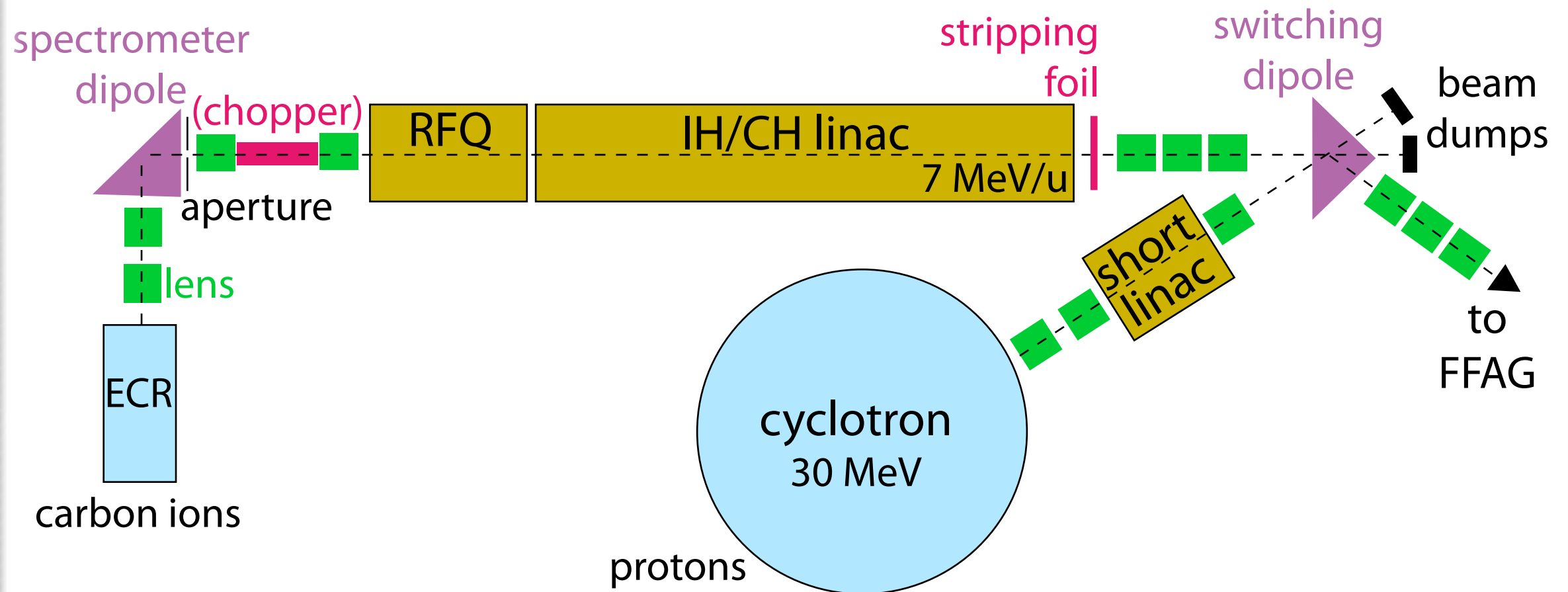
ns-FFAG accelerators

Non-Scaling Fixed Field Alternating Gradient



PAMELA injector

carbon 6+ injector for FFAG

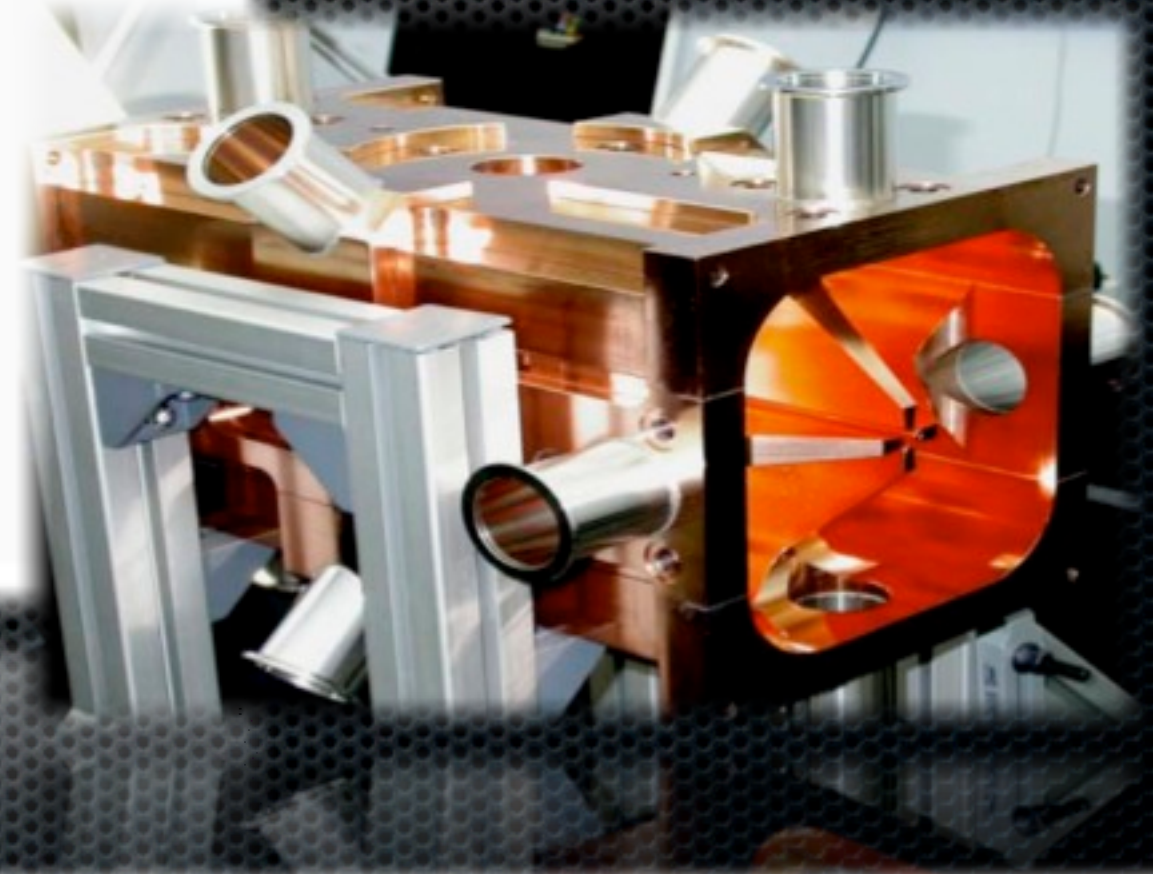
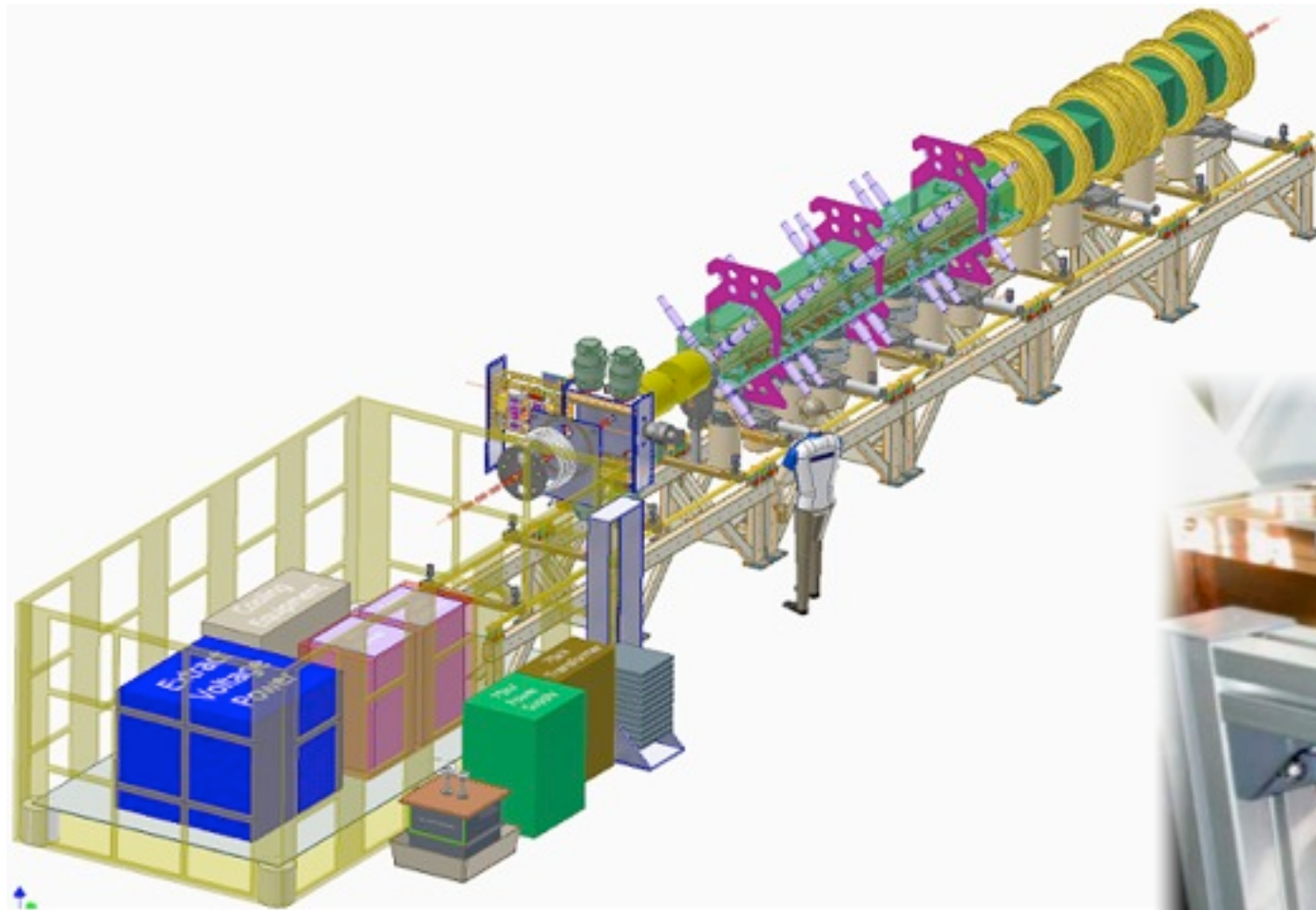


RFQ Design

CST ElectroMagnetic Studio

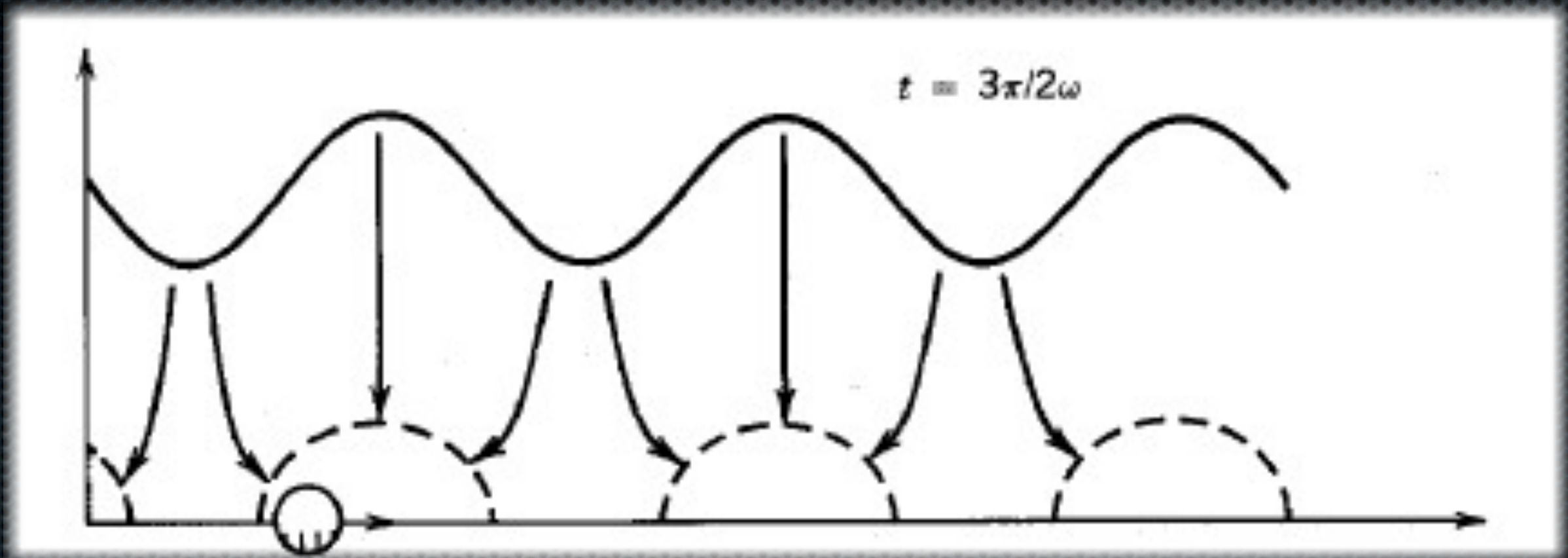
FETS RFQ

Front End Test Stand: Radio-Frequency Quadrupole



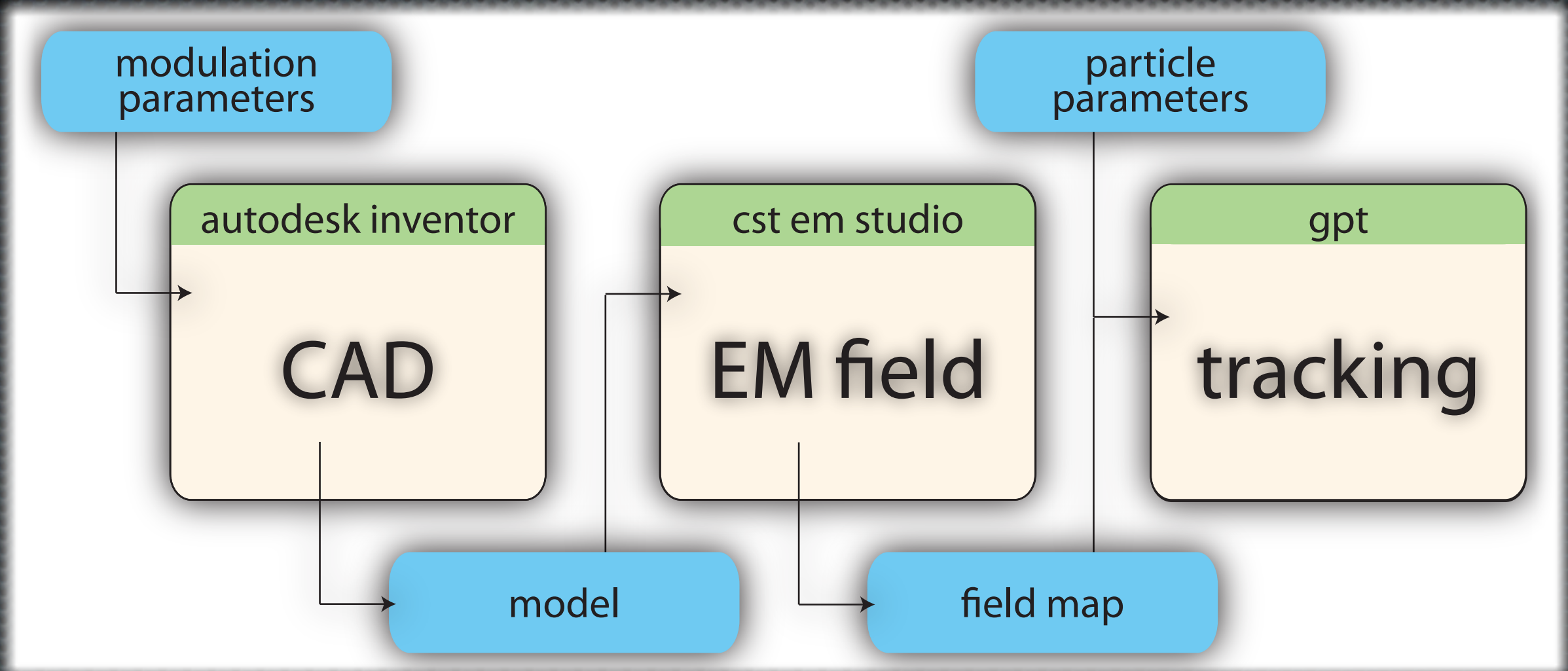
RFQ acceleration

Vane modulations produce accelerating field



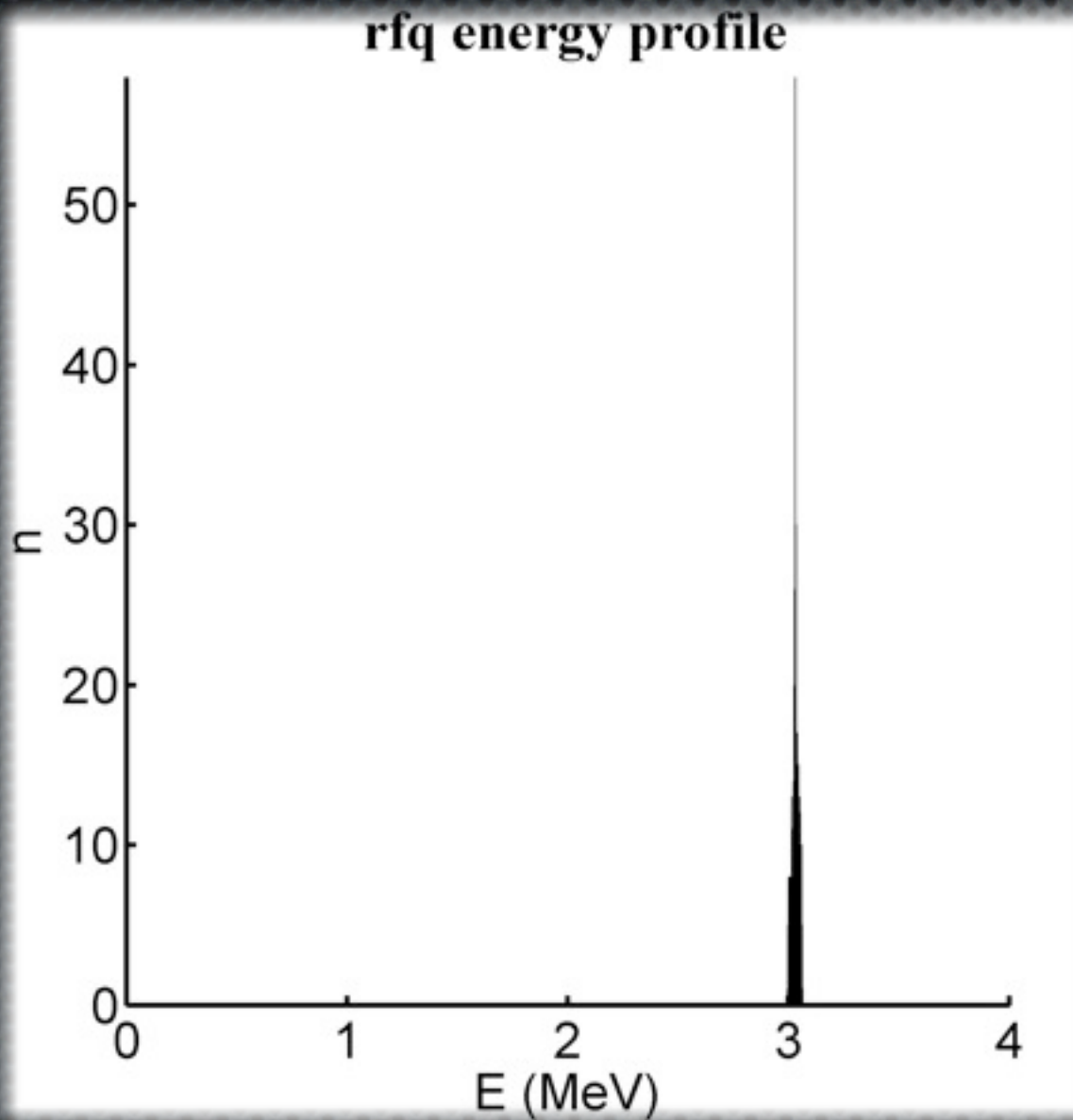
design model

using *CST EM Studio*

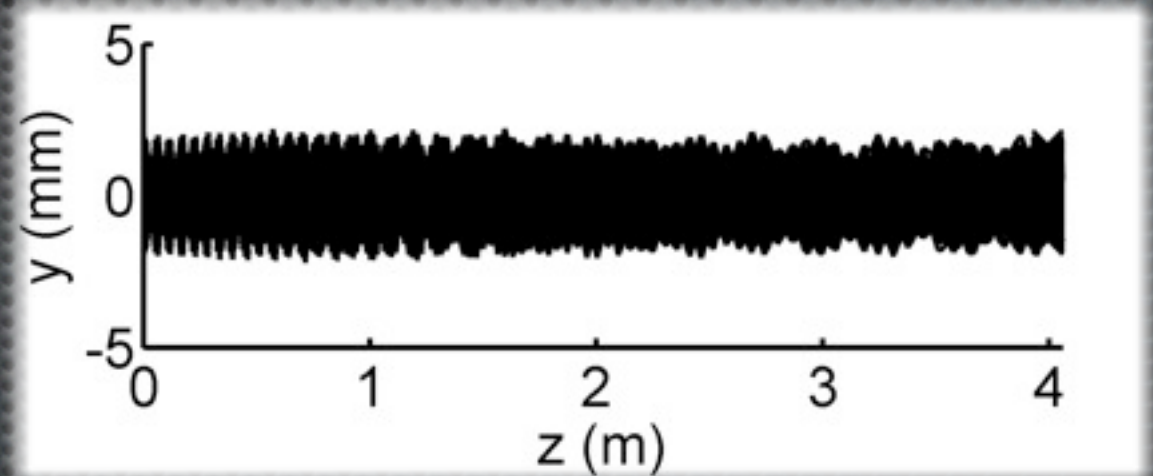


FETS field map

produced from *RFQSIM*, tracked with *GPT*

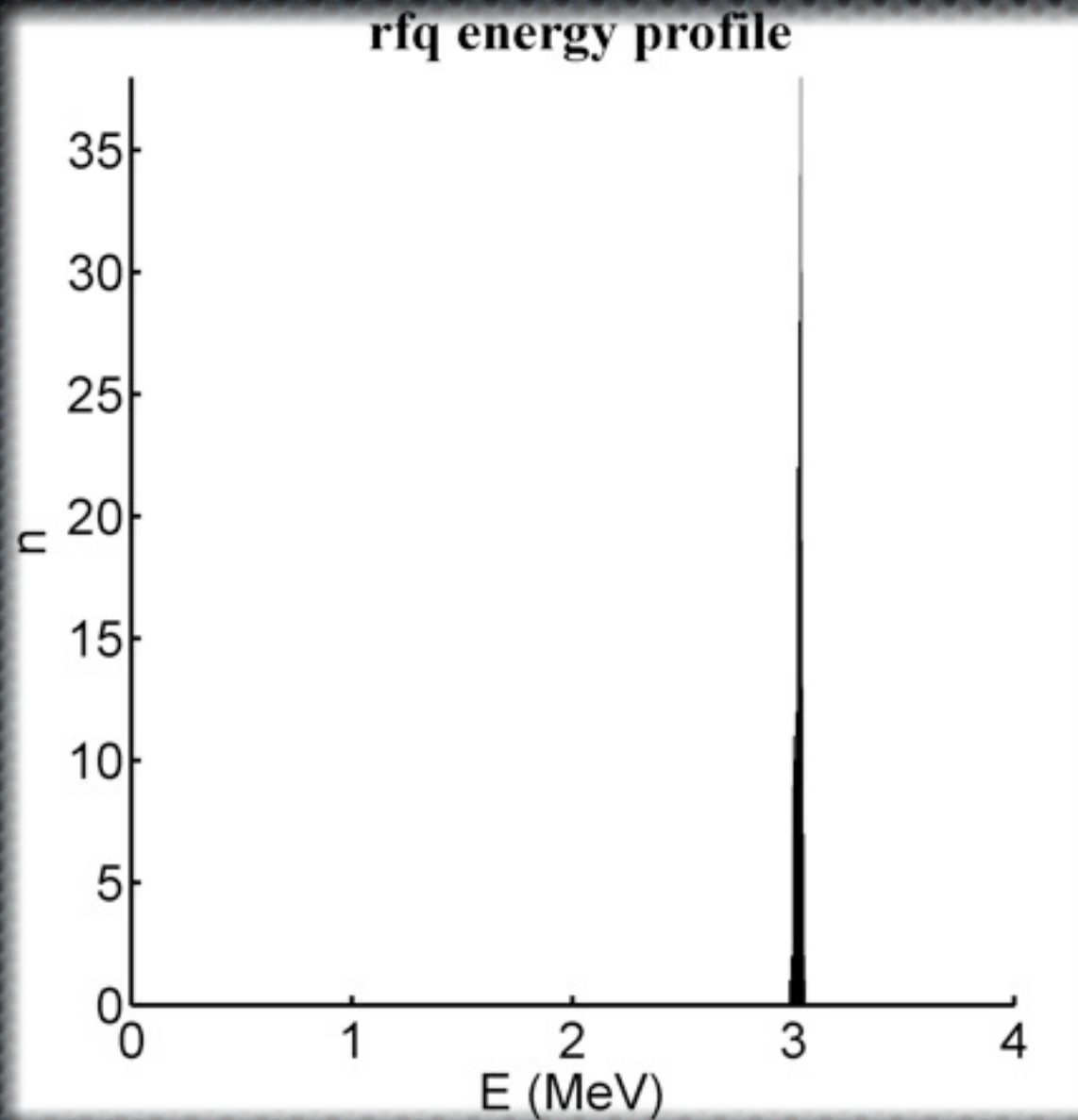


transmission = 100%
mean energy = 3.03 MeV
energy rms = 14 keV

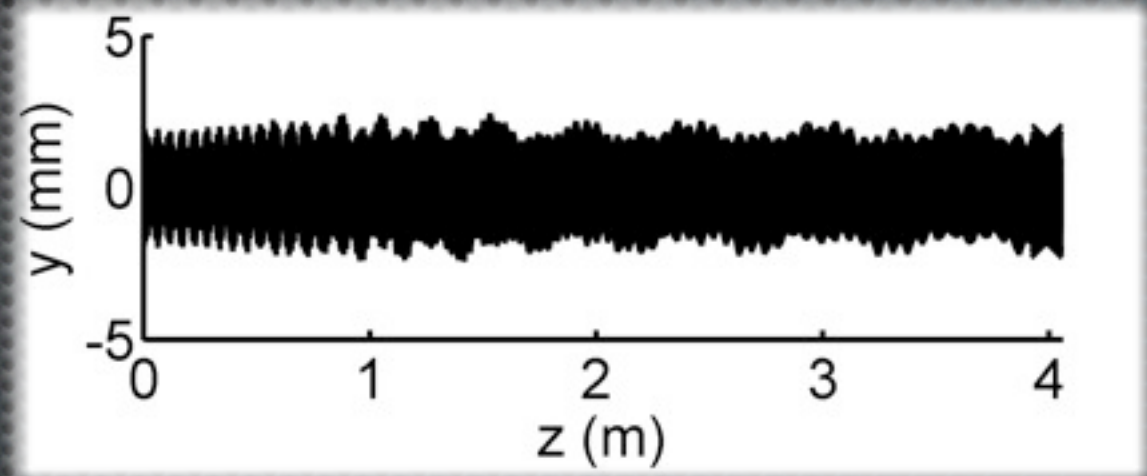


FETS field map in CST

based on *Inventor* CAD model in five sections



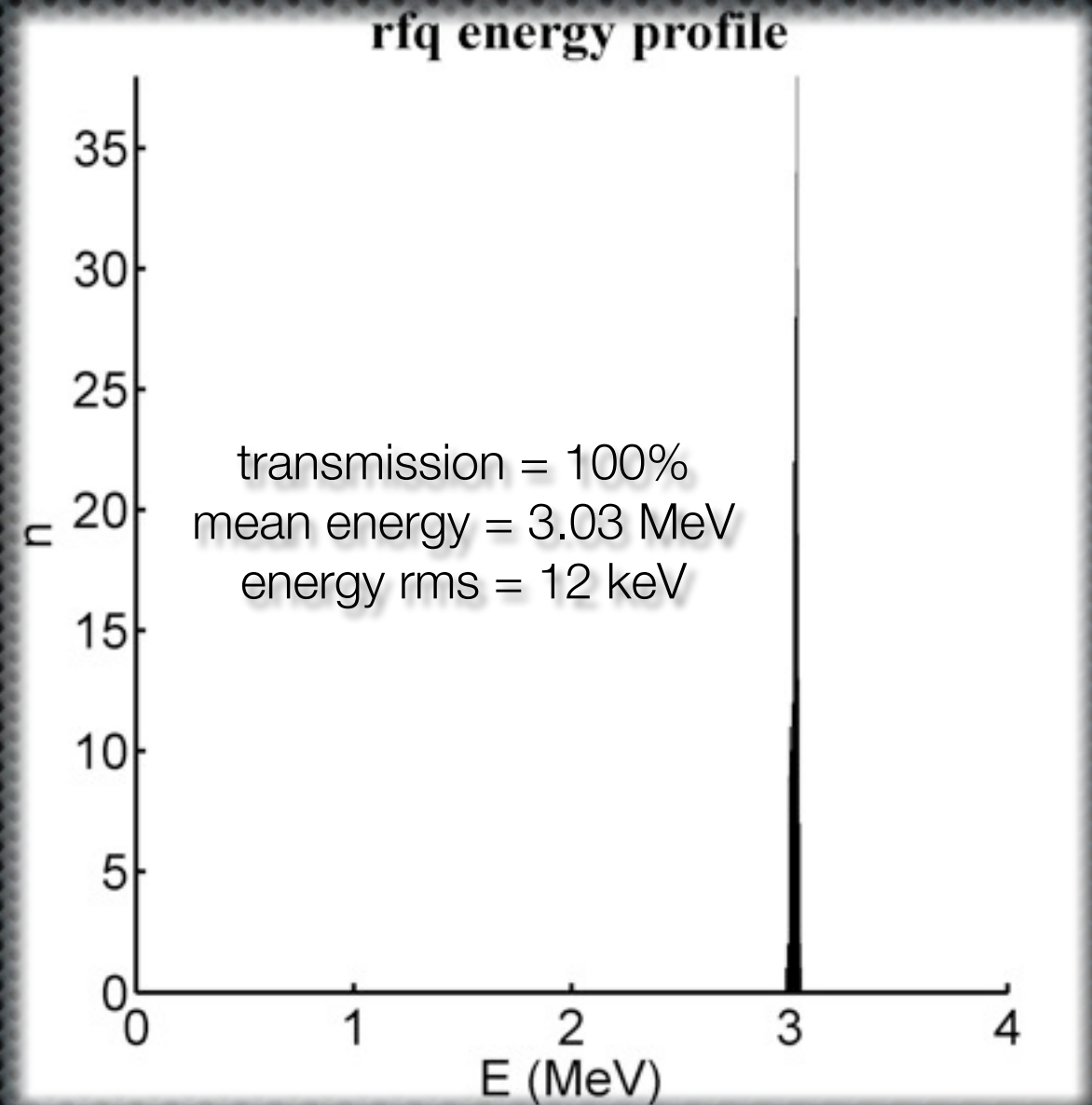
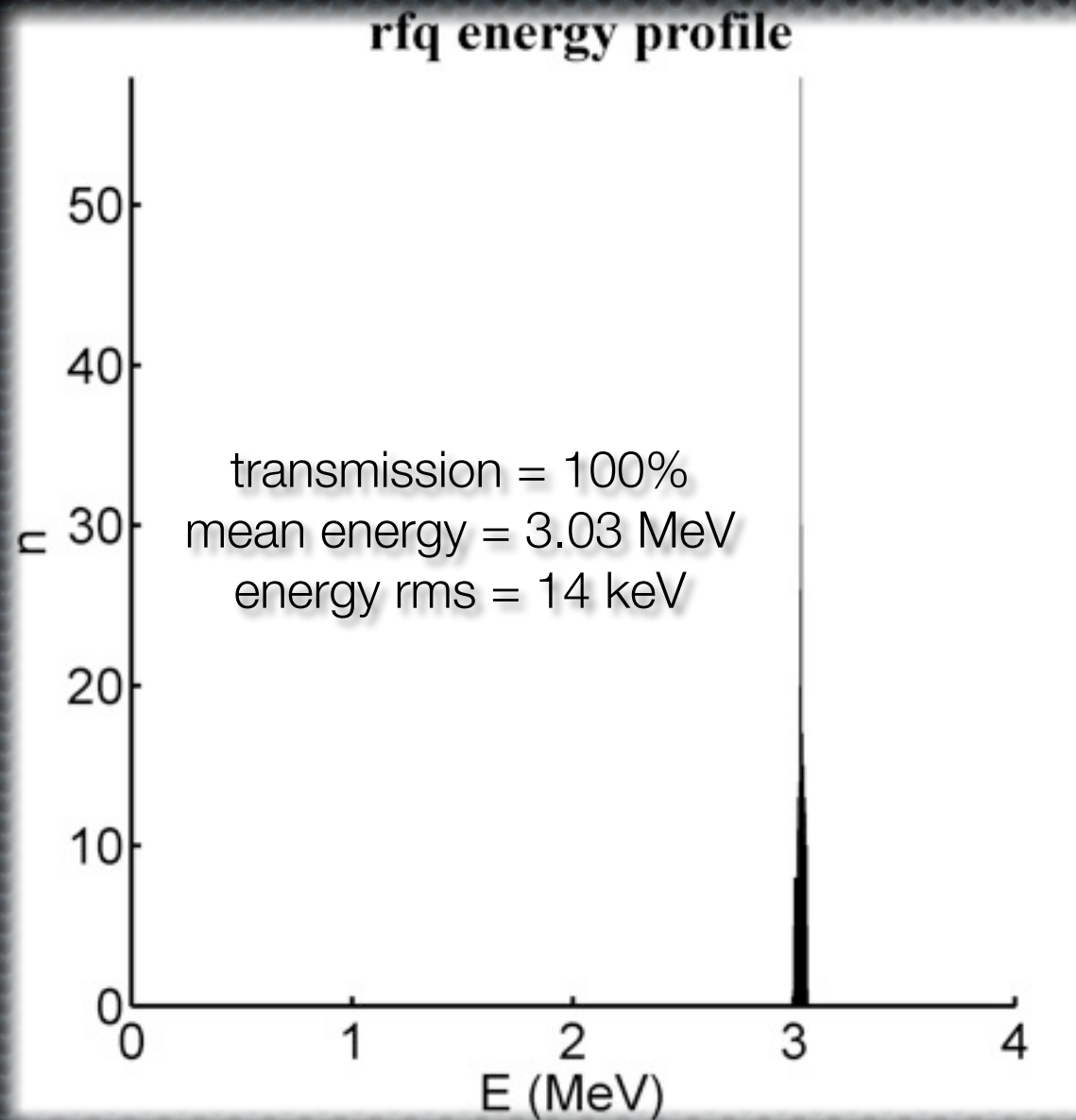
transmission = 100%
mean energy = 3.03 MeV
energy rms = 12 keV



FETS field map comparison

Theoretical field

CAD field



field scaling for *PAMELA*

- ✦ reduced input energy from 65 keV to 12 keV/u
 - ✦ velocity reduction by factor of 0.43
 - ✦ requires reduction in synchronous velocity of RFQ

$$\beta_s = \frac{D\omega}{2\pi c}$$

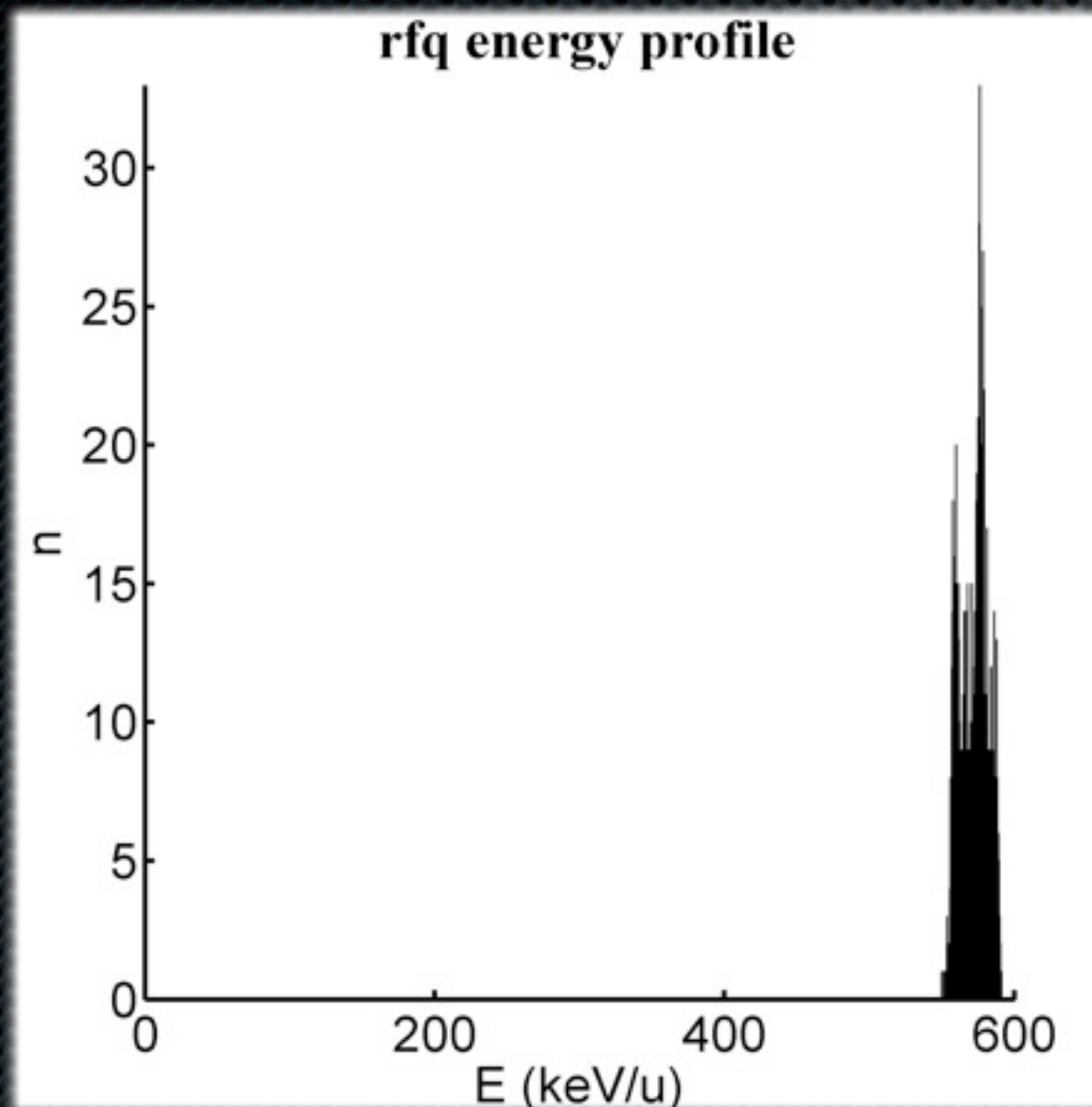
field scaling for *PAMELA*

- ✦ reduce frequency from 324 MHz to 280 MHz
 - ✦ factor of 0.86
- ✦ reduce length from 4.1m to 2.0m
 - ✦ factor of 0.50
- ✦ total reduction of 0.43 as required

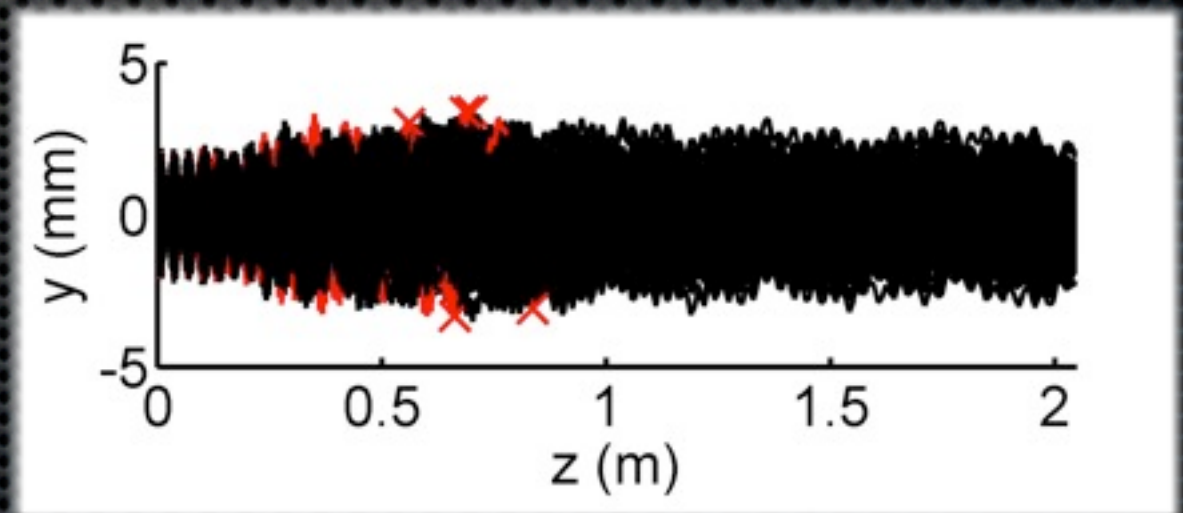
$$\beta_s = \frac{D\omega}{2\pi c}$$

first *PAMELA* field map

based on a scaled version of the *FETS* RFQ field map



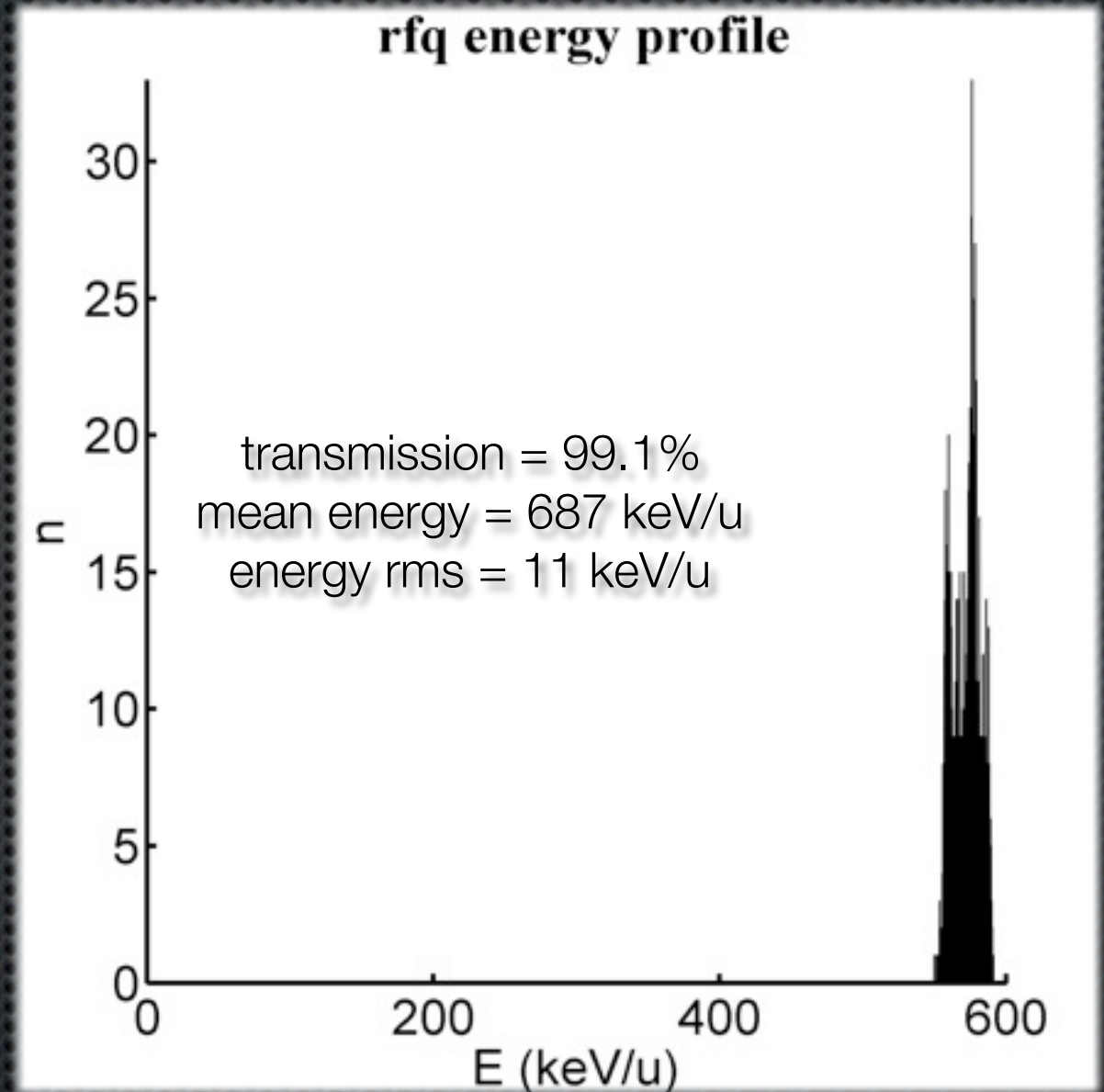
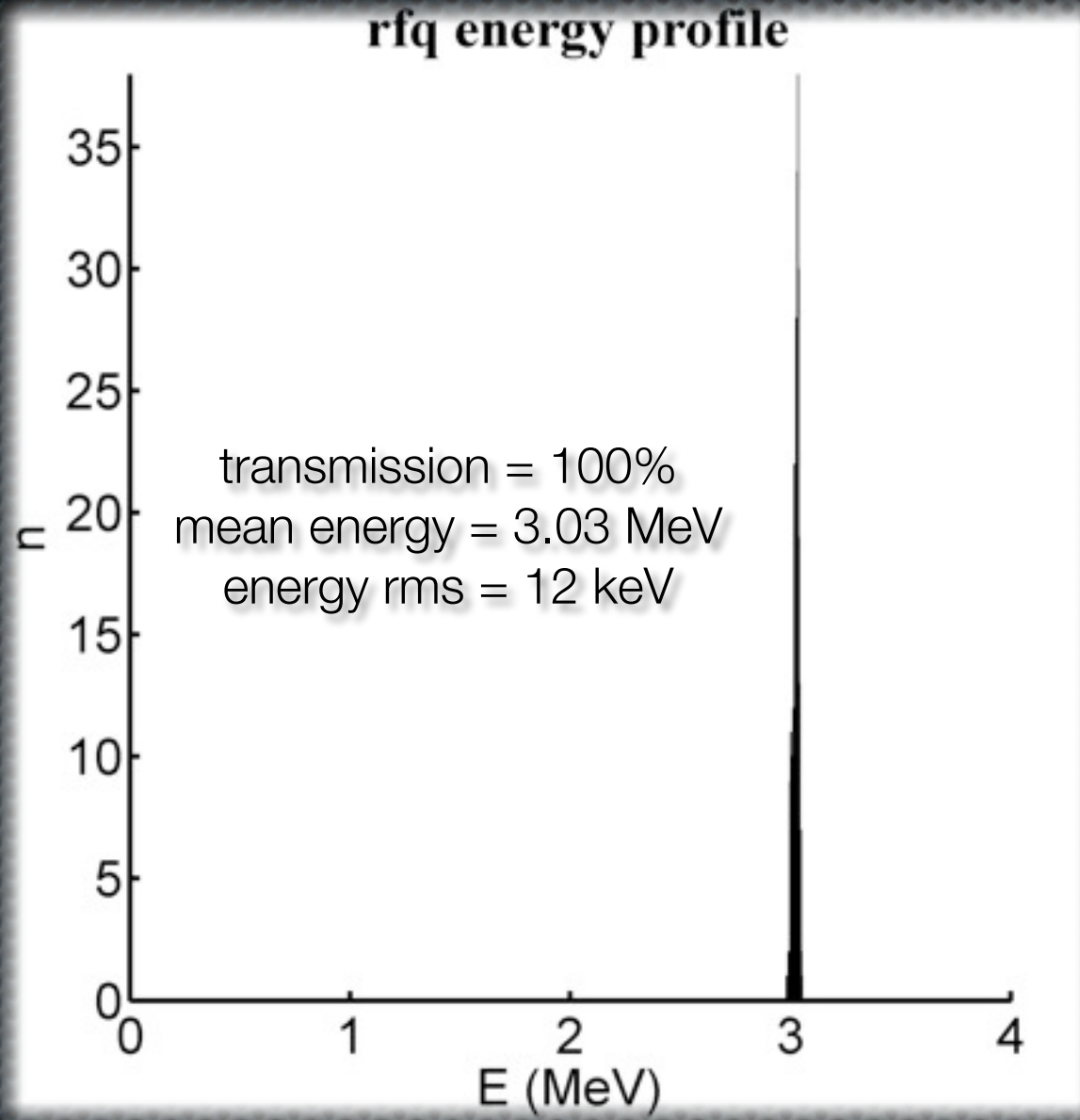
transmission = 99.1%
mean energy = 687 keV/u
energy rms = 11 keV/u



field map comparison

FETS field

PAMELA field



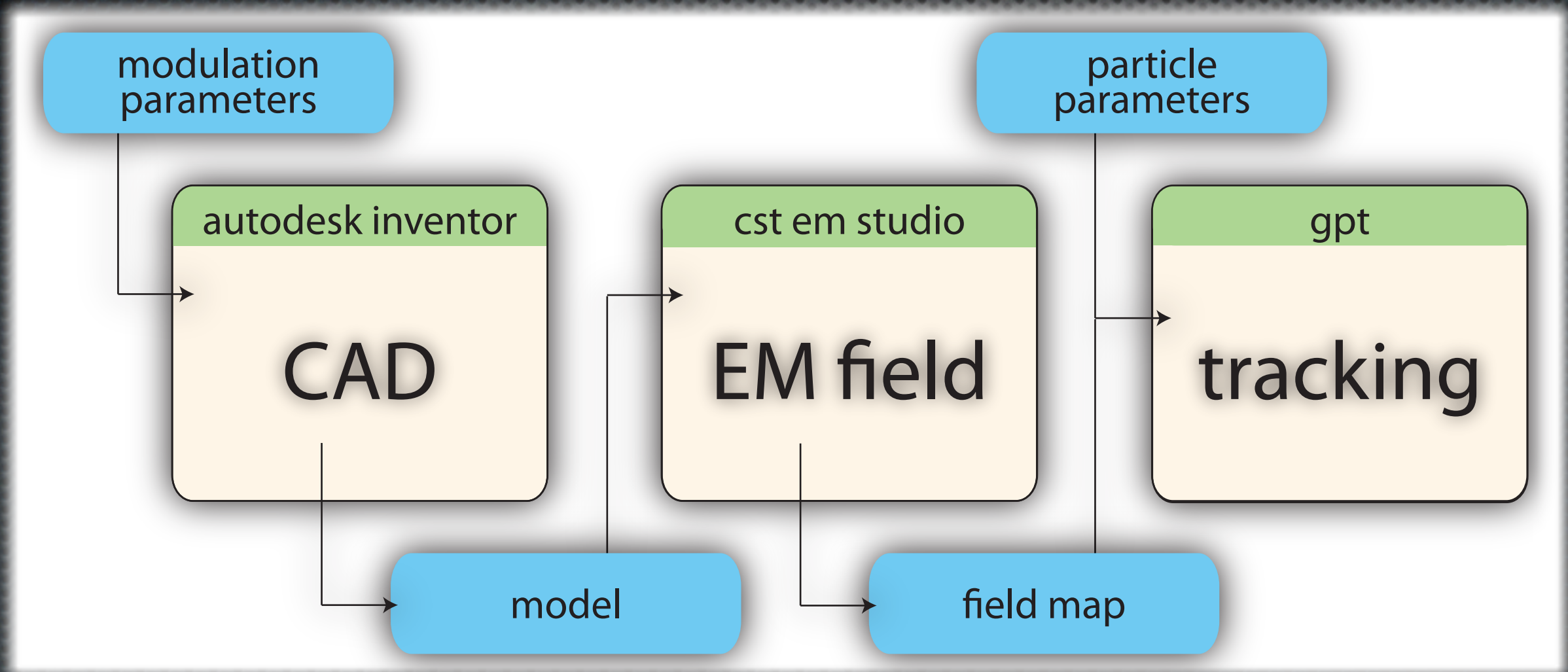
RFQ Design

Upgraded design model

Comsol and Matlab

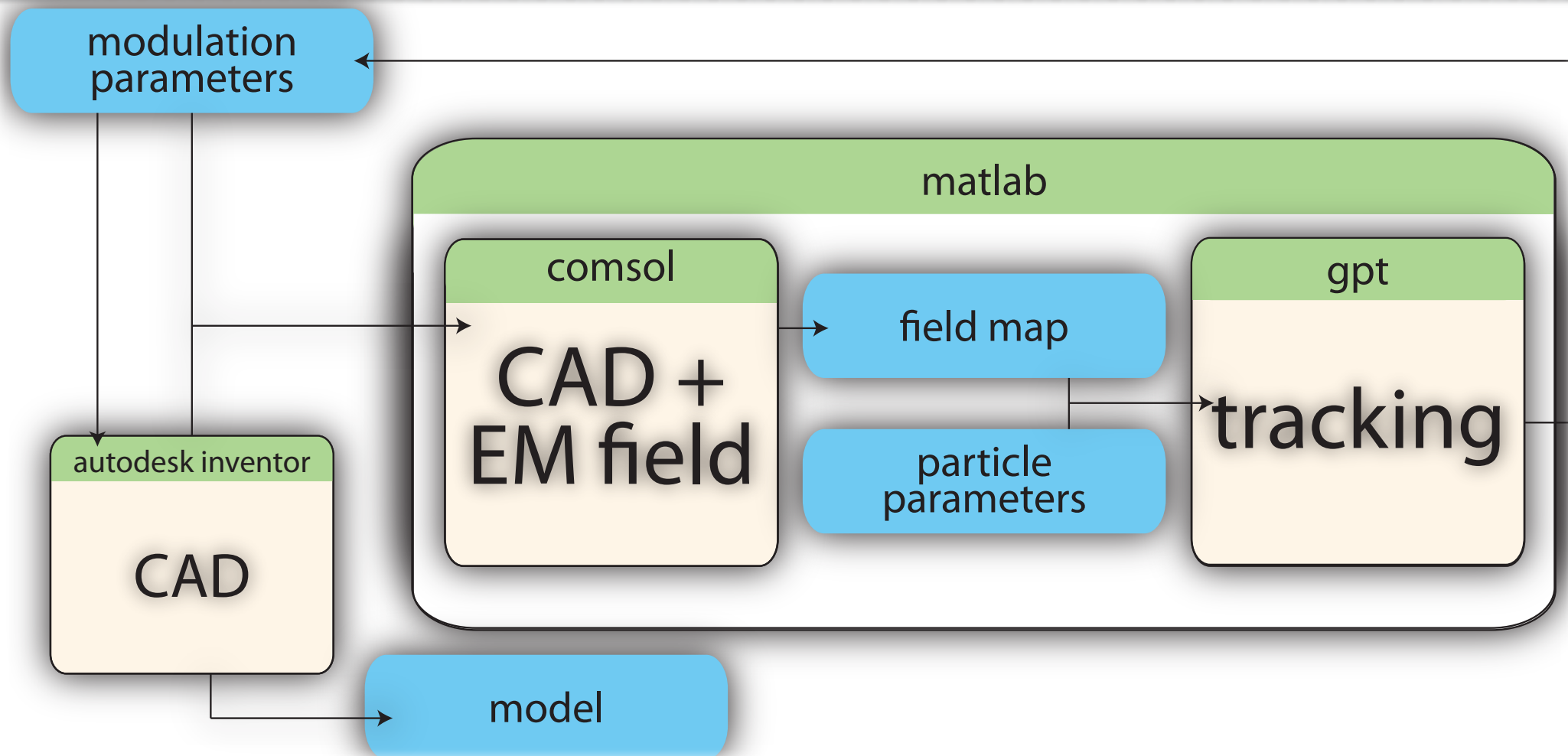
original design model

using *CST EM Studio*



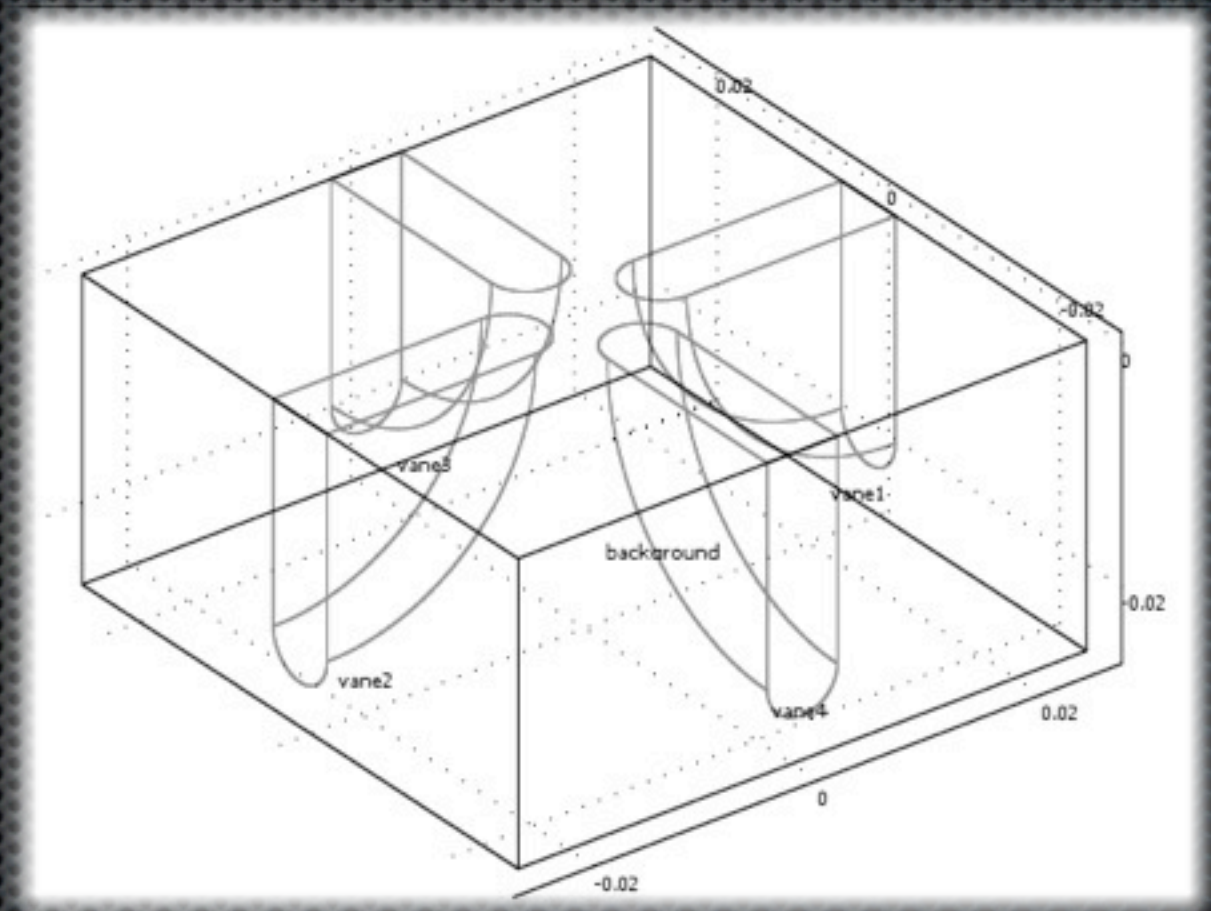
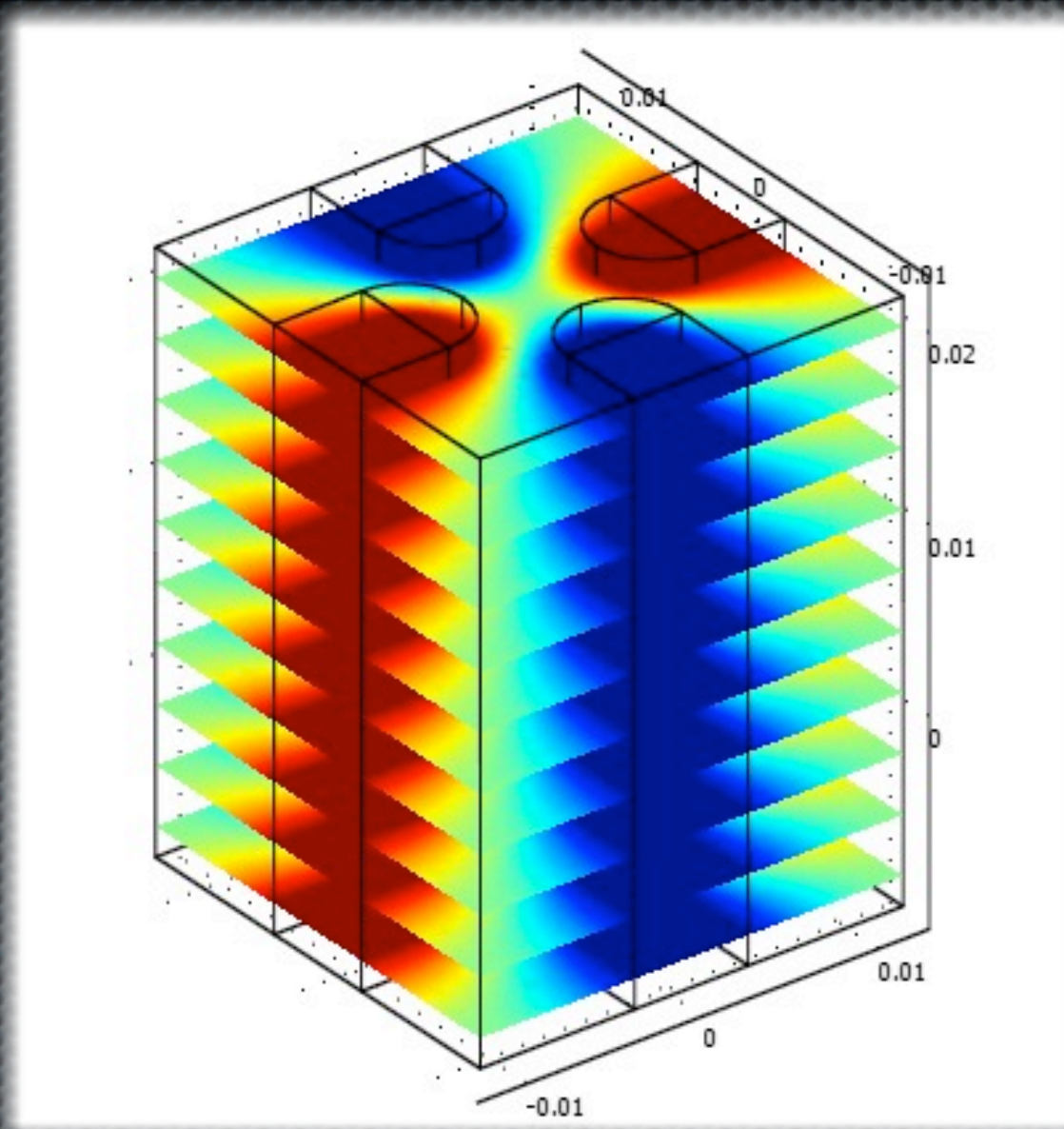
upgraded design model

using *Comsol* and *Matlab*



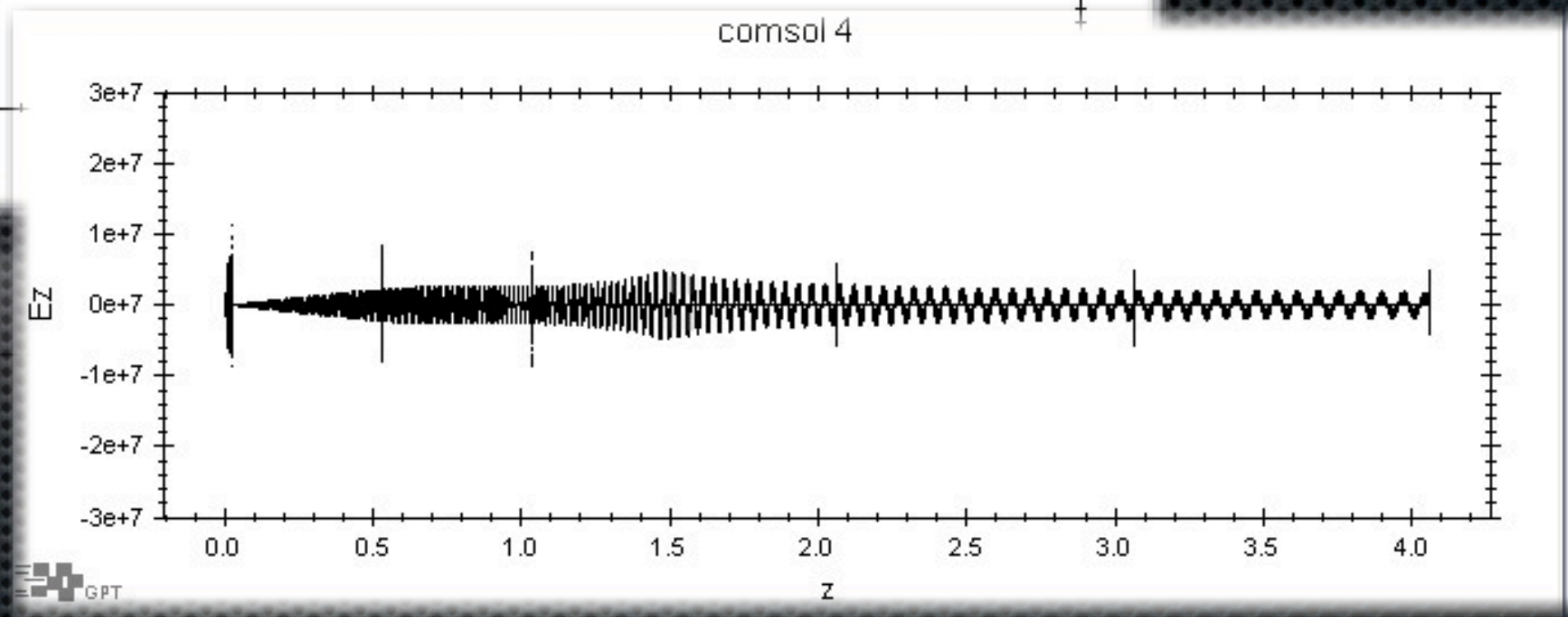
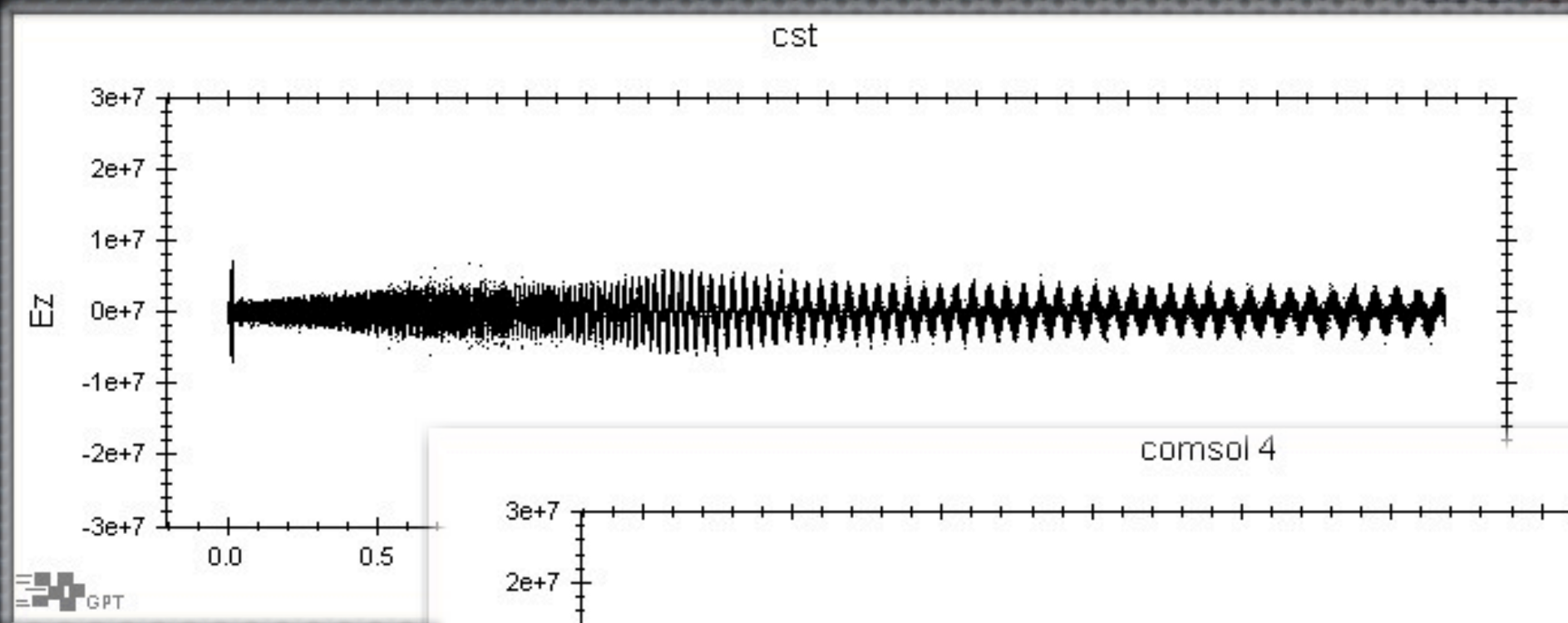
Comsol

FETS RFQ simulations



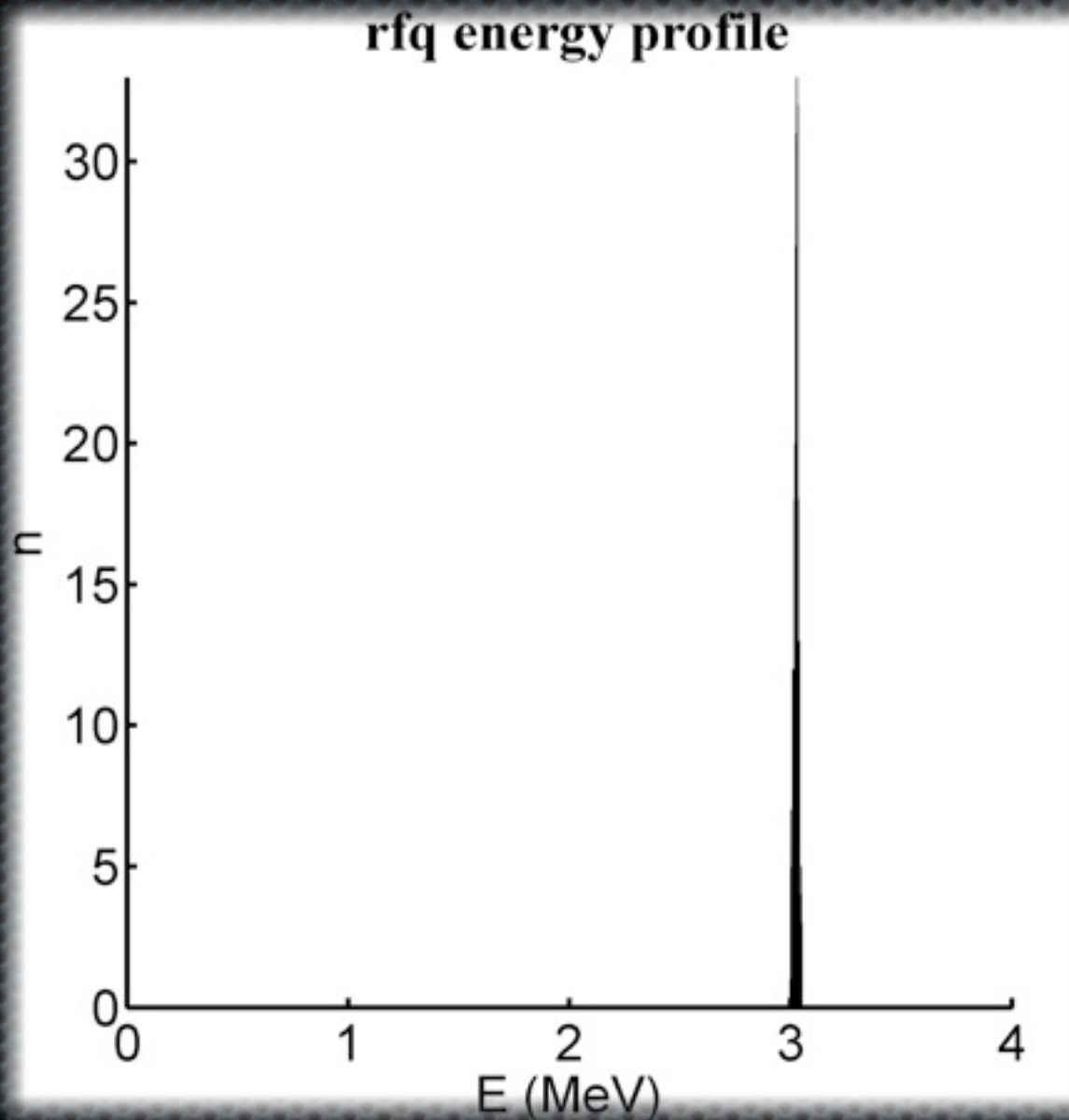
Comsol

FETS RFQ simulations

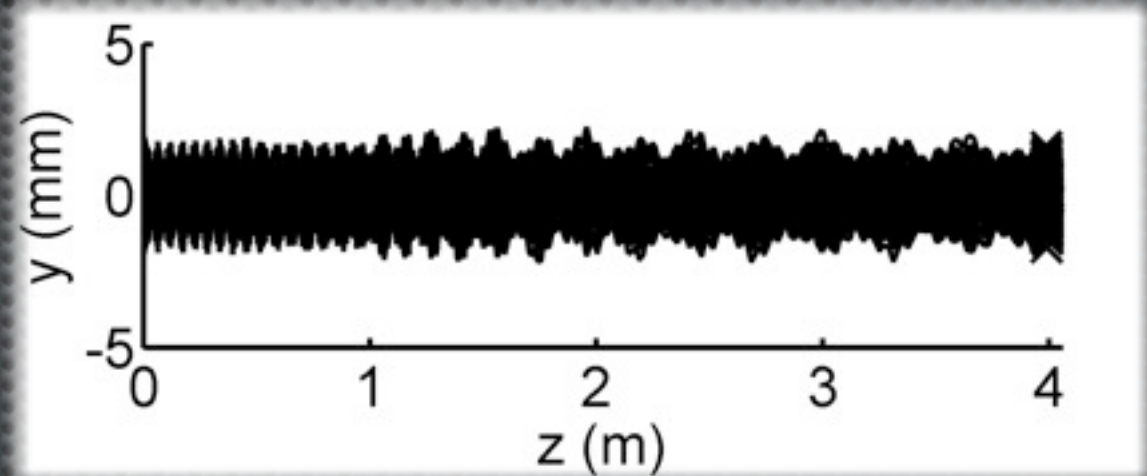


Comsol

FETS RFQ simulations



transmission = 100%
mean energy = 3.03 MeV
energy rms = 9 keV



to do:

- ✦ integrate *Comsol* with *Matlab* and *Inventor*
- ✦ build new *PAMELA* RFQ design
- ✦ optimise new design through iteration
- ✦ find the optimum point to switch from RFQ to Linac
- ✦ produce complete simulation from ion source to injection

RFQ Injector for *PAMELA* FFAG

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